Res Sci Educ
DOI 10.1007/s11165-014-9458-2

The Contribution of the Human Body in Young Children's Explanations About Shadow Formation

Evagelia Herakleioti · Panagiotis Pantidos

Abstract This paper begins with the view that the generation of meaning is a multimodal process. Props, drawings, graphs, gestures, as well as speech and written text are all mediators through which students construct new knowledge. Each semiotic context makes a unique contribution to the conceptualization of scientific entities. The human body, in particular, can function as a factor in both representation and explanation, serving as a link between verbal discourse and setting. Considering this perspective, a body-based activity was designed for kindergarten children, involving the concept of a shadow. The 3-D arrangement of the light from the light source, the human body (the obstacle), and the resulting shadow plays a central role. Using their own bodies as obstacles to the light, the children were able to explore the direction of the light and to change the relative positions of the light source and the obstacle. They formed hypotheses and were able to test them by moving on the stage. This body-centered activity explicitly incorporates the rectilinear movement of light into the process of shadow formation, while also providing learning through direct experience. Positive effects on learning were achieved for the group of children who participated in the activity, while the video analysis showed that many of the children were able to use their bodies to transfer to a different setting the embodied knowledge they acquired. This, according to researchers in the field of science education, is a powerful indication of conceptual change.

Keywords Shadow formation · Human body · Embodied knowledge · Transfer of knowledge

Introduction

Research in science education has shown that children at preschool age are ready to learn about various scientific ideas (e.g., Kamii and Kato 2007; Ravanis 1994; Russell et al. 1989; Sharp 1995). With respect to teaching strategies for science in kindergartens, a number of researchers have preferred a sociocognitive framework for the design of activities (e.g., Ravanis et al.

E. Herakleioti · P. Pantidos (✉)
School of Early Childhood Education, Faculty of Education, Aristotle University of Thessaloniki,
541 24 Thessaloniki, Greece
e-mail: panos_pantidos@yahoo.gr

E. Herakleioti
e-mail: litsairakleioti@gmail.com

Published online: 03 February 2015

2013; Tsatsaroni et al. 2003). In their perspective, students' cognitive development is a social practice (Lemke 2001; Roth 1998). Children construct knowledge through interaction with their community, by using as cultural tools such mediators as language, visual representations, the human body, educational software, books, etc. Such teaching activities allow children to formulate predictions and explanations in respect to physical phenomena, to verify their reasoning by experiment and reshape their ideas in an interdependent context of agreement, disagreement, or conflict with their classmates (Christidou et al. 2009; Tytler and Peterson 2001). For their part, teachers encourages the use of trial tasks, forming questions, focus on specific elements, comparison, conflict, and the final synthesis of views (Venville et al. 2003). By entering into sociocognitive processes of knowledge building, the children are assisted with constructing precursor models of the natural world.

These precursors are cognitive constructions (concepts, models, procedures, etc.) generated by the educational context. They constitute the molds for subsequent cognitive constructions, which, without their help, would be difficult or impossible (Weil-Barais 2001, p. 188).

In research conducted using the formal, constructivistic approach, the view was taken that individual interviews adequately represented students' thinking. However, in sociocognitive research approaches, what interests us is how students' reasoning (internal) is formed in its connection to the properties of the external context (e.g., teaching material, use of gestures, level of teacher's intervention).

Contemporary views of learning do not accept that knowledge is simply constructed internally by the individual. It is also built up through the child's interactions and the modes used to represent it. In any educational setting (including the kindergarten), children conceptualize scientific entities using their *preexisting ideas*, the *social dynamic* which unfolds, and the *modes of representation*. Thus, a prominent role is played, inter alia, by the semiotic context of mediation between children's thinking and their actions. Props, drawings, gestures, wordings, etc. are used to assign meaning to specific events all activated in the meaning-making process.

Our study provides a theoretical framework from science education literature emphasizing that the generation of meaning is a multimodal process. Through the example of the shadow formation phenomenon, the study examines how the properties of various semiotic resources can guide the children's thinking and lead them to specific actions. This analysis focuses on the different semiotic profiles (i.e., material objects, 2-D representations, simulations, human body) used in science activities proposed for preschool children to teach the phenomenon of shadow formation. Study of the above activities has shown that the human body (i.e., gestures, displacements, inclination of the trunk, etc.) is not taken into account as a crucial semiotic agent in the construction of meaning. For this reason, a body-based activity has been devised and used with preschool children. The intention was twofold: (a) to verify whether such an activity can have a positive impact on learning of dimensions in the phenomenon of shadow formation and (b) to explore how children conceptualize aspects of the phenomenon through bodily expression representation.

Shaping Meanings: a Semiotic Approach

A strand of the research that has been developed in science education has tended to focus on meaning-making as a process which essentially relies on interplaying various vehicles of signs (e.g., Kress et al. 2001, Pantidos et al. 2010, Pozzer-Ardenghi and Roth 2010). Quite a few researchers understand semiotic resources (e.g., spoken language, written text, drawings, graphs, body movements, spatial arrangements) as *grammatical* (meaningful) genres which charge any teaching event with meanings. Hwang and Roth (2011), as well as Pozzer-Ardenghi and Roth (2007), approaching physics *concepts as heterogeneous performances*, consider that addressees (i.e., students) receive, and inevitably conceptualize, addresser's (i.e., teacher's) spoken, spatial, and bodily performances of concepts, all of these serving to interweave a communicative *whole*. In essence, such a viewpoint highlights the fact that scientific entities are also semantically charged by the modalities used for their representation.

Kress et al. (2001) have argued that any resource of representation gives *knowledge shape*, maintaining that the transition within various modal accounts does not merely serve to represent the same thing through different forms but reshapes the knowledge itself. Understanding learning "as a dynamic process of sign-making" (Kress et al. 2001, p. 129), the aforementioned researchers consider that students can shed light on various aspects of knowledge through their bodily, spatial, visual, or textual semiosis. Along a similar trajectory, Tytler et al. (2007) draw on how different representational modes constructed by the students can contribute to learning, promoting "a richer conceptual understanding" (Tytler et al. 2007, p. 313). In the context of investigating the relation between semiotic resources and student's learning as regards evaporation, the above researchers approach the *modes of representation* "*as epistemological tools* through which students can explore science ideas and clarify for themselves their understandings" (Tytler et al. 2007, p. 327). In fact, they emphasize the view that no notion can be seen separately from its representation(s).

Vosniadou et al. (2004) provided evidence of how two different methods of questioning concerning the shape of the earth and the day/night cycle elicited dissimilar types of reasoning in young children (grade 1 and grade 3). Actually, the forced-choice method of questioning (FCQ) extracted from children more scientifically correct responses than the open method of questioning (OQ). Besides, the researchers—by adopting in both methods the same criteria for the evaluation of the consistency of the mental models constructed by the children—showed that in FCQ, children produced distinctly less consistent responses than in OQ. Finally, Vosniadou et al. (2004) argue that the method of questioning as well as the presence or the absence of external representations (i.e., material model of a sphere) influence children's reasoning in elementary astronomy fostering different *modes of knowing*.

