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Shadow Formation at Preschool from a Socio-materiality Perspective

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Abstract The paper is set in socio-material farming to offer a way of conceptualising actions and interactions of children in preschool involved in the understanding of scientific concepts. A model of early science education about the physical phenomena of shadow formation is implemented in group work in a French context. The research involved 44 children (13 females and 31 males) of 5–6 years old. The research design was organised in three video recording steps: pre-test, teaching session and post-test. We focus on the analysis of nine teaching sessions to investigate children's 'understanding' of shadow formation. A descriptive and qualitative approach was used. In particular, we have identified three main categories (the interaction of the children with the tools, the embodiment and verbal dimension)—with respective indicators—to perform the analysis. From the results, all the categories explored seem to influence each other: all material, human and social dimensions contribute to the children's understanding of shadow formation. Also we have identified some elements that can serve as a potential source of improvement of the teaching session on shadow formation. Finally, the research provides insights on how to improve science activities in preschool with the aim of supporting early understanding of physical phenomena.

Keywords Early education · Preschool · Shadow formation · Young children · Science education

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Introduction

The way in which young children approach the natural world is a central topic in science education (Boilevin 2013; Ergazaki et al. 2010; Fleer and March 2009). The interests of this educational researcher is to shed light on how a child develops a better comprehension of the material world, from an early and naive understanding to the most advanced forms of scientific thought (Fleer and Robbins 2003). For young children, both the process of the development of logical and critical thinking and the acquisition of scientific knowledge are central resources for the understanding of the natural world around them, and the enrichment of their skills (Dockrell et al. 2007).

Scientific and political communities stress the importance of education at an early age and agree on the fact that it is possible and relevant to start science education as early as possible for all children (Eshach and Fried 2005; Léna 2009). However, in many countries, the standard preschool curricula for young children (aged three to six) do not give any significant weight to scientific knowledge (Eurydice 2009). Activities often include familiarisation with material objects and entities of the environment without going into the conceptual understanding of scientific phenomena (Ravanis 2010).

Nevertheless, a variety of methods and pedagogical tools are present in the scientific literature to support science education from an early age (e.g. Chalufour and Worth 2005; Worth and Grollman 2003). Teachers with a scientific attitude can implement specific activities to help children to overcome the difficulties associated with understanding scientific phenomena (Fleer et al. 2014).

In this paper, we explore how children (aged five to six) approach the physical phenomenon of shadow formation through a specific teaching session, defined by the obstacles and difficulties associated with the understanding of this phenomenon by young children. From the analysis of this teaching session, we were interested in how young children, in small groups and in a particular physical arrangement, use particular tools. We also explore the social interaction between children and with ideas, mediated by the teacher, regarding the concept and the physical manifestation of a shadow.

The paper is set in the socio-material context to offer a way of conceptualising the actions and interactions of children in preschool involved in understanding scientific concepts. It provides insights into how to improve science activities in preschool, with the aim of supporting the early understanding of physical phenomena.

The first part of the paper provides a theoretical presentation of socio-material learning, considering the development of scientific knowledge in young children and focusing on the phenomenon of shadow formation. Then we present the research undertaken in a French preschool. We provide a summary and discussion of results obtained and implications for teaching practices in preschool, and also further research.

Social Materiality in the Learning Process

Increasing attention is being paid to theoretical approaches which emphasise the meaning of interactions between subject and materiality (Clark 2010; Lenz Taguchi 2010) in learning (Sørensen 2009). The perspective of materiality concerns how tools are part of human actions, bringing in the notion of social interaction between artefacts and humans: in the socio-material perspective, the material, human and social dimensions are inseparable (Orlikowski and Scott 2008; Suchman 2007).

In preschool settings, material-semiotic approaches are of interest in the analysis of the everyday practices of children. In a study of preschool children, Kontopodis (2012) discusses material action (how things are set up in relation to other things), and semiotic action (how this set up reflects theories or values). Considering also the perspective of Latour, it is important 'to trace the link between the material and the semiotic as enacted in concrete ways each time people and things do something with each other' (1996, p. 8). In another study based on ethnographic fieldwork with young children (aged two to five) in Norwegian kindergartens, Nordtømme (2012) explores how spaces and materiality can be vital for children's exploration. It shows how the physical environment enables children to interact and position themselves when they play, and that 'meaning and meaning making are embodied in children's actions and through dialogue and interactions with others' (Nordtømme 2012, p. 319).

Such studies stress the importance of considering how the physical environment, material actions, and semiotic actions influence children's comprehension. In the context of the preschool science we consider here, such social materiality is expressed in teaching sessions addressed to small groups (five to six children), using tools specific to approaching the phenomenon of shadow formation with young children, involving embodiment and verbal interactions.

Tools, Embodiment and Verbal Interaction In this section, we focus on the three dimensions we consider central to socio-material learning: interaction with tools, embodiment dimension and verbal interaction.

We consider the interaction with tools in the more general framework of artefacts in the sense that all human activities are mediated by artefacts made of signs and tools. The term 'artefact' is an aspect of the material world that people use when interacting with their physical and social environment (Cole 1996). Artefacts are considered both material objects (tools, images, drawings, etc.) and ideas (meanings, values, norms, etc.) (Wartofsky 1973). Artefacts allow mediation between subject and the world. They expand and augment cognitive possibilities (Clark 2010) and, at the same time, the use of a particular tool changes and constrains the cognition (Ackerman 2007).

Regarding this embodiment, there are very different notions of exactly what it is (Ziemke 2013). In embodied cognition research, mind and body are inextricably intertwined and cannot be viewed in isolation: "the basic assumption is that cognition is a continuous process with changing boundaries and, thus, much more than what takes place within the individual mind" (Rambusch and Ziemke 2005, p. 1805). The focus on the 'body' in learning activities allows a shared understanding of the world between individuals. From this perspective, human bodies are considered both a medium and a locus of experience, that "move through socially structured experiences, and, in a likewise manner, human minds move through experiences shaped by complex cultural artefacts" (Gillespie and Zittoun 2013, p. 524).

