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Abstract

This paper presents an epistemological analysis of typical didactical activities noted in early-years science lessons, which was carried out in an attempt to diagnose the extent to which the teaching practices adopted by early-years educators are successful in supporting young children's understanding in science. The analysis of didactical activities used a framework that allowed us to discover whether they promoted desired connections between theoretical ideas, evidence and the material world. Theoretical ideas, evidence and the material world are entities internal to scientific inquiry and, in educational contexts, connections between them are considered essential in assisting the development of young children's scientific thinking. The results indicated that in the early-years science classroom scientific activity was mainly confined to the representational level. Intervention practices into the material world were limited, and were based on collected evidence. No interventions based on ideas were identified in the science lessons. Missing links between evidence and theory and between ideas and the material world suggest that the didactical activities analysed did not promote scientific understanding.

Introduction

Recent research suggests that during their early years children begin to construct science concepts of increasing complexity (Lind, 1999). From the educational perspective, there has been a growing realization over the past two decades that appropriate scientific work can and should begin in infant classes (e.g. Chaille & Britain, 1991; Duckworth, 1996; Eshach & Fried, 2005; **Fleer & Robbins, 2003a**; Frost, 1997; Harlen & Jelly, 1995; Lind, 1999). Brain research and modern neuroscience has shown that learning in specific domains occurs most efficiently within a critical period, which begins early in life. The pre-primary period (ages 4 to 6) falls within this critical span, as learning is apprehended as a modification of neural structure and the formation of new synapses, related to the weight of the brain, which reaches 90% of its total weight by the age of 5. This critical period, called 'window of opportunity', begins to close at around the age of 9 (Bransford *et al.*, 2000; Gramann, 2004; Nash, 1997; Shore, 1997). However, for essential science skills, the window seems to close quite early (Begley, 1996; Eshach & Fried, 2005). According to Eshach and Fried (2005) early-years science is an effective means for developing scientific thinking and is expected to contribute to the formation of a background that will lead to better understanding of difficult scientific concepts and scientific phenomena studied later in a more formal way.

Several researchers and research projects (e.g. the American Association for the Advancement of Science, 2003; Bybee & Champagne, 2000; Millar & Osborne, 1998; the Programme for International Student Assessment, 2003) suggest that science education should aim at delivering useful scientific knowledge to students by developing their understanding of representations of the material world. Students should understand how scientists represent the world in terms of concepts and models and how to use these models in coping with everyday needs. But science, apart from representations of the world, also involves ways of intervening in the world by putting things to work in the laboratory according to theories and models. This sort of laboratory-centred interventionist practice supports theoretical production and distinguishes scientific literacy from other types of literacy (e.g. philosophical or literary). It can be argued that understanding science implies also some understanding of the practices involved in scientific inquiry, aspects of which are essential for the teaching of scientific subjects. Hacking (1992, 1995), by mapping the actual laboratory science activities practiced by scientists and subjecting them to a systematic bottom-up analysis, suggested that theoretical ideas, evidence and material world are entities internal to scientific inquiry and that making connections between them is characteristic of scientific practice. Based on Hacking's framework, Psillos, Tselfes and Kariotoglou (2004) suggested that, in educational contexts, establishing connections between theoretical ideas, evidence and material world is essential in assisting children's understanding in science and their scientific thinking. Research on matters related to young children's ability to connect theoretical ideas with evidence is presented later in this section.

Several ideas have been expressed as to what science education for very young children should comprise and how it should be approached. One of the most prominent reforms in science education has been the introduction of inquiry. The teaching of science through inquiry methods aims at enabling young children to obtain experiences that are authentic to scientific experience (Peters, 2006), and is thought to make their learning more meaningful and to improve their scientific understanding (Hogan 2000, Hogan & Maglienti, 2001). Inquiry is considered by many (e.g. de Boo, 2000; Lind, 1999; Novac, 1977) as a major area of interest in young children's education in science. Research findings overwhelmingly support the teaching of science through inquiry (see Lind, 1999); and National Science Education Standards (NSES, American National Research Council, 1996) advocates, in line with the guidelines from the Association for the Education of Young Children (Bredekamp & Copple, 1997), that children at all grade levels and in every domain of science be given the opportunity to use scientific inquiry and to develop the ability to think and act in ways associated with scientific inquiry, including skills such as conducting investigations, using appropriate tools and techniques to gather data, thinking critically and logically about relationships between evidence and explanations, and communicating scientific arguments.

Coordination of evidence and theory involves inquiry skills, which is why inquiry is considered inherent to science. It involves scientific thinking that relies on both concepts and procedures, the latter being those we "tend to have in mind when we speak about scientific thinking as analytical and critical thinking or, especially, the thinking which connects evidence and theory [emphasis added]" (Eshach & Fried 2005, p.327). Yet learning with understanding involves the development of ideas through the learner's own thinking and action, and in science this means developing the skills to deal with new situations (Harlen, 1996). Lind argues that pre-primary-level science is an active enterprise "…seen as a way of thinking and trying to understand…". Educators should, therefore, aim at introducing young children to the investigative nature of science, fostering their understanding and use of the modes of reasoning of scientific inquiry and relating new science knowledge both to previously learned knowledge and to new experiences of phenomena (Lind, 1999; NSES 1996).

Given the above, there logically arise the questions of whether pre-primary children can understand and think scientifically and how in their early exposure to science they can be assisted to develop understanding through scientific thinking.