Likewise, in an attempt to shed light on how iconic gestures improve learning about the conservation of a quantity, Ping and Goldin-Meadow (2008) explored preschool children's understandings through comparing a gesture-plus-speech instruction with a teaching context based solely on spoken words. The results indicated that although in pretest the two groups solved the same number of problems, after the respective instructions, the (equivalent) posttest revealed a significant difference (positive) for the gesture-plus-speech group. This clearly demonstrates that using teacher gestures facilitated children's learning about specific aspects of the topic. Moreover, Ping and Goldin-Meadow (2008) tested children's ability to adopt into their explanation knowledge that had not been acquired during gesture-plus-speech or speech-alone instruction. The results revealed that children are more likely to produce novel explanations about the notion of conservation of quantity in the former instructional context only when the material objects that the gestures referred to are absent from the space where the task takes place. Essentially, the two researchers came to the conclusion that iconic gestures do not merely construct a bridge between language and the entities of the real world but, by being applied without mediation to the mental images of the absent objects, extend children's understandings as well as their competencies in solving more abstract problems.

At the level of *embodied cognition*, Hadzigeorgiou et al. (2009) compared the performances of two groups of preschoolers in applying rules which have been taught through two contextually different tasks about mechanical equilibrium. Initially, in two preliminary-training tasks, the first group had been exposed to sensorimotor activities and the second one participated in hands-on activities. The children in the first group, by walking on a beam, were trying to balance themselves (i.e., their bodies) by holding buckets of various sizes and weights, while the children in the other group were asked to equilibrate a typical (plastic) mechanical balance by choosing and placing objects of unequal sizes and weights on it. Subsequently, both groups were subjected to posttests in which a typical scale was used, consisting of a horizontal stick which could revolve around an axis passing through its center. The results, among other things, showed that only the children who had been exposed to and had internalized sensorimotor tasks retained their ability to apply (up to 4 weeks after the initial activity) the rules that had been internalized in their bodies.

All the aforementioned researchers recognized that concepts are also shaped by means of heterogeneous performances (e.g., Pozzer-Ardenghi and Roth 2007) which take place in the science classroom. The main idea behind such a view is that semiotic resources create teaching contexts which give knowledge shape (e.g., Kress et al. 2001), influencing the way students make sense of, and thus construct, different modes of knowing (e.g., Vosniadou et al. 2004). Actually, what is mentally constructed relies not only on what has already been conceptually shaped (i.e., students' preconceptions) but also on the forms and modalities used to represent it.

The human body, on which this article focuses, makes a unique contribution to the shaping of students' mental representations with respect to various scientific entities. More generally, bodily actions may represent concepts and endow with meaning entities which are not visible (e.g., movement of electrons) (Roth 2001), while also expressing dimensions which verbal discourse cannot communicate (Pantidos and Givry 2014). In cases of experimental teaching, research has demonstrated that in the mental processing of data, the teacher's gestures precede or replace verbal discourse (Roth and Lawless 2002). Moreover, gestures, changes in body stance, movements in space, and actions involving material objects form conceptual links between what is being uttered by the teacher and the spatial components of the learning environment (Hwang and Roth 2011).

Various Semiotic Contexts Construct Various Aspects of Shadow Formation

Shadow formation is a common subject of teaching, particularly with young children (Murmann and Schwedes 1999; Osborne et al. 1993; Parker 2006). Many of the recommended activities can be staged within the classroom, with the shadows produced by material objects to be found there (e.g., Ravanis 1996; Ravanis et al. 2010). In other cases, the children create their own shadows using the light of the sun, outside in the playground (e.g., Vincent and Cassel 2011). Furthermore, other teaching strategies can be used in the classroom, which refer to external (non-tangible) spaces, for example, discussion of the role of the shadow in relation to various planetary phenomena, such as the eclipse of the sun and moon or the alternation of day and night (e.g., Young and Guy 2008).

Many researchers suggest teaching approaches to the shadow phenomenon based on various semiotic systems. Actually, each environment, with its different semiotic profile, has a different effect on the children's thinking and leads them to different actions. The use of light sources and opaque material objects as obstacles which interact with the light is a widespread practice in kindergartens (e.g., Barrow 2007; Segal and Cosgrove 1993). A *3-D arrangement* of torch–object–shadow offers a *realistic representation* of the concept of *obstruction*. Additionally, the student can, to some extent, test with his or her own hand the possibility of the light passing or not passing through the spaces in front of and behind the obstacle. More generally, these arrangements allow children to form hypotheses, to experiment, to record, and to test their hypotheses. This has been confirmed by research, with shadow activities based on material objects for children aged 5–6 having an effect on learning (Ravanis 1996). More specifically, the children showed positive change in their performance on the semi-level of shadow formation, an explanation of the phenomenon in terms of obstruction of light, and the correspondence in number of light sources and shadows (Ravanis 1996). In another similar setting, the children experimented with changing the distance between light source and obstacle, using different objects (e.g., dolls, bricks) (Hadzigeorgiou 2003). They were encouraged to think about the way in which they should hold the torch in order to form larger or smaller shadows or to change the shadow's shape. In another instance, Vincent and Cassel (2011) used a human figure and a torch to light it. In this setting, the children tried to find out how the size of the shadow changes and to link this to their movement in the external space.

2-D representations (e.g., drawings) also play a central role in these activities and can also be used as an independent tool for exploring children's ideas (Chang 2005; Kress 1997; Shepardson et al. 2007; Trend et al. 2000). Such representations might include a sketch made by the children to illustrate the relevant positions of torch, obstacle and shadow (Papandreou 2012), cards representing shadows to show their correspondence with the real objects in the setting (Barrow 2007), and (modified) photographs requiring the child to choose between true and false situations with respect to the position and size of one or more shadows (Chen 2009). It is worth noting that in sketches, shadows were represented symbolically and not formed naturally as in the 3-D arrangements of objects. From a semiotic point of view, the absence of the third dimension led the child to form the shadow on just two semi-levels (either right or left of the object). However, this was likely to induce a sense of linearity, thereby implying that light moves in a straight line. In general, 2-D representations do not allow experimentation but codify the experimental data as a result of mental processing. In other words, once the experiment has been conducted, the children use drawings or photographs to convert their 3-D experience into two dimensions (conceptual challenge).

For young children in particular, activities based on *simulations* are recommended (Barab and Dede 2007; Rieber 2005). These can simulate the formation of shadows in arrangements of material objects or in the movement of the Earth around the sun (Trundle and Hilson 2012). Compared with material objects, simulations relating to the formation of shadows represent more clearly the image of light beams and the movement of light in a straight line. Actually, when real torches are used, the edges of the light beams are not always clear. More generally, simulations allow experimentation in 2-D and 2-D*.[1] They combine the symbolism of the sketch and the experimentation associated with material objects. A good example would be the virtual applications relating to shadow formation at the *Cité des Sciences et de l'Industrie*. There is persuasive evidence that educational activities for young children (5–6 years old) based on a virtual visit to these applications lead to positive learning results (Georgoutsou et al. 2010).

Other shadow formation activities recommended include those involving the human body. Most of them take place outdoors, where the light source is the sun and the children's own bodies are used as the obstacles. In this setting, the children can work on the mechanism of shadow formation (Hadzigeorgiou 2003; Segal and Cosgrove 1993) or measure the length of their shadows at different times of the day (Trundle and Hilson 2012; Vincent and Cassel

[1] Two-dimensional drawings conveying the idea of a third dimension (perspective).