Basic areas of research in embodiment and social interaction are gestures and positions of the body. Specifically, gestures are limited and coordinate motor actions, designed to generate a meaning and notify us of the other party's intentions (Levy and McNeill 2013). According to Goldin-Meadow (2003), gestures not only reflect learning but also contribute to learning to a significant degree. In addition, the study of Roth (2002) shows that the use of gestures in combination with tools does not simply replace language as a means of understanding but plays a role in the proper use and development of required scientific concepts. From the embodiment perspective, the human body itself must be conceived of in terms of malleable borders and distributed networks (Bennett 2010).

Regarding the third dimension, verbal interaction, discussion practices are central to the learning process. Recent approaches insist on exploring these argument dynamics in context (Rigotti and Greco Morasso 2009; van Eemeren 2010), with broader attention paid to the place of debate in science education (Newton et al. 1999), understood as 'the process of evaluation and justification of claims to scientific knowledge' (Naylor et al. 2007, p. 17). This point of view focuses generally on knowledge-oriented debate in children (Muller Mirza and Perret-Clermont 2009; Perret-Clermont et al. 2014), with recent interest in the role of objects in discussions (Mehmeti et al. 2014). At the same time, according to Grossen (2001), adults and children contribute to the construction of the interaction, and the definition of the context and of the task in which they are involved.

In a science classroom, verbal interaction usually involves a child or a group of children engaging with the teacher in an activity of scientific problem-solving, often performed in a collaborative way. In the context of science in preschool settings, the role of teacher mediation is often stressed, with a dialogic relationship between everyday concepts and scientific concepts (Fleer 2009; Ravanis et al. 2008). Participation in a complex activity mediated by the teacher helps children to access to a new zone of proximal development (ZPD) (Weil-Barais 1994). The ZPD is generally defined as the distance between the current level of development, determined by the person's ability to solve a problem independently, and the level of potential development, determined by the ability to solve a problem by working with a more experienced person (Vygotsky 1978). Below, we specifically focus on children's understanding of the scientific phenomenon of shadow formation.

Understanding Physical Phenomena

In the learning process, scientific understanding requires a complex synthesis of knowledge (Parker 2006). A strong influence on the study of the mental functions of children is provided by Vygotsky (1978). From this perspective, the cognitive development of children takes place via interactions with physical and social elements through the production of artefacts, allowing the externalisation of knowledge (Bruner 1990). The Vygotskian development of scientific concepts is synthesised by Gredler (2009) into four points: (1) the child has a syncretic conceptualisation of phenomena that allows them to perceive complex concepts, (2) pseudo-concepts are developed by symbolic and instrumental mediations and exterior stimuli, (3) a conceptual thought is given by the internalisation that leads to reconstruct internal and external stimuli mediations and (4) the child invests these concepts in self-organised activities and different reasoning opportunities.

Driver et al. stress that children start first with descriptive reasoning, based on the phenomenon, then move to reasoning based on relationships and, only at the most advanced stage, to modelling reasoning.

The conceptual change approach focuses, instead, on the cognitive evolution of concepts. Changes in mental representation appear when individuals face a number of inconsistencies or contradictory facts that disturb the established theories (Dawson and Lyndon 1997; Fleer 1990; Delserieys et al. 2014). Carey (1985) points out two kinds of conceptual changes that can happen: a weak restructuring when additional information and knowledge in a theoretical model can cause a low restructuring, or a strong restructuring when the individual radically changes the explanatory model.

In general, we can consider that children, even at an early age, have representations about physical phenomena and that these representations play a role in their experience of learning science (Baillargeon 2002; Duit and Treagust 2003; Karmiloff-Smith 1992; Lécuyer 2004). They can discover relatively quickly simple regularities of the world, establishing causal links between perceptible elements. One early skill is that of predictions of physical phenomena: children can predict fairly well certain events in physics without having a background explanation. The correct predictions may indicate a form of early practical knowledge (Kohn 1993). These skills constitute the basis upon which the child will construct scientific knowledge.

The Understanding of Shadow Formation The formation of a shadow is explained by a topological relationship between a light source, an obstructive object and a projection plane. This phenomenon is part of the common experience of children. Indeed, children soon discover the shadow phenomenon and play with shadows in different contexts (Herakleioti and Pantidos 2015), making a naive representation of it (Chen 2009).

The representations of young children on the formation of shadows have been extensively studied in science education (Delserieys et al. 2014; Parker 2006), in diverse areas, such as developmental psychology (e.g. Forman and Carr 1992) or preschool science education (Dumas Carré et al. 2003; Gallegos-Cázares et al. 2009), using quantitative or qualitative approaches.

Fleer (1996) established that, after a suitably planned teaching intervention, preschool children are in a position to discuss the concept of light and to refer to light sources and material objects used in teaching. Upon studying their drawings, a certain progress in the children's thinking is established, although it is also noted that they have not fully understood the nature of light. A similar result is achieved by Gallegos-Cazares et al. (2009), proving that, after an organised teaching intervention, substantial progress is made, since the majority of the children studied recognised and discerned light and its behaviour towards the material objects that produce or receive light. Starting from the view that the generation of meaning is a multimodal process, Herakleioti and Pantidos (2015) proposed a specific study about the concept of shadow in preschool with a body-based activity, in which the human body serves as a link between verbal discourse and context.

Considering previous research into children's understanding of physical phenomena, in the following section, we present a teaching model that supports the understanding of shadow formation in preschool. This model allows, in our opinion, the consideration of the implication of the tools, embodiment and verbal interaction in the learning process for a socio-material analysis.

The Didactic Model for Scientific Concepts in Preschool

The starting point of the didactic approach discussed here is the work on representation, seen as the product of the dynamic individual and social history of children. It has its roots in socio-contextual elements; in particular, it has been shown that children's representations that attempt to provide an initial interpretation of the physical world are often not in tune with the scientific explanation (DiSessa 2006; Duit and Treagust 2003). Consequently, the need to teach physics means proposing educational interventions that can foster the transition in which the initial conceptual structures are enhanced and restructured (Bächtold 2013). In this process, the teacher can act as a mediator between the conceptual systems of children and scientific knowledge (Otero 2004).

Lemeignan and Weil-Barais (1994) proposed the so-called precursor model, defining it as an intermediate entity between the representations of children and the scientific explanation (Weil-Barais 2001):

> These are cognitive schemata compatible with scientifically appropriate knowledge, since they are constructed on the basis of certain elements pertinent to scientific models, which have a limited range of application and which prepare children's thinking for the construction of scientifically appropriate models (Ravanis et al. 2013, p. 2259).