2011). Games with the sun offer a more direct, lived experience but do not provide the same distinct beam of light, so its movement in a straight line is not so obvious. Moreover, the shadow appears to be a continuation of the obstacle. In contrast with these activities, Fleer (1996) *separates* the *human body* from the *shadow*. More specifically, in one of her studies of how young children understand the concept of light, the child's body plays the role of the obstacle and its shadow is projected on a screen behind it. In a dark room, a projector creates a beam of light, which is broken by the child's body. That situation allows the children to reason about the mechanism by which a shadow is formed.

All the above activities make a unique contribution, as semiotic contexts, to conceptualization of shadow formation. Yet, absent from them is a study of the human body as a factor generating explanations and constructing knowledge. Even the activity suggested by Fleer (1996) does not attempt to engage children's reasoning with their gestures or bodily acts. The human body is the material factor of mediation between children's thinking and children's actions. In the current study, an activity was designed based on the 3-D arrangement of the light from the light source, the human body (the obstacle), and the resulting shadow. Using their own bodies as obstacles to the light, the children were able to explore the direction of the light and to change the relative positions of the light source and the obstacle. They formed hypotheses and were able to check them by following the light's direction moving on the stage. Moreover, in a test conducted after the activity (posttest), the children were encouraged to think with their bodies, providing a kind of corporeal explanation.

Children's Bodies Help Construct Explanations of Shadow Formation

The research involves three aspects of the shadow phenomenon, namely (a) the mechanism by which the shadow is formed (aspect 1), (b) the relationship between the size of the shadow and the distance between obstacle and light source (aspect 2), and (c) the correspondence between the number of shadows and the number of light sources (aspect 3). These three features are the usual aspects which adequately describe the phenomenon of shadow formation and which have been studied as concepts in preschool children (e.g., Ravanis et al. 2010).

Research Questions

- Does a shadow formation activity based on the human body produce positive learning results in preschool children?
- How do children use their bodies to explain aspects of the shadow formation?

Methodology

Participants

The sample was a state-school kindergarten class of 16 children aged 4–5.5 of whom five were prekindergarten and 11 kindergarten. The children had not previously been taught the concepts of light and shadow. The human-based activity used involved by its nature both light as a physical entity (the children's bodies represent the light when they move) and the rectilinear movement of light (the rectilinear movement of the children; see Fig. 3).

Research Design

The research was conducted in three phases: exploring the children's ideas (pretest), teaching intervention based on the human body, and posttest. The pretest took place 1 week before and the posttest 1 week after the teaching intervention. With respect to the first question, the data were gathered through interviews in the pretest and posttest. With respect to the second question, the three phases were videoed. Video was deemed particularly important, allowing us to study not just the children's reasoning but also their bodily expressions at each stage of the research. However, emphasis was placed on the posttest data, in which the children sought to explain the phenomenon in terms of their bodies.

Both the teaching and the exploration of the children's views in the two tests were carried out by the first author, who was not their class teacher, and thus before the procedure, she visited the kindergarten frequently to get to know the children. Furthermore, during the preparatory stage, a pilot study was conducted in another class to test the suitability and efficacy of the methods to be used.

Pretest

At this stage individual, semi-structured interviews were carried out in another part of the school, not in the classroom. The interviews were individual and semi-structured in an attempt to provide an authentic and as close as possible to a comprehensive picture of what each child knows and what obstacles he/she faces. Exploration of the children's ideas took place during free play periods and breaks. Discussion with each child lasted 5–7 min. The materials used comprised two torches, a wooden block, and a sheet of A4 paper (see Fig. 1). The block was placed in a specific position on the paper, and the teacher held one (or two) torch(es) in front of it (see Fig. 2). More specifically, with the torch turned off, the teacher asked the children to make predictions and to give reasons for their answers. Questions involved the three aforementioned aspects of shadow formation. Children gave their answers standing in front of this arrangement of objects.

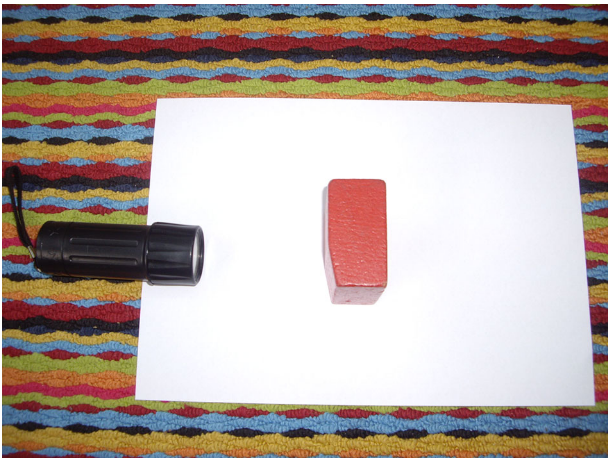

Fig. 1 The materials used to explore the children's ideas

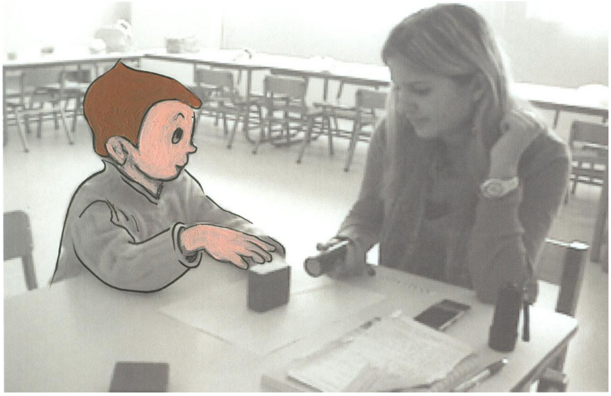

Fig. 2 "If I turn on the torch, where do you think the shadow will be?" "Here" (*points to the block*)

The main questions put to the children were as follows:

a) *Aspect 1*: mechanism by which a shadow is formed (the following questions were formulated twice, one for each different position of the torch)
   "If I turn on the torch, what do you think will happen?"
   "With the block here, if I turn on the torch, where will the shadow be?"
   "Why was the shadow formed here?" (the *here* referring to the point indicated by the child in response to the previous question)
   "When the light leaves the torch, where does it go?"
   "And when it encounters the obstacle, what happens?"
   "Is there light behind the block?"
   "If I take away the block, will there be a shadow?"
b) *Aspect 2*: relationship between the size of the shadow and the distance from the light source to the obstacle
   "How can I make the shadow of the block smaller?"
   "How can I make the shadow of the block bigger?"
   "Can you tell me another way to make the shadow smaller?"
   "Can you tell me another way to make the shadow bigger?" (the last two questions were asked only when the child had answered the two preceding questions)
c) *Aspect 3*: correspondence of the number of shadows and the number of light sources
   "How can I have two shadows?"
   "If I bring another torch, what will happen? How many shadows will I have? How will they be formed?"

Teaching Intervention

The activity was designed to allow the children to use their bodies to express reasoning and construct knowledge. As we have said, the interviews were used to explore the children's initial ideas. The recall of these conceptions formed the main starting point for the teaching intervention. The children then formulated hypotheses for the three aspects of the phenomenon and tested them. In all the tasks, the children reported cases in their own daily lives where they had observed shadows and, with the teacher's encouragement, attempted to explore them using the classroom arrangement. The materials used were two tripods, two torches, a white sheet (2 m×1.5 m), sticky tape, and blue cards. The torch was attached to the tripod using the tape, the white sheet was fixed on the wall, and the blue cards were fixed over the window panes to darken the room. The activity lasted 45 min. The children were able to explore all aspects of the phenomenon using the 3-D arrangement of the light from the torch, their bodies (the obstacle), and the resulting shadows. Every time the child forming the obstacle stood between the light source and the sheet, the other children first, with the torch still turned off, made their predictions concerning the three aforesaid aspects of the phenomenon. Then the torch was turned on and their hypotheses concerning the movement of the light were tested (see Fig. 3). Children formulated hypotheses and were able to test them by investigating the movement of the light (aspects 1 and 3, see Figs. 3 and 4) or by changing the relative positions of the light source and the obstacle (aspect 2, see Fig. 5). The activity was intended to familiarize children with the shadow formation and specifically:

- To explore the way that the shadow is formed by opaque objects obstructing the passage of light. To realize that the obstacle is always located between the light source and the shadow.
- To explore the way in which the size of the shadow changes if the objects are moved. To discover that when the distance between the light source and the body is great, then a large shadow is formed. When the distance is less, the shadow is smaller.
- To discover that the size of the shadow is due to the change in distance between the object and the light source, and a change in distance of the light source.
- To discover that every light source casts a shadow, and every shadow implies a light source.
- To use their bodies to approach the straight line of the light.
- To use their bodies to express their ideas about shadow formation.

To explore the mechanism by which the shadow is formed, the teacher asked the children to come up with predictions while the torch was still switched off. In other words, she asked "Where will the shadow be formed if I turn on the torch?", "Show me how this happens.", "Where does the light come from?", "What does it find in its way?", "What will happen?", and "How can I make a shadow form there?" (the teacher points to an area on the cloth). To answer the questions, the children move from the point where the torch is to the point where they think that the shadow will be formed, representing with their bodies the movement of the light until the obstacle. It is worth noting that the questions "Where does the light start from?", "What does it find in its way?", "Is there light here?" (i.e., behind the body of the child playing the obstacle), and "What happens in the end?" are formulated to help the children if they cannot answer the question "Show me how this happens."

Fig. 3 Here, the teacher plays the part of the obstacle and a child explains the shadow formation ("The light comes from here—It encounters you—And here is your shadow")

Fig. 4 The movement of light in schematic terms

In testing the hypotheses (with the torch turned on), the discussion focused on the concept of the obstacle and particularly on the interaction of light–obstacle. To this end, the following questions were posed: "Why did the shadow form here?", "Show me what happened.", "What does the light find in its way?", "What is (name of child) doing in the light?", "Is there light behind (name of child)?", and "If (name of child) moves out of the way, will there be a shadow?".

The children were able to place their hands (or their entire bodies) behind the obstacle (point B) to establish whether a shadow would be formed on the sheet. Likewise, they were able to test what would happen when they placed their hands at point C (at point B, the child's hand does not form a shadow; at point C, it does). Through comparison, they were thus able to establish reasons to explain these two opposite situations. Figure 4 shows the teacher, but this same position can be taken by the children during the lesson.

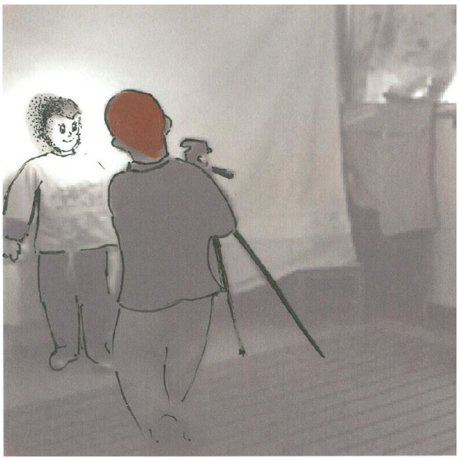

Fig. 5 Without speaking, a child provides a bodily response by moving the torch to increase the size of the shadow cast by the child playing the obstacle

With respect to the relationship between the size of the shadow and the distance from the light source to the obstacle, hypotheses were again formed with the torch switched off. The children had two choices: either to move the torch or to move the obstacle. The teacher began with the question “How can I make the shadow bigger or smaller?”. When the children responded, the teacher encouraged them to turn on the torch and test their answers. The children, depending on the type of hypothesis, thus moved the lit torch back and forth (one way, see Fig. 5) or moved their own bodies (other way) as obstacles, keeping the torch in one place. Depending on what each child achieved, the teacher asked supplementary questions, such as “Is there another way?” and “What will happen if I move the torch nearer to or farther from (child’s name)?”.

To explore the correspondence between the number of shadows and the number of light sources, the children were asked to come up with predictions in response to the question “How can we form two shadows?” (see Fig. 6). Some of the children proposed, and tested, a solution using a second torch. When they had responded in this way, the teacher asked “Which torch is making this shadow, and which torch is making that one?” and “How can we make this shadow (pointing to the shadow on the screen) bigger or smaller?”. The last question ensured that the children were not giving random answers, as they had to move the torch which they believed corresponded to the shadow in question.

It is worth noting that adding a second torch is not the only way to form a second shadow. In fact, many children proposed using a second obstacle.

Posttest

The evaluation of the activity was conducted in the same context as the exploration of preexisting knowledge (pretest). The same materials were used, in the same way, and the same questions formulated.

Data Analysis

The children’s responses, in relation to each aspect, before and after the teaching intervention, were characterized as inadequate, fair, or adequate (see Table 1, Ravanis 1996). In both pretest and posttest, the assessment of the children’s performance was carried out by the teacher–researcher and by an external researcher. The degree of agreement between them was over 91 %.

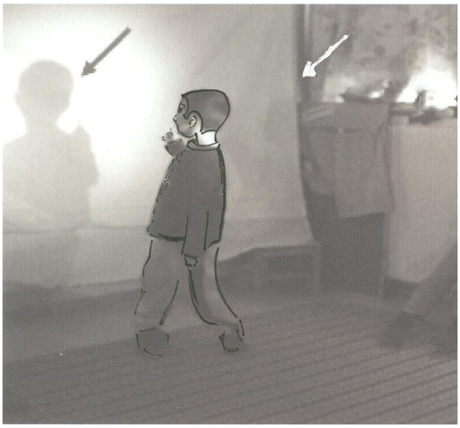

Fig. 6 A child uses two light sources to establish correspondence of the two shadows

Table 1 Framework for analysis of children's responses

	Adequate	Fair	Inadequate
Aspect 1	Identifies, with help or alone, the point where the shadow will be formed and can give correct reasons for the way it has been formed.	Identifies, with help or alone, the point where the shadow will be formed but gives the wrong or no reasons.	Cannot identify the position where the shadow will be formed and does not offer any explanation.
Aspect 2	Indicates 1 of the 2 ways, answering correctly in respect to how the shadow increases or decreases. One way is to move the torch; the other is to move the obstacle.	Indicates 1 of the 2 ways, answering correctly *only* in respect to how the shadow increases or decreases, not both. (or) Indicates 1 of the 2 ways, engaging the concept of *displacement*, using however the term *decrease* instead of *increase* and vice versa.	Finds neither of the 2 ways.
Aspect 3	Finds that a second torch is needed to form a second shadow *and* also indicates the correct point for formation of each shadow.	Replies that there will be a second shadow *only* when the second torch is suggested to him/her *and* at the same time indicates the correct point at which the shadow will be formed. (or) Refers to a second torch as a condition for the formation of the second shadow but does not indicate the correct point at which each shadow will be formed.	Replies that there will be a second shadow *only* when the second torch is suggested to him/her *and* at the same time indicates the incorrect point at which the shadow will be formed. (or) Does not reply that there will be a second shadow, even when the second torch is suggested. (or) Refers to a different number of shadows in relation to the number of torches.