Precursor models have been proposed to structure teaching strategies in different studies of physics education (Ntalakoura and Ravanis 2014; Weil-Barais and Resta-

Schweitzer 2008). In general, it is a challenge for young children to understand scientific phenomena beyond descriptive reasoning. The idea of proposing a precursor model is to propose a relational perspective between concepts, in order to facilitate intellectual development.

An introduction to physical concepts at an early age should push children to reflect and to understand 'the relationship between the world as it is presented to our senses, and the way in which it is represented' (Weil-Barais 2001, p. 381). At the same time, the teacher mediates and guides the student to access a new ZPD (Weil-Barais 1994).

Specifically regarding shadow formation, Ravanis (1998) has previously identified the main obstacles and difficulties associated with the understanding of this phenomenon by young children. These obstacles concern the recognition mechanism of shadow formation and are expressed in the difficulty most children have in determining the position of the shadow of an opaque object, relative to that of the light source and the opaque object, and identifying the correspondence between the number of light sources and the number of shadows.

On the basis of the difficulties identified regarding the understanding of shadow formation by young children, a script was constructed, divided into three main activities. The first two activities were intended to overcome the difficulty with determining the position of the shadow of an opaque object, relative to that of the light source and the opaque object, and the third activity was structured to deal with the difficulty of identifying the correspondence between the number of light sources and the number of shadows. A schematic summary of the three activities is shown in Table 1.

The activities proposed were also designed on the basis of being implemented in small groups of children with teacher support, and using simple objects which are easy to manipulate by young children. In this way, the activities are thought to support a perspective of socio-materiality.

Below we present our study, based on a tailored teaching session implemented in a preschool to foster the understanding of shadow formation. We will focus on the interplay between the manipulation and interaction with tools, embodiment (as it relates to the human body) and verbal interactions as aspects that influence children's understanding during the teaching sessions.

Table 1 Activities implemented by the teachers in the study, based on the difficulties identified for the understanding of shadow formation

Activity	Goal	Description of teacher and children activity	Difficulty to overcome
1	Production of one shadow	The teacher asks the children to produce one shadow with the flashlight	To determine the position of the shadow of an object relative to that of the light source and the object
2	Prediction of shadow position	The activity is the prediction of shadow position by children. The teacher also proposes a 'impossible task' (position the light on the same side of the object than the shadow)	
3	Production of multiple shadows	The teacher provides each child with a flashlight and encourages them to produce multiple shadows and to identify the correspondent source of light	To identify the correspondence between the number of light source and the number of shadows

The Study

Research Question

In this paper, we explore how young children, in small groups in a particular physical arrangement, use particular tools. Furthermore, we focus on the social interaction within the small groups of children with the teacher, and the ideas mediated by the teacher (the concept and physical manifestation of a shadow) to understand the scientific phenomenon of shadow formation. There are two research questions:

1. How is the interplay between the manipulation and interaction with tools, the embodiment (as it relates to the human body) and the verbal influence expressed during a teaching session aimed at developing children's understanding of shadow formation?
2. How is this interplay expressed during each of the activities in the training section?

This study intends to provide insights into a socio-material approach in the early years of science education.

Context and Participants

The research was organised in a French preschool. The school is located in a culturally diverse area. Forty-four children (13 females and 31 males) aged five to six, were involved in the entire research study and 33 children were present for the three phases of the full research (pre-test, teaching session and post-test). Two teachers were involved in the study, chosen because they were experienced teachers (more than 10 years of teaching experience) and skilled in practice analyses as they are also teacher educators.

Research Design

The full research design involved three steps: the pre-test, the teaching session implemented two weeks after the pre-test, and the post-test implemented four weeks after the teaching session.

The pre-test and post-test sessions were identical, conducted individually by one researcher with one child to assess the child's progress. The analysis of the pre- and post-test, as previously published (see Delserieys et al. 2014), serves as a benchmark for the analysis of the teaching sessions in this paper. From the first study, the difference between the results in the pre- and post-tests showed that children do progress in their ability to explain shadow formation (significant progress was observed for 22 children out of the 33).

The same teaching session was repeated nine times with nine different small groups of children. A teaching session lasted 15 min on average. Each teaching session was performed by one teacher in a group of children with, on average, five children per group. The teacher and children were seated around a circular table or a circular arrangement if the first solution was not available. The sessions were planned in with the ordinary classroom activity for a naturalistic setting. The two teachers were trained by one of the researchers to implement the teaching session. A detailed written script (four pages of A4) was given to the teachers with a specific indication to perform each activity as shown in Table 1. Although it is not the subject of the analysis in this article, it was identified that the way the teachers used the script across the nine sessions presented a sufficient level of regularity to address the key activities expected in the teaching session. The tools involved during the training session were as follows:

- Rectangular flashlights (that could be turned on and off and stand alone on the table, see Fig. 4) for the production of light. The script provided one flashlight in the first and second activities. For the third activity, the number of flashlights corresponded to the number of children involved in the group of the teaching session.
- An opaque stick for the production of shadows, a standard plastic tube 20 cm in length.

In addition, the two teachers used chalk to indicate the pupils' predictions of the position of a shadow on the table before turning the flashlight on, and a stick to indicate the position when asking children to place the flashlight to get the shadow at the selected position.

Data Collection

The three steps of the research (pre-test, post-test and training sessions) were videotaped in their entirety by the researchers. For our research aim, in this paper, we will focus on the videos of the nine teaching sessions.

In the teaching sessions, the data was collected with a video camera fixed at one corner of the classroom, with a high angle shot focused on the group of children, the teacher and the table on which the activities were carried out. In this way, it was possible to focus on the body positions and gestures, and register the verbal interactions. Each video of the training sessions lasts 15:05 min on average, corresponding to the duration of one teaching session. All the children were familiar with the video camera (used in many educational projects in the preschool), so they did not pay particular attention to it. A researcher attended all the training sessions, positioned near the video camera and taking field notes in support.