It should be noted that in the verbal reference to the obstruction of light, the use of the term *obstruct* by the children does not necessarily mean a reference to the mental image of the light being reflected off the object. This is made clear, when the teacher asks the children if they think there is light behind the block. Example 1 is a characteristic case of agreement between what is said and what is meant by the term *obstruct.*

Example 1 T: So what did we say the block does to the light?
S: Obstructs it.
T: What do we have here? (pointing behind the object)
S: Shadow.
T: Will I have light here? (pointing behind the object)
S: No.
T: Why?
S: Because it is shadow.
T: What happened to the light?
S: It stopped here (pointing in front of the block).

In essence, the child in question speaks the word *obstruct* and at the same time is saying that there is no light behind the block. In these cases, the children's responses were classified as adequate.

In other cases (see Example 2), some of the children, although indicating the right point of shadow formation and explaining by the use of the verb *obstruct*, at the same time claim that there is light behind the object.

Example 2 T: Where does the light go?
S: (pointing forward)
T: And what does it encounter?
S: (points to the block)
T: What does the block do to the light?
S: It obstructs it.
T: And what do we have?
S: Shadow.
T: So here I will have light? (pointing behind the block)
S: Yes.

Answers like this are classed as fair because the *obstruct* is in conceptual conflict with the response of the child relating to whether there is light behind the block.

With respect to the second research question, the posttest video was analyzed. Only the posttest was analyzed because the researchers felt more emphasis was laid here on the body and because, as an individual interview, it could provide an objective record. The children had already been exposed in the teaching intervention (body-based activity), and so we assumed that they would make more use of their bodies in the posttest. Initially, each author conducted an individual analysis. The two authors then met repeatedly to view the video and to discuss their emerging assertions. These assertions related to how the children involved their bodies (i.e., use of gestures, inclination of body) in their explanations of shadow formation. Thus, both researchers ran through all the data (posttest) and tested their assertions until agreement was reached and the interpretation was established. All examples given in this paper originated in this procedure. The criteria used for the analysis were the use of deictic and iconic gestures by the children, as well as other actions like turning of the body. Any movement involving the child's body and intended to point in a direction is regarded as deictic. The classic such gesture is made using the index finger, but any other part or area of the body could be used. The iconic corporeal acts are somatic figures which indicate, in a more or less abstract way, a human action or a non-animate entity (Pantidos et al. 2008). It should be mentioned that although in the literature corporeal acts manipulating objects are called ergotic (e.g., Givry and Pantidos 2012; Roth 2003), in the current article, the second of the authors perceives as an iconic gestural sign any bodily form which represents something, whether it uses material objects or not (Pantidos et al. 2008).

Results

Impact of Activity on Learning

Using the criteria described in Table 1, the performance of the children was categorized by aspect before and after the procedure and is shown in Table 2.

The children's responses can also be classed according to the progress between pretest and posttest. Progress is deemed to have been made when the child moves towards improved results, regardless of the type of change (e.g., inadequate to fair). Regression has occurred when the posttest response is less successful than the pretest, regardless of the level of success (e.g., adequate to inadequate or adequate to fair). No change means that the child's performance was the same (e.g., fair to fair).

Table 2 Adequacy of children's responses

	Inadequate	Fair	Adequate
First aspect (mechanism of shadow formation)			
Pretest	11	3	2
Posttest	1	10	5
Second aspect (relationship between the size of the shadow and the distance between the light source and the obstacle)			
Pretest	13	3	0
Posttest	2	6	8
Third aspect (correspondence between the number of shadows and the number of light sources)			
Pretest	9	5	2
Posttest	2	5	9

It transpires that the specific body-based activity has positive learning results for all three aspects of the phenomenon. Specifically, we observe from the children's responses that there are significant changes in all three aspects before and after the activity. With respect to the first aspect, a total of 11 children moved to fuller answers in comparison with those they had given in the pretest; with respect to the second aspect, 13 children gave fuller answers; and with respect to the third aspect, 12 children showed a positive change (see Table 3).

Explanations and the Human Body

A total of 11 of the 16 children used their bodies to explain the shadow formation mechanism in the posttest interview. In most cases, the children were encouraged to use their bodies after they had had difficulty in coming up with a verbal response. Either by verbal reference to the activity or turning the unlit torch on the child, the teacher triggers off the use of the body to generate a response (see Example 3, Fig. 7).

Example 3 T: So where will the shadow be?
S: (still pointing ahead)
S: (again pointing in the wrong direction)
T: If the block was a person, where would the shadow be?
S: Here (pointing in front).
T: If I shine the light on you, where will your shadow be? (pointing the unlit torch)
S: Behind (pointing to the wall, correctly).

A first conclusion from the analysis of the video was that the modalities may present inconsistencies. In Example 4, if the verbal discourse is interpreted together with the gesture of

Table 3 Children's responses in terms of change between the two tests

	Regression	No change	Progress
Aspect 1	2	3	11
Aspect 2	0	3	13
Aspect 3	0	4	12

Fig. 7 The teacher *illuminates* the child with the unlit torch

pointing (i.e., the child shows the correct point for formation of the shadow), we may be led to the conclusion that the child has understood the way in which the shadow is formed.

Example 4 S: The shadow will be here (indicates the correct point, illustrates the rectilinear movement of light).
T: Why do you think that?
S: Because the shadow will come out here (indicates the correct point, illustrates the rectilinear movement of light). Because it will come out here (indicates the correct point, illustrates the rectilinear movement of light). Because the torch will be here and the shadow will come out here (indicates the correct point).

However, at the same time, the child illustrates the rectilinear movement of light behind the block, in the space where the shadow is. He is thus implying that there is light behind the obstacle, while at the same time saying that there is shadow there. In other words, there are two frameworks leading to different interpretations.

In other instances, the bodily expression complements the verbal utterance. In Example 5, meaning is conveyed through speech and a pointing gesture, the two complementing one another in content.

Example 5 (the torch is fixed to a tripod and pointing to the sheet)
T: With the torch where it is now, how can I make a shadow?
S: Turn on the torch and…(points to the middle) and there will be a shadow.

It is evident that the spoken word defines the entities *light source* (i.e., torch) and *screen* (i.e., there) (i.e., the semi-level of shadow formation), while the gesture indicates where the obstacle should be to form a shadow.

With respect to the type of corporeal expressions used by the children, two types which convey aspects of children's thinking can be seen: (a) deictic and (b) iconic. There are two forms of deictic acts: (a1) children point to the space where they think the shadow should be

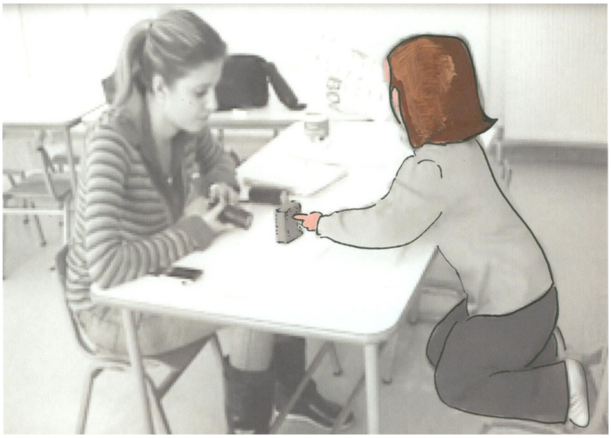

Fig. 8 The child points to the block

(see Fig. 8) and (a2) they turn their bodies looking for the sheet behind them, while pointing in the same direction with a finger (see Fig. 9).