Methodology and Data Analysis

The analysis was carried out on the nine videos of teaching sessions. Video data have the advantage of allowing a cyclical analytical process (Jacobs et al. 1999), useful in unveiling 'how young children use the full range of material and bodily resources available to them to make and express meaning' (Flewitt 2006, p. 25). First, all nine videos were reviewed by all the researchers involved in the study. Then, we identified three main categories, with respective indicators, to perform the analysis. This process was performed through a process of tuning, in a progressive comparison between the theoretical aspects and data analysis (Glaser 1998). The three main categories and respective indicators are given below.

1. Children's manipulation of the tools: actions made by each child towards the tools involved in the training session (opaque stick, flashlight) and shadow/light performed (materialised by surface areas on the table or on the opaque stick). Specific indicators of this category are as follows:

    - Touching/pointing at the opaque stick;
    - Touching/pointing at an area on the table surface to predict the location of the shadow of the opaque stick;

- Touching/pointing at an area on the table surface to predict the location of the flashlight to form a shadow at a predetermined position;
- Touching/pointing at an area on the table surface where the shadow of the opaque stick appears when the flashlight is on;
- Touching/pointing at an area on the table surface where there is light from the flashlight, and
- Turning the flashlight on or off.

2. Children's body position and gestures: movements in the posture, the head and hands in relation to participation during the training activities. Indicators considered are as follows:

- Posture: bending forward/pulling back position;
- Head: act of nodding/denial, and
- Gestures with hands: raising their hands (to ask the teacher to take part); hands on the table; hands on their face/in a pocket; gesture of help in flashlight use.

(3) Teacher's and children's verbal expressions: all sentences of the teacher and the five children during the execution of activities. For this category a codebook was built, with specific dimensions (Table 2).

These subcategories are built in a circular process both from the literature (Lemke 1990; Mercier 2011) and the data. The defined categories and indicators were first used for an in-depth focus on one video of a teaching session which was fully transcribed. The selected video lasts 18 min and 41 s and involves five children (one girl and four boys). This specific video was selected because all the children in the group participated in all phases (pre-test, post-test and teaching session). Moreover, this group of children represented an interesting case (Yin 2014) as the five children had different profiles in terms of progression from the pre-test to the post-test.

The video was split into three main phases, corresponding to the three activities of the teaching session: activity 1 (from 1:00 to 7:11 min); activity 2 (from 7:22 to 12:35 min) and activity 3 (from 12:36 to 18:41 min). A joint content analysis (Ghiglione and Blanchet 1991; Hsieh and Shannon 2005) was applied by the researchers until a high level of consent (agreement rate = 90 %) was reached.

Finally, for a deeper exploration into a socio-materiality perspective on the three activities of the training session, we present a broad description of three episodes selected from different training sessions. All the videos from the different training sessions were scrutinised, looking for sequences with cases illustrating the theoretical perspectives on tools, embodiment and verbal influence as stated above. The analysis was carried out by two researchers, who first worked independently to select the pertinent episodes, and then compared and agreed on their final choices. The selected episodes involved the manipulation of, and interaction with tools, the embodiment and the verbal influences in the understanding of shadow formation. The three selected episodes take from 3 to 10 min, considering the average duration of 15 min for teaching sessions.

In the following sections, the results from the single full teaching session and from the selected cases in different teaching sessions are presented successively.

Table 2 Codebook of teacher's and children's verbal expressions during the teaching session

Dimensions	Description	Example
Aim of activity	When the aim of the activity is highlighted	*Here I speak to you about the shadows. I do not ask you where you see the light.*
Challenge	When a situation of problem solving is introduced	*Where will be the shadow?*
Expanding	when the utterance has the aim to extend the discussion with new points of view or concepts	*Do you have a different suggestion?*
Rephrasing	when the aim is to reformulate something already expressed before or more focus in modelling the cognition of the children	*In fact, when it gets dark we lit. Okay, you've changed your opinion then?*
Prediction	when the position of the shadow or of the light is verbally predicted	*The shadow will be here.*
Position	When expressing an own understanding (that can be true or false)	*Yes, he's right.*
Explanation	Concept is explained verbally	*He had not put the light here, otherwise the shadow would be here.*
Modality of Activity	Description of procedures and rules for carrying out the activities	*We will work with this, we will call it an opaque stick.*
Phatic	Rhetorical questions to capture the attention or express agreement	*Do we agree?*

Results

Tools, Embodiment and Verbal Influence During a Full Teaching Session

In this section, we outline the analysis of the selected video. Five children (one girl and four boys) were involved in the selected teaching session. We designated them with a letter (A, L, R, S and N). Considering the previous research into this video (Delserieys et al. 2014)), the comparison of results in the pre- and post-tests for this group of children revealed different levels of progress in their understanding of the shadow phenomenon after the teaching session: L made significant progress, A and N showed medium progress and S and R made no progress.

The categories identified (children's manipulation of the tools, children's movement of the body and gestures, and the verbal expressions of the teacher and children) are considered here for a close analysis of the process of understanding shadow formation during the teaching session.

Children's Manipulation of the Tools and Interaction with Shadow/Light This first category, examining the relationship of children with the tools and the light/shadow produced, is analysed in relation to the three activities developed during the teaching session.

In activity 1, pointing towards the presumed location of the shadow or predicting a position for the light source are recurrent interactions performed by the children. In activity 2, the interaction with the flashlight the children manipulate is predominant. In activity 3, children are exposed to multiple shadows of the same opaque stick. The act of pointing towards the shadow of the opaque stick forming on the table from the flashlight is the main interaction that the children performed, whether they were invited to do so by the teacher or not. These types of interactions are in line with the corresponding activities that the children performed during the teaching session: indeed, the use of artefacts is functional to the activity performed.

In Fig. 1, we can see the percentage of manipulation and interaction with the tools and the act of pointing towards the shadow/light for each of the five children during the three activities.

The interaction is relatively equal amongst the children in activity 1. A clear distinction in the style of interaction appears in activity 3, where child L is interacting the most, followed by N and A, and children S and R are not interacting as much. It is interesting to note that this difference is consistent with the progress of the children identified from the pre- and post-tests: child L demonstrated strong progress, children A and N, medium progress and children S and R made no progress at all.

Below, we analyse some verbal extracts that emphasise the children's relationship with the manipulation of tools and the interaction with the light and the shadow.

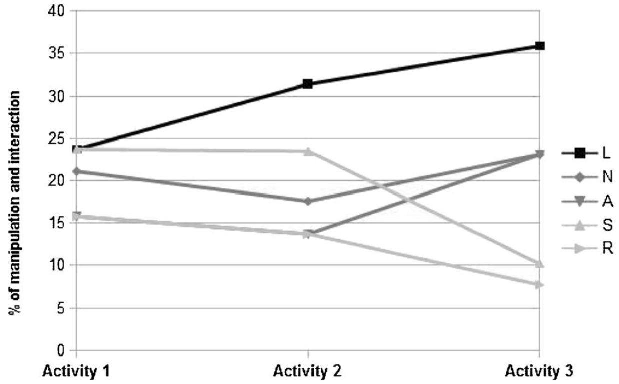
During activity 1, children often performed the act of pointing before the teacher explained the request, as indicated by extract 1 and 2.

Extract 1
5.54 (Teacher): Now I put the stick... *here*... [The teacher raises the stick and puts it on the table next to L and A]
5.55 (L): *Here* [L points to a position on the table]
5.56 (Teacher): Wait! I haven't told you where I will put the light. I put the light *here*.

Extract 2
8.04 (Teacher): Okay. Attention, I will ask each of you. Okay? [R, S and N raise their hands] [The teacher moves the stick toward S and N] I want that the shadow … [*L and S point to the table*]
8.09 (Teacher): … no… as long as I haven't said anything, it is useless. [Children retreat]

The repetitive patterns (teacher asking the children to predict the position of the shadow or light) led the children to use the artefact as a tool of cognition. This activity of anticipation stressed here is also found in all the other videos of the teaching sessions,

Fig. 1 Interaction with the tools for each child in the three activities



especially in activity 1 and activity 2. This ‘game’ of communication (Wittgenstein 1965) is reduced in activity 3, probably as comprehension progresses, giving space for a more internalised understanding. We can consider this interaction as trial and error behaviour, which gives the children the opportunity to explore and understand their external environment (Lockman 2000) and, in this case, the phenomenon of the formation of the shadow.

In the same way, during the ‘impossible’ task (see Table 1 for a description) in Activity 2, the children used the act of manipulating the stick to test and guide their understanding. In Extract 3, we report an example of how the children interacted with tools to try and answer the impossible question asked by the teacher, which they still consider possible at that stage.

Extract 3
11.01 (Teacher): Where should I position the flashlight to have the shadow and the flashlight *on the same side?*
11.04 [S points to a *position for the flashlight on the other side of the table*]
11.05 (Teacher): *Here* ... [L points to anticipate the position of the shadow] so here I light up … [L points the shadows on the table]
11.09 (R): *There, in front!*
11.11 (Teacher): The shadow, *it is there, it is not here*
11.14 (S): I was wrong…

In the impossible task, the children’s attitude is to find an answer through the tool manipulation. Only the verbal guidance of the teacher shapes the children’s reasoning and helps them to realise the impossibility of the task.

The Children’s Body Positions and Gestures In the following section, we analyse the children’s body positions and gestures during the examined teaching session. Each child performed an average of 13 body-changing positions and gestures (A, 11; L, 10; R, 16; S, 14; N, 15; for a total of 66) during the three activities of the teaching session. In Fig. 2, a summary of the occurrences is presented.

The greatest number of gestures is found in activities 1 and 2. In particular, in activity 1, the children’s posture is bent forward, and they express non-verbal agreement or disagreement with the prediction activity. These gestures go along with the trial and error behaviour already identified, as we also see in Extract 4.

Extract 4
14.52 (Teacher): Is it still there? [The teacher tips the table]
14.53 (N): It disappeared
14.54 (Teacher): We now look at L’s point [all the children get up]

We can interpret this posture as active involvement of the children in the activity. In activity 3, all children hold a flashlight in their hand, positioned on the table in front of them. Their posture is more static than in the previous activities in terms of gesture, and the children are waiting to answer the teacher’s requests.

The body position gives us an indication of the spatial arrangement of the children within the context, considering the body as the publicly visible place for the construction of an action

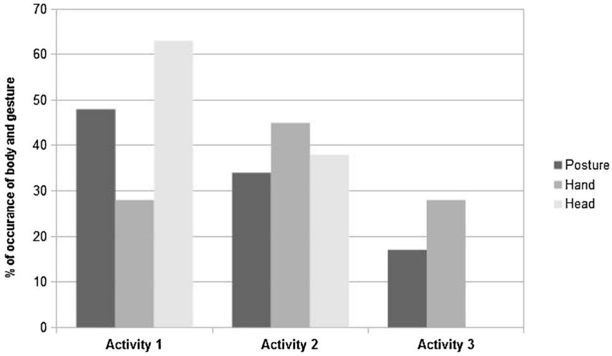


Fig. 2 Occurrences of body positions and gestures during the activities

(Goodwin 2000), and the gestures capture the instant aspect of thought that is built into instant interactions (Levy and McNeill 2013). Other gestures are used in more emphatic functions, as in Extract 5.

> Extract 5
> 11.55 (Teacher): S, here, is it lit there? [The teacher shows the face of the stick in the shadow]
> 11.55 (S.): No [*S hides his face behind his hands*]

The act of raising a hand arose as a spontaneous gesture that children introduced in the teaching session without an explicit invitation from the teacher to use this routine which is typical of a formal lesson. Finally, we note how the act of helping other children emerges only at the end of the session and always by the same child toward the others (performed by N). We can note that N demonstrates a medium level of progress.

The Verbal Expressions of the Teacher and the Children In the analysis of the examined teaching session, we identified 327 speaking turns performed during the teaching session selected. Two hundred and sixteen turns were executed by the teacher and the remaining 111 were distributed amongst the five children, with a significant discrepancy between them (S, 53; R, 10; N, 24, L; 19 and A, 5). Although verbal interaction was mainly conducted by the teacher, the children were encouraged to express their views regularly throughout the teaching session, and to verbalise their predictions and observations.

Most of the speaking turns were performed in activity 1 (139 turns), probably due to the need of the teacher and children to deal with the novelty of the experience of the phenomenon of shadow formation. In activities 2 and 3, the number of speaking turns were quite similar (respectively, 96 and 92).

Below, we provide a more in-depth analysis of the categories that emerged from the content analysis conducted. The categories, organised in the codebook, were applied to speaking turns for the teacher and the children involved, divided into the three activities.