In Fig. 9, the turning of the child's body is a sort of connecting link between the context of the question and the context of the teaching intervention. In other words, it seems that the child is thinking in bodily terms—terms used during the teaching intervention—and using them to explain the formation of the shadow in a different context, that with the block.

Furthermore, some of the children also use iconic gestures either to recall some elements of the teaching that came before or explicitly to relate the two contexts. In general, two narrative spaces are presented: the *here* (the space with the block) and the *there* (the body-based teaching activity), and these spaces intersect, in Example 6, at one point only—the child's gesture.

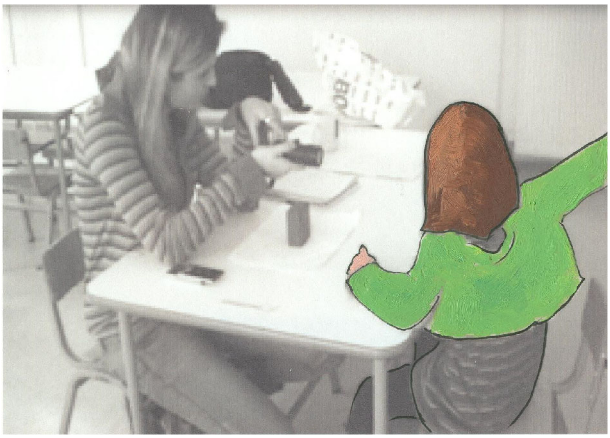

Fig. 9 The teacher *illuminates* the child and she points to the back

Example 6 T: If I turn on the torch, what will I have?
S: Shadow.
T: Where will it be?
S: Here (points in front of the torch).
T: Will it be there?
S: Yes.
T: Do you remember downstairs, when we made your shadow, and those of the other children? Where did it happen?
S: Behind, on the big piece of paper.
T: Where had we put it?
S: Where the little table was (shows the sheet with her hands, see Fig. 10)
T: And the shadow from the block, where will it be?
S: Behind.
T: Where is the behind?
S: (indicates the right place)

More specifically, when the teacher asks the child to remember what happened during the teaching (line 7), the child answers *behind on the big piece of paper* (line 9) and goes on to indicate the sheet with her hands (line 11). In Fig. 10, we observe that the gesture is not *directed* to the table; the inclination of the child's body conveys *distancing* and the gesture itself is almost parenthetical—lasting only a moment. This means that the specific corporeal representation of the *sheet* is used by the child merely to recall what happened in the activity. It refers for a moment to the *there* in order to specify where *behind* is—thus representing an internal procedure for understanding the existing material context (block) and not an attempt to unite the two contexts. Actually, she uses the gesture to understand where *behind* was during the teaching, thus solving the problem there, and then she locates where *behind* is in the current context and she solves the problem here.

By contrast, in Example 7, the *here* and *there* are united. The paper coming from *there* (teaching intervention) is located in front of the block of *here* (interview) (see Example 7, line 8, Fig. 11).

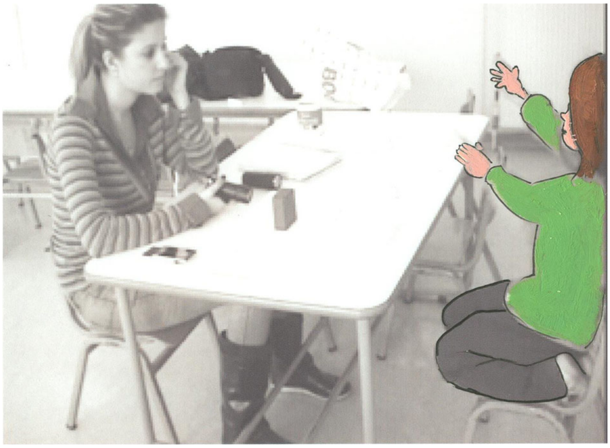

Fig. 10 The child represents the sheet using her hands

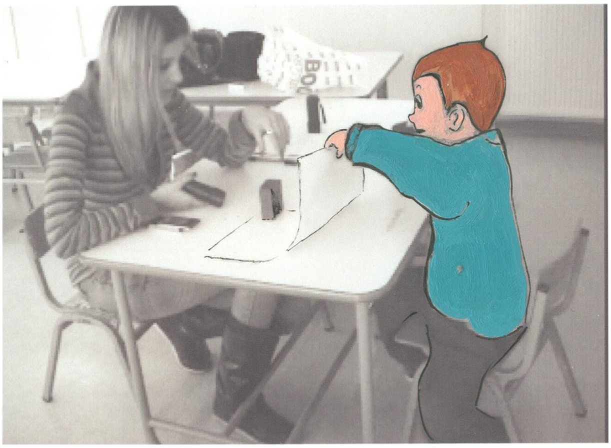

Fig. 11 The child uses a piece of paper as a screen

Example 7 T: So, here, where will the shadow be?
S: (points in front of block)
T*:* Shouldn't it be behind it?
S: Yes.
T: So where?
S: Like this (takes the piece of paper and puts it behind the block, like the sheet).
T: So, where will the shadow be, the way you have it?
S: Here (points to the correct point on the paper)

In this way, the child in question constructs a hybrid context consisting of the units light source, block, and paper. The first two relate to the *here* and the third to the *there*. The sheet of paper (screen) is a material used in the teaching intervention, not in the interview. Despite this, the child uses the sheet of paper to explain what is asked of him in the interview. In other words, he appears to use his imagination to think of what happened in the lesson and to attempt to adapt it to the context of the interview. But this does not happen only for a moment, as in the preceding example. The sheet of paper is introduced into the arrangement with the block and remains there. It should be noted that the sheet of paper used was not given to the child but simply left lying on the table. In other words, it appears that the kinesic construction *raising of the piece of paper* is grounded in the existing, visible context. This is demonstrated by the fact that the child raises the piece of paper not only to locate but also to indicate the point where the shadow will be formed (see line 8). This in itself indicates the link between his thoughts and his corporeal expression. In other words, the reasoning which appears to be generated in the teaching intervention and through a mediator (i.e., a piece of paper) is transferred to the interview, creating a hybrid explanatory framework.

Discussion

The activity organized was effective with regard to the three aspects of the phenomenon shadow formation. The sample of children used was too small to allow generalization, but the methodology adopted and the results recorded make clear the feasibility of the specific activity. More generally, the specific activity allows the children to frame hypotheses and test them, while being part of the phenomenon. In this way, lived experience is combined with the experimental process, as the children try to explain their own acts—and this leads to effective learning (Grammatikopoulos et al. 2012; Hadzigeorgiou et al. 2009; Ogborn et al. 1996). In contrast to the usual shadow formation activities which include the human body, in this activity, the use of a screen behind the *obstacle* separates the three entities (light, obstacle, shadow) (see Fig. 4). For example, in the classic activities where children are exposed to the sun, in the school yard, the shadow is *attached* to the children. Compared to the arrangement of material objects, in the body-based activity the student can play two roles: the *role of the material object* on which the light falls and the *role of the light*. More specifically, with respect to the latter, the learner can, by moving place, follow the trajectory of the light. Thus, compared with the material objects, the rectilinear movement of light is illustrated (made perceptible) more clearly because the learner is required to change place in a rectilinear manner. A child can also verify the presence or not of the light in areas A, B, and C (see Fig. 4). By alternating their position between areas B and C, a child can check whether or not they see the light from the source. This provides data which can stimulate thought and allow the framing of productive reasoning.