In Fig. 3, we see the distribution of the frequency of each category compared to the three moments of the activity. The analysis of the verbal expression of the teacher

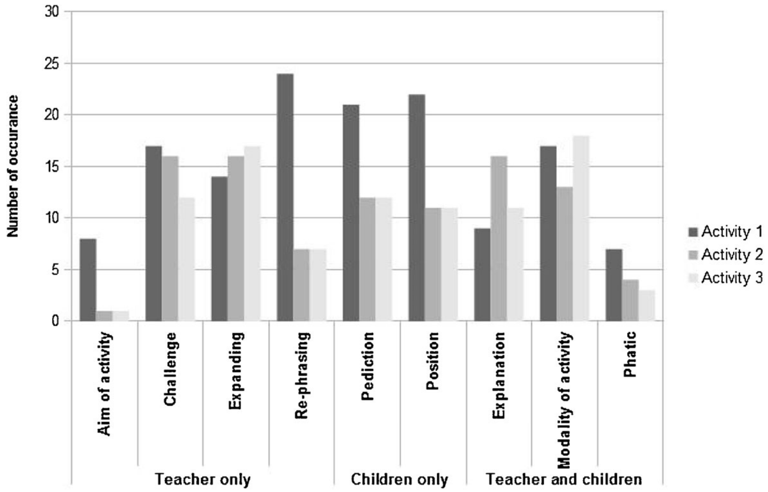


Fig. 3 Frequency of verbal subcategories during the teaching session

and the children shows that most categories identified are exclusive to the teacher (aim of activity, challenge, expanding and rephrasing). Some categories are shared between teacher and children (explanation, modality of activity and phatic) and others are specific to the children (prediction and position). We can consider, from a pragmatic perspective, that the language becomes action (Austin 1962) to perform the activity.

In activity 1, the category more present is the aim of activity, to stress the aim of the discussion, such as, ‘Here I speak about shadows. I do not ask you where you see any light’. This is clear, considering that the teacher needs to explain the purpose of the activity, which is new to the children. At the same time, the teacher needs to model the interactions and reformulate the statements of the children (e.g. ‘In fact, when it gets dark we see light’), giving shape to the interaction. The phatic category (e.g. ‘Do we/you agree?’) supports this interaction process and the children perform the prediction (e.g. ‘The shadow will be here’) and position (e.g. ‘Yes, he’s right’).

The explanation (such as, ‘He had not put the light there; otherwise, the shadow would be here’) becomes more evident in activity 2, probably because the teacher leads the children to the ZPD (Vygotsky 1978), particularly with respect to the use of the impossible task.

Modality of action (e.g. ‘We will work with this, we will call it a stick’) is equally distributed amongst all the activities, considering the change in the task to being performed by the children. In the same way, the relatively constant occurrence of verbal interactions of the challenge (e.g. ‘Where will the shadow be?’) and expanding (e.g. ‘Do you have a different suggestion?’) highlights the effort of the teacher to scaffold the activity and engage children in the learning process (Wood et al. 1976).

Prediction anticipates the explanation, allowing the children to build a pseudo-hypothesis of the phenomenon observed. For example, the contradiction that emerges in the impossible task stimulates the children to do more prediction and then revise their knowledge, often guided by the teacher. This task highlights the main difficulty for children in identifying non-transparent objects as obstacles to light (Ravanis 1996).

In extract 6, after incorrect attempts at predicting made by the children, the teacher explains the impossibility of the request of having the shadow and the light on the same side.

Extract 6: (during activity 2)
11:17 (Teacher): So … is … I repeat my question …Is it possible to have the shadow and the light on the same side …?
11:21 (murmur of several children): …no…
11:22 (Teacher): … of the stick?
11:24 (N): Ah, I know!
11:25 (Teacher): So, is it possible?
11:26 (N): *You have to put it here … it must be put here*
11:29 (S): no…here there is the sun and there … [points on the lighted side of the flashlight and on the other side of the flashlight]
11:32 (L): [points to the shadow on the other side of the stick with her hand] *it is here*
11:36 (Teacher): *So no!* I asked you a question which is impossible. To have a shadow, you always need a light and there must be an obstacle to the light. You see the stick; it is an obstacle to the light…

The extract shows the manipulation of tools to get to the solution and the contradictions that children encounter between the use of tools and the request made in the understanding of the task. The mediating role of the teacher to achieve understanding is explicit here: the identification and resolution of these contradictions seem dependent on individual cognition but is also mediated by the social processes. Indeed, the teacher forces the children's attention onto specific contradictions and a possible resolution.

Interestingly, during the teaching session, the number of explanations given by the children increases: children become more 'expert' and more able to verbally explain the observed phenomenon, even before the direct manipulation of tools, as we see in extract 7.

Extract 7: (during activity 2)
8:30 (Teacher to N): So are you right?
8:33 (S): Yes … .no
8:34 (L): *It was wrong to put the light there; otherwise it will make a shadow here. [L shows the place of shadow if the flashlight is placed as indicated by R]*
(Teacher): Good
8:39 (R): But I said that here, here, there was the light [points toward the flashlight turned on] and here there was a shadow [points toward the shadow]
8:42 (Teacher to R): Okay! So you changed your mind then
8:45 (R): Yes

The explanation by L provides insight to R, so that he claims to have changed his mind. Children possess at least rudimentary argument skills and they are able to reap the benefits of social reasoning from very early on (Mercier 2011).

The categories of expansion, prediction and explanation seem to better support the process of talking about scientific concepts: it is particularly useful that each child manages to explain, with more or less intervention from the teacher, his or her own actions and thoughts (e.g. Ogborn et al. 1996). Patterns of 'talk science' (Lemke 1990) become visible in the moment-by-moment interactions and they are co-constructed during the situated interaction. Indeed, according to the same author, learning science means being socialised into scientific ways of reasoning and acting, where students should learn to argue and discuss with the specific patterns of scientific discussion (Lemke 1990).

In conclusion, from a comparison with the post-test taken by the children in this group, we can see that child S talked a lot but did not progress much, whereas child A showed a medium level of progression and hardly spoke but his interactions with artefacts increases toward the end of the teaching session. Child L, who demonstrated strong post-test progress, combines speech (with the use of well-argued explanations), non-verbal interactions and the use of artefacts offered by the teacher.