The children's bodies assume the *role of representation* (i.e., obstacle, movement of light), while also acting as *agents providing explanations* (i.e., children's gesticulations). The children construct their reasoning about shadow formation using various corporeal acts such as deictic and iconic gestures, movements in space, and turning and inclining their bodies. In some cases, there will be inconsistencies between the modalities (see Example 4), and in others, the corporeal movements will complement the verbal utterance (see Example 5). In all cases, the meaning is not generated only by speech or bodily expression but by the entirety of each semiotic event. Actually, other semiotic systems (e.g., human body, drawings) convey aspects of thought which are not, or cannot be, expressed by the speech (e.g., De Ruiter 2007; Mathewson 1999; Rennie and Jarvis 1995). All these reinforce the view that knowledge is shaped through the semiotic resources which, as mediators, are enlisted to assist in its construction.

The study highlighted the knowledge transferability between two different situations. More specifically, some of the children were initially able to recognize the equivalence between the two contexts (i.e., block—human body) and then to transfer elements of one (teaching intervention) to the other (posttest). It appeared from the analysis of the video that the children used their bodies or the objects (i.e., piece of paper) as mediators to transfer themselves from the classroom context to that of the interview. In other words, during the teaching intervention, the children learned or discovered, mainly through their bodies, the aspects of shadow formation. It then appears that they tried, without being asked, to use their body as a tool to think and explain the phenomenon in the context of the interview. According to a number of researchers, this contains elements of conceptual change because the children achieve a kind of knowledge restructuring, transferring it or applying it to different settings (e.g., Eraut 2009; Georghiades 2000; Huffaker and Calvert 2003). Along that trajectory, Givry and Roth (2006) refer to conceptions and, by extension, to conceptual change as

> (a) evolution in the use of modalities (e.g., using words to describe an object, instead of designating it by deictic gesture); (b) evolution in the same modality (e.g., using more gestures to describe the same objects); and (c) evolution of the link between different modalities (e.g., the time between talk and gesture decreasing) (p. 1105).

Accordingly, the results of the current study have demonstrated that body-based teaching led to a type of evolution on the part of the children in the use and interdependence of modalities. In fact, most children who in the pretest used only deictic gestures to indicate the point where the shadow would be formed expressed themselves in the posttest also through other modalities such as iconic gestures, in order to represent elements of the environment (see Examples 6 and 7). With respect to the same modality, an evolution in deictic gestures was observed. In Fig. 9 for example, the child developed, with the help of her body, a novel deictic gesture creating a link between the teaching context and the context of the question put to her. Actually, the same child during the pretest used only typical deictic gestures; she was just pointing to the block with the pointer without any other movement of her body. Finally, the context of the teaching itself upgrades the children's use of their bodies. In other words, in the formal environment with the block (see pretest), oral discourse is dominant, with descriptive discourse linked only to the pointing gesture with the finger. In this case, the pointing accompanies the spoken adverb *here* (see Fig. 2). By contrast, in the teaching process, the children expressed meanings by developing a fruitful relationship between spoken word and human body. Once the speech described each situation, the children's body in some cases added some new element (i.e., rectilinear direction of the light, see Fig. 3). In other cases, children without speaking gave bodily responses substituting (see Fig. 5) or complementing speech (see Example 5). All of the above may indicate conceptual change in the sense of an evolution in the use of modalities. However, a deeper analysis of our data could offer clear evidence of this. The two researchers intend to carry out a comparative analysis of the two tests with respect to the use of corporeal expressions by children.

Research, both in cognitive science and in the field of science education, has demonstrated that the sign vehicles used to represent scientific entities assign meaning to them in a unique way (Jaipal 2010; Pozzer-Ardenghi and Roth 2010; Rahm 2004). Thus, images, material objects and space in general, the human body, and oral (and written) discourse assist in all instances of learning in shaping the way that students form their ideas (Kress et al. 2001). Effective learning outcomes of activities based on a specific semiotic framework (e.g., the human body) are not better than others (e.g., material objects). However, alternating between different semiotic settings helps to shape knowledge itself, creating the conditions for more effective and meaningful learning (Ogborn et al. 1996).

Acknowledgments We would like to thank the artist Pantelis Constantinou for the drawings.

References

Barab, S., & Dede, C. (2007). Games and immersive participatory simulations for science education: an emerging type of curricula. *Journal of Science Education and Technology, 16*(1), 1–3.

Barrow, L. (2007). Bringing light onto shadows. *Science and Children, 44*(9), 43–45.

Chang, N. (2005). Children's drawings: science inquiry and beyond. *Contemporary Issues in Early Childhood, 6*(1), 1,104–106.

Chen, S.-M. (2009). Shadows: young Taiwanese children's views and understanding. *International Journal of Science Education, 31*(1), 59–79.

Christidou, V., Kazela, K., Kakana, D., & Valakosta, M. (2009). Teaching magnetic attraction to preschool children: a comparison of different approaches. *International Journal of Learning, 16*(2), 115–128.

de Ruiter, J. P. (2007). Postcards from the mind: the relationship between speech, imagistic gesture, and thought. *Gesture, 7*(1), 21–38.

Eraut, M. (2009). Transfer of knowledge between education and workplace settings. *Knowledge, Values and Educational Policy: A Critical Perspective*, 65.

Fleer, M. (1996). Early learning about light: mapping preschool children's thinking about light before, during and after involvement in a two week teaching program. *International Journal of Science Education, 18*(7), 819–836.

Georghiades, P. (2000). Beyond conceptual change learning in science education: focusing on transfer, durability and metacognition. *Educational Research, 42*(2), 119–139.

Georgoutsou, M., Panagiotaki, A., & Koliopoulos, D. (2010). Application of an educational programme on the concept of the shadow through the use of simulations on the website of the museum Cité des Sciences et