Tools, Embodiment and Verbal Interaction in Each Activity For a further exploration of the three activities of the teaching session, in this section we present a broad description of three episodes isolated from different teaching sessions. These episodes are intended to be read as representative of key ideas emerging from a socio-material perspective of the three activities in the different teaching sessions. The same three categories and indicators of the first analysis are considered. However, the following extracts were selected mainly for their illustrative nature of the children's manipulation of tools and interactions with shadow/light and the body and gesture movement of the children.

Activity 1: Production of One Shadow This extract involved six children (two girls, four boys) and the teacher. The teacher is not directive in the questions and addresses generic questions to all children. The responses of the children are chaotic and overlapping (all respond at the same time). This leads the children to look at each other before giving an answer, in a form of mutual support. The three children placed in front of the teacher receive a greater amount of eye contact. In fact, during activity 1 (up to 5:14 min) the conversation takes place between the teacher and the three children in front and on one side. The two children at the other end of the table showed forms of non-involvement in the interaction (Fig. 4a).

The situation changes when the teacher directly addresses the child next to her (Fig. 4b). This action activates the immediate attention of the peer, who mimics the other's body position, without verbally intervening (Fig. 4c). One of the two children not involved finally becomes active when he gets the flashlight in his hand to manipulate (Fig. 4d).

After this, the same child stays active only with imitation of the others and is easy to distract by watching the others. The attention restarts in activity 3 when all children manipulate a flashlight in their hand. The direct manipulation of the flashlight draws again the attention of all the children.

This extract, in our opinion, highlights how the direct manipulation of tools draws the attention of the children and the involvement in the group activity encourages the participation. Considering the ecological viewpoints on cognition and tool manipulation (Gibson 1986), knowledge evolves through perceiving and acting: 'action and manipulation, accordingly, seem to be fundamental for acquiring knowledge about and the use of objects' (Rambusch and Ziemke 2005, p. 1806).

Activity 2: Prediction of Shadow Position In activity 2, three extracts drew our attention. Six children (one girl, five boys) and the teacher are involved.

In Fig. 5a (5:34 min), a child imitates the gesture of the teacher to indicate where the shadow is. The children's gesture we can consider 'superfluous', considering that the teacher is

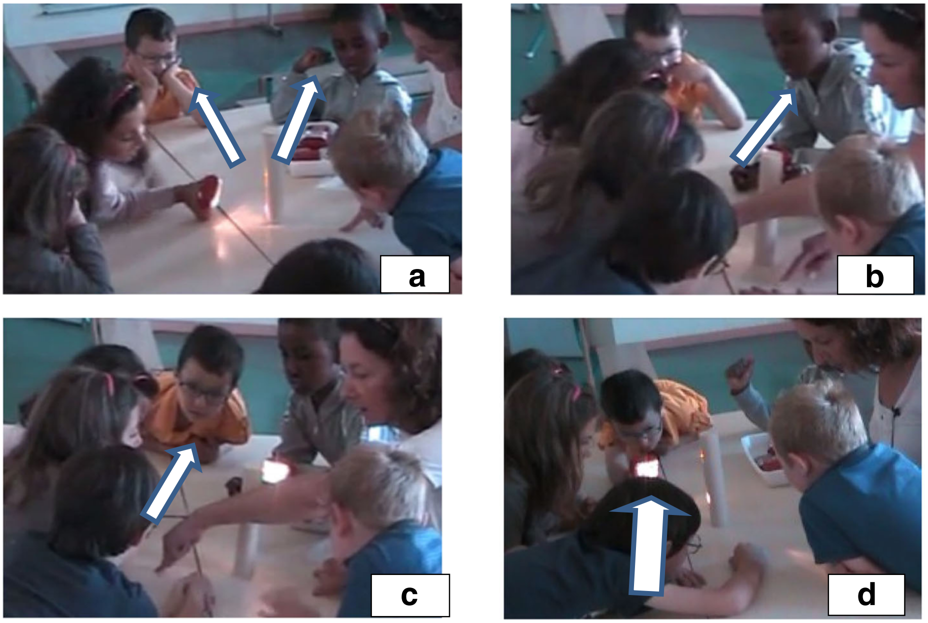


Fig. 4 **a** (4.43. **b** 5.38. **c** 5.46. **d** 7.43.The experimental setup of activity 1

still formulating the request and uses the gesture to explain how to carry out the activity. The gesture of the children can be explained as an effect of emulation, to follow the reasoning. In Fig. 5b (9:12 min), we can see the activation of almost all the children in the activity, shown by all the hands on the table to indicate where the shadow is as made by the flashlight. There are more non-verbal attempts in the response to the teacher requests than verbal. One child never shows involvement (probably due to his position further away from the focus of the activity).

In the second activity, particular attention is dedicated by the teacher to the impossible task. In Fig. 5c (10:19 min), a child tries a first attempt to solve it, by placing the flashlight next to the opaque stick, trying at the same time to answer the question of the teacher. This produces a gesture-speech mismatch, an effect by which gestures and speech convey conflicting information. Goldin-Meadow (2003) argues that children producing such mismatches are more likely to benefit from indications and are ready to learn.

Next, it is interesting to note how the teacher helps the children to reach the correct understanding of the impossible question (11:31 min). After different children manipulate the stick, the teacher introduces a new point of view at 13:13 min: 'Is it possible or not?' This question opens up another way of reading the situation, contradicting usual teaching practice (the impossibility of the request). It leads to a shift in the children's manipulation of the stick.

Fig. 5 **a** 5.34. **b** 9.12. **c** 10.19. The experimental setup of activity 2

Consequently, children express a generic ‘no’ to the teacher’s questions. After the teacher orients the attention by asking ‘Why not?’, one child arrives at the right answer directly through the manipulation of the tools (15:05 min) without any verbal explanation. Another child expresses a verbal explanation only at the end of activity 2 (15:40 min). The solution to the impossible task seems to be co-constructed in an interactive process between manipulation of the stick by the children and the verbal guidance of the teacher.