de l' Industrie. In A. Tzimogiannis (ed.), Proceedings of the 7th panhellenic conference on ICT in education], vol. II (pp. 727–735). University of the Peloponnese, Corinth, 23–26 September 2010 (in Greek).
Givry, D., & Pantidos, P. (2012). Toward a multimodal approach of science teaching. *Skhole, 17*, 123–129.
Givry, D., & Roth, W.-M. (2006). Toward a new conception of conceptions: interplay of talk, gestures, and structures in the setting. *Journal of Research in Science Teaching, 43*, 1086–1109.
Grammatikopoulos, V., Gregoriadis, A., & Zachopoulou, E. (2012). Acknowledging the role of motor domain in creativity in early childhood education. *Contemporary perspectives on research in creativity in early childhood education*, 159–176.
Hadzigeorgiou, Y. (2003). *Sound and light–water and air: a beginning in the natural sciences*. Athens: Grigoris Press (in Greek).
Hadzigeorgiou, Y., Anastasiou, L., Konsolas, M., & Prevezanou, B. (2009). A study of the effect of preschool children's participation in sensorimotor activities on their understanding of the mechanical equilibrium of a balance beam. *Research in Science Education, 39*(1), 39–55.
Huffaker, D. A., & Calvert, S. L. (2003). The new science of learning: active learning, metacognition, and transfer of knowledge in e-learning applications. *Journal of Educational Computing Research, 29*(3), 325–334.
Hwang, S., & Roth, W. M. (2011). The (embodied) performance of physics concepts in lectures. *Research in Science Education, 41*(4), 461–477.
Jaipal, K. (2010). Meaning making through multiple modalities in a biology classroom: a multimodal semiotics discourse analysis. *Science Education, 94*(1), 48–72.
Kamii, C., & Kato, Y. (Eds.). (2007). *Piaget's constructivism and early childhood education: I. physical knowledge activities*. Okayama City: Daigaku Kyoiku.
Kress, G. (1997). *Before writing: rethinking the paths to literacy.* London and New York: Routledge.
Kress, G., Jewitt, C., Ogborn, J., & Tsatsarelis, C. (2001). *Multimodal teaching and learning—the rhetorics of the science classroom*. London and New York: Continuum.
Lemke, J. L. (2001). Articulating communities: sociocultural perspectives on science education. *Journal of Research in Science Teaching, 38*(3), 296–316.
Mathewson, J. H. (1999). Visual-spatial thinking: an aspect of science overlooked by educators. *Science Education, 83*(1), 33–54.
Murmann, L., & Schwedes, H. (1999). Learning processes concerning 'light and shadow' during science education in elementary school. *Research in Science Education-Past, Present, and Future, 1*, 110–112.
Ogborn, J., Kress, G., Martins, I., & McGillicuddy, K. (1996). *Explaining science in the classroom*. Buckingham/ Philadelphia: Open University Press.
Osborne, J. F., Black, P., Meadows, J., & Smith, M. (1993). Young children's (7–11) ideas about light and their development. *International Journal of Science Education, 15*(1), 83–93.
Pantidos, P. & Givry, D. (2014). Ambiguities in representing the concept of energy: a semiotic approach. *Review of Science, Mathematics and ICT Education*, 8.
Pantidos, P., Valakas, K., Ravanis, K., & Vitoratos, E. (2008). Towards applied semiotics: an analysis of iconic gestural signs regarding physics teaching in the light of theatre semiotics. *Semiotica*, *172*(1/4), 201–231.
Pantidos, P., Valakas, K., Vitoratos, E., & Ravanis, K. (2010). The materiality of narrative spaces: a theatre semiotics perspective into the teaching of physics. *Semiotica*, *182*(1/4), 305–325.
Papandreou, M. (2012). My shadow and me: children's drawing in the context of teaching shadow formation in the kindergarten. In K. Plakitsi (Ed.), *Sociocognitive and sociocultural approaches to science in early childhood* (pp. 362–375). Athens: Patakis Press (in Greek).
Parker, J. (2006). Exploring the impact of varying degrees of cognitive conflict in the generation of both subject and pedagogical knowledge as primary trainee teachers learn about shadow formation. *International Journal of Science Education, 28*(13), 1545–1577.
Ping, R. M., & Goldin-Meadow, S. (2008). Hands in the air: using ungrounded iconic gestures to teach children conservation of quantity. *Developmental Psychology, 44*(5), 1277.
Pozzer-Ardenghi, L., & Roth, W. M. (2007). On performing concepts during science lectures. *Science Education, 91*(1), 96–114.
Pozzer-Ardenghi, L., & Roth, W.-M. (2010). *Staging & performing scientific concepts: lecturing is thinking with hands, eyes, body, & signs*. Rotterdam: Sense Publishers.
Rahm, J. (2004). Multiple modes of meaning-making in a science center. *Science Education, 88*(2), 223–247.
Ravanis, K. (1994). The discovery of elementary magnetic properties in pre-school age. A qualitative and quantitative research within a Piagetian framework. *European Early Childhood Education Research Journal, 2*(2), 79–91.
Ravanis, K. (1996). Stratégies d'interventions didactiques pour l'initiation des enfants de l'école maternelle en sciences physiques. *Spirale-Revue de Recherches en Éducation, 17*, 161–176.
Ravanis, K., Zacharos, K., & Vellopoulou, A. (2010). The formation of shadows: the case of the position of a light source in relevance to the shadow. *Acta Didactica Napocensia, 3*(3), 1–6.

Ravanis, K., Christidou, V., & Hatzinikita, V. (2013). Enhancing conceptual change in preschool children's representations of light: a sociocognitive approach. *Research in Science Education, 43*(6), 2257–2276.
Rennie, L. J., & Jarvis, T. (1995). Children's choice of drawings to communicate their ideas about technology. *Research in Science Education, 25*(3), 239–252.
Rieber, L. P. (2005). Multimedia learning in games, simulations, and microworlds. *The Cambridge handbook of multimedia learning*, 549–567.
Roth, W.-M. (1998). Situated cognition and assessment of competence in science. *Evaluation and Programming Planning, 21*, 155–169.
Roth, W. M. (2001). Gestures: their role in teaching and learning. *Review of Educational Research, 71*(3), 365–392.
Roth, W. M. (2003). From epistemic (ergotic) actions to scientific discourse: the bridging function of gestures. *Pragmatics and Cognition, 11*(1), 141–170.
Roth, W.-M., & Lawless, D. (2002). Signs, deixis, and the emergence of scientific explanation. *Semiotica, 138*(1/4), 95–130.
Russell, T., Harlen, W., & Watt, D. (1989). Children's ideas about evaporation. *International Journal of Science Education, 11*, 566–576.
Segal, G., & Cosgrove, M. (1993). The sun is sleeping now: early learning about light and shadows. *Research in Science Education, 23*, 276–285.
Sharp, J. (1995). Children's astronomy: implications for curriculum developments at key stage 1 and the future of infant science in England and Wales. *International Journal of Early Years Education, 3*(3), 17–49.
Shepardson, D. P., Wee, B., Priddy, M., & Harbor, J. (2007). Students' mental models of the environment. *Journal of Research in Science Teaching, 44*(2), 327–348.
Trend, R., Everett, L., & Dove, J. (2000). Interpreting primary children's representations of mountains and mountainous landscapes and environments. *Research in Science and Technological Education, 18*(1), 85–112.
Trundle, K. & Hilson, M. (2012). Shadows play. *Science and Children,* 49(5).
Tsatsaroni, A., Ravanis, K., & Falaga, A. (2003). Studying the recontextualisation of science in preschool classrooms: drawing on Bernstein's insights into teaching and learning practices. *International Journal of Science and Mathematics Education, 1*(4), 385–417.
Tytler, R., & Peterson, S. (2001). Deconstructing learning in science: young children's responses to a classroom sequence on evaporation. *Research in Science Education, 30*(4), 339–355.
Tytler, R., Prain, V., & Peterson, S. (2007). Representational issues in students learning about evaporation. *Research in Science Education, 37*(3), 313–331.
Venville, G., Adey, P., Larkin, S., & Robertson, A. (2003). Fostering thinking through science in the early years of schooling. *International Journal of Science Education, 25*(11), 1313–1331.
Vincent, D., & Cassel, D. (2011). Shadows that enlighten. *Science and Children, 48*(5), 50–54.
Vosniadou, S., Skopeliti, I., & Ikospentaki, K. (2004). Modes of knowing and ways of reasoning in elementary astronomy. *Cognitive Development, 19*(2), 203–222.
Weil-Barais, A. (2001). Constructivist approaches and the teaching of science. *Prospects, 31*(2), 187–196.
Young, T., & Guy, M. (2008). Moon's phases and the self shadow. *Science and Children, 46*(1), 30–35.