This extract highlights the support the children get from the tools in reaching an understanding and supplying the correct answer to the teacher’s questions. According to Tudge and Winterhoff (1993), the feedback from the tools participates in the ZPD of the children. At the same time, peers and the teacher guide and shape the interaction and co-construction of knowledge. Indeed, cognition cannot be studied in isolation, but must consider the context in which the individual works, being distributed among individuals, artefacts and environment (Hutchins 1995).

Activity 3: Production of Multiple Shadows In the last extract selected, the group is composed of five boys. We see a child in a dominant communication posture: he anticipates the teacher’s answer (overlapping the questions) and proposes an explanation throughout the session, from the start (Fig. 6a) to the end (Fig. 6b). The teacher often directs communication to him (also favoured by a central position that allows a greater amount of eye contact). As a result, the other members of the group are less involved in the interaction and only active after a specific request by the teacher.

Usually, the small group situation encourages children to manipulate tools and engagement in the activity. However, Tudge (1989) suggests that peer interactions promote cognitive change, without presupposing progress: the presence of a more advanced partner does not necessarily lead other peers to improve during the post-test. Group work becomes useful from a certain level of development of the children, when they are capable of interacting with others, to consider different perspectives and revise their own knowledge (Perret-Clermont and Carugati 2001).

Discussion

The paper is set in the socio-material field (Clark 2010; Lenz Taguchi 2010) to offer a way of conceptualising the actions and interactions of children in preschool involved in the understanding of scientific concepts.

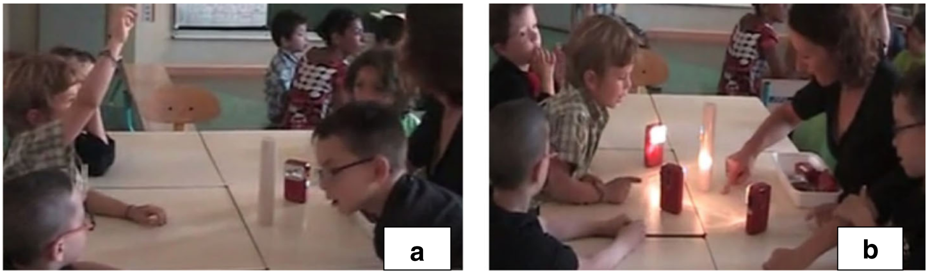


Fig. 6 **a** 00.43. **b** 11.14. The experimental setup of the activity 3

The point of departure for our study was the willingness to explore the process of understanding scientific concepts in a preschool context. In particular, it was the understanding of the formation of shadows through a specific teaching session, defined from the obstacles and difficulties associated with the understanding of this phenomenon by young children. We investigated the children's understanding of shadow formation specifically through the interaction of children with a tool; embodiment and verbal dimension. All the categories explored seem to influence each other: all material, human and social dimensions (Orlikowski and Scott 2008; Suchman 2007) contribute to the children's understanding of shadow formation.

From the analysis of the training session, we can consider the importance of the verbal guidance by the teacher in the mediation of understanding. The teacher's role is central in guiding the children's understanding: the complexity of the physical phenomenon is coupled with the social interaction, and the effort of the teacher deals with the difficulties encountered by the children. Indeed, 'the mediating role of the teacher consists, on the one hand, in becoming actively involved in diagnosing the students' contradictions and, on the other hand, in responding to these contradictions' (Dedes and Ravanis 2009, p. 59).

In the analysis performed, we can consider that the argument is a sketch, considering the young age of the children. However, taking into consideration the complexity of the children/teacher interaction, the development of scientific knowledge should be presented, starting at preschool, as a creative and interactive process, and not closed and static, considering the importance of debate to discover and improve knowledge (Lubart et al. 2003). Also, the small group activity forces children to be explicit about their points of view and to take positions, supporting the interactivity of the learning process. Indeed, specificity of scientific knowledge helps students to recognise and take positions (Mäkitalo et al. 2009). In general, considering the pre- and post-test results, we can make the hypothesis that interactions with simple and specific tools enhance children's engagement in the learning process and their understanding of the physical phenomenon of shadow formation.

From the case studies, we can consider how the direct manipulations of tools are related to the participation and involvement in the group activity. At the same time, the manipulation of tools supports cognition, giving feedback to the action (Tudge and Winterhoff 1993).

From the methodological point of view, we consider socio-materiality relevant to the analysis of preschool children's understanding of scientific phenomena. In this analysis, we can consider also the implications of the specific physical space and material arrangement (Nordtømme 2012), organised in the teaching session by the teacher and the researcher. We have to read the results in relation to the constraints of the actions of the children related to their performance in constructing their first explanatory models of shadow formation.

Conclusion

The study is primarily descriptive and the number of participants is limited. Also, we selected illustrative cases to highlight socio-materiality perspectives in scientific activities in preschool and, as a consequence, did not systematically identify the occurrence of the selected episodes in each activity across all the videos of the teaching sessions.

However, for the use of such teaching sessions in fostering young children's understanding of physical phenomena in future research, we have identified some elements that can serve as potential sources of improvement in the teaching sessions on shadow formation:

- Familiarisation with the tools: this first step could be useful during the teaching sessions. Some children showed difficulties in the use of the tools, showing the desired amount required to manipulate them during the teaching session.
- Involvement of each child in the activity: the role of the teacher to trigger each child's attention and help them to focus on the goal of the activity was essential in this study. For example, it could be suggested that role taking could be implemented by giving different roles to the group (Hare 1994).
- Promote individual or collective 'externalisation' of knowledge: for example, engage the children in a collaborative production of a shared artefact or an individual production of a written drawing as a moment to 'rise above' the knowledge process (Scardamalia and Bereiter 2003).
- Encourage open-ended questions at the end of the teaching session*:* to stimulate creativity and reflection, and open new cycles of curiosity and scientific inquiry, making the child feel active in the interaction and engaging them with the expression of explanations. This aspect is particularly critical at the age in this study (five to six) where the development of language is encouraged at school (Eurydice 2009).

In conclusion, we can consider that science education and, in particular, research into preschool could benefit significantly from the focus on material-semiotic action: 'sociocultural processes such as social interactions and tool use need to be discussed in much more detail from an embodiment perspective to gain a more profound understanding of cognition and learning' (Rambusch and Ziemke 2005, p. 1807). A broader base of evidence is necessary to explore how greater socio-material engagement can be linked to greater achievement.

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