Some researchers (e.g. Klahr, Fay & Dunbar, 1993; Kuhn, Black, Keselman, & Kaplan, 2000) claim that inquiry-based learning is difficult for very young children. They support the view that "…the skills required to engage effectively in typical forms of inquiry learning cannot be assumed to be in place by early adolescence" (Kuhn *et al.* 2000, 515). David (1990), however, in her extensive review of the early education literature, suggests that "research evidence seems to indicate that, in some preschool settings, children under five are indeed being undereducated because insufficient cognitive demands are being made of them and, generally speaking, it is the adult intervention which presents the challenge..." (David 1990, p.87). The literature (e.g. Metz 1995, 1998) also shows that young children can think abstractly about scientific concepts that even adults may find hard to grasp and, if they have the requisite domain-specific knowledge, can reason on the basis of 'deep structural principles' (Brown, 1990; Gelman & Markman 1986 as cited in Metz, 1998). Other research (e.g. Sodian, Zaitchik & Carey, 1991) has shown that children's understanding of the hypothesis – evidence relation has been underestimated. Gelman and Markman (1986) and Ruffman, Perner, Olson, and Doherty (1993), for example, have shown that even children of 4 and 5 years of age could, when they had access to deeper information, select the information needed to form inductions depending on the question asked, and distinguish between conclusive and inconclusive tests of hypothesis.

Exercising scientific thinking in contexts where scientific concepts are investigated through experimentation helps children learn to be critical and analytical (Eshach & Fried 2005). With this in view, investigation of concepts should include such skills as identifying relevant variables and gradually progressing to manipulating them, altering one or more of them in ways that influence the phenomena under study (see Funk, Fiel, Okey, Jaus & Sprague, 1985; Harlen, 1996). This can focus children's attention on the meaning of variables, allowing them to reflect on problems that can arise from these alterations, form hypotheses and suggest ways of testing them (Eshach & Fried, 2005; Havu-Nuutinen, 2005). Although pre-primary children may not immediately grasp the precise scientific ideas, these experiences develop their background knowledge and assist them in forming 'precursory' concepts that will help them grasp more complex scientific concepts and ideas later on (see e.g. Havu-Nuutinen, 2005). Thus, "if children have the seeds of skills that allow them to connect theory and evidence it is reasonable that exposing them to situations where they can exercise these skills, they will further develop them" (Eshach & Fried 2005, p.333). These situations must be planned in advance. Educators, whose role is to lead children in their conceptual thinking **(Fleer, 1993)**, should provide them with appropriate materials and activities, progressively increasing in conceptual depth and complexity, in order to develop their scientific reasoning (Bredekamp & Cople 1997; Eshach & Fried, 2005; Lind, 1999). This brings to the foreground the issue of educators' competency in science. Educators themselves need to have understanding, "for without it they are not in a good position to guide children to materials and activities which develop their understanding" (Harlen 1996, p.222). Research studies (e.g. Kallery & Psillos, 2001) have indicated, however, that early-years educators' background knowledge of and understanding in science is rather weak. Research regarding early-years educators' active practices in the science classroom appears to be limited. A study (Kallery & Psillos, 2002) that investigated early-years educators' science curriculum implementation activities identified divergences between the proposed (see contextual information) and the implemented curriculum.

The present work was undertaken against this background. The investigation was carried out in Greece, where a pre-primary science curriculum is in effect. In the study reported in the rest of this paper, and given that children's thinking is influenced by what teachers say and do **(Fleer & Robbins, 2003b)**, an effort is made to diagnose to what extent early-years educators' teaching practices are successful in supporting children's learning in science, viewed in the context described above. This is attempted through an analysis of typical didactical activities noted in pre-primary science lessons, using a framework that allows us to discover whether these didactical activities promote the desired connections between theory, evidence and the material world. The theoretical foundation of this framework draws on the works of Hacking (1992, 1995). As was discussed earlier, theoretical ideas, evidence and the material world are, according to Hacking (1992), entities internal to scientific inquiry and, in educational contexts, connections between them are essential in assisting children's understanding in science and their scientific thinking (Psillos *et al.*, 2004). The present work is part of a larger study aimed at identifying and analysing early-years educators' practices in science, in an attempt to optimise factors that can assist children's learning through understanding and through development of their scientific thinking, which, as has been extensively discussed, are crucial, given that the foundations of science education are laid in the early years.

Contextual information

In Greece, the children in pre-primary education are between 4 and 6 years old. Classes are multi-age. Pre-primary classrooms are organized with separate ‘corners’, including a ‘science corner’, which the teachers are expected to design and equip.

Activities are of two kinds: ‘free’ activities for the children, which are activities chosen and carried out by the children themselves without the teacher’s direct involvement, and ‘teacher-organized’ activities, which are activities planned and organized by the teachers according to the objectives that have to be met. This includes choosing activity topics, selecting instruction materials, deciding the didactical approach, and guiding the children at their work. The present study concerns ‘teacher-organized’ activities in the context of science lessons.

The content of science activities is drawn from the domains of physics and biology. Physics topics are related to concepts such as weight, colour, sound, light, motion, temperature and magnetism, to properties of matter such as floating / sinking, melting, dissolving in water, etc., and to phenomena such as water evaporation, rain, snowfall (and generally changes in the state of matter), rainbows and gravity, plus topics relating to the earth, moon, sun and the phenomenon of day and night. In biology children are introduced to living things (plants and animals).

The curriculum stresses the importance of children’s mental and physical involvement in science activities. Its guidelines state that children should be actively involved in experimenting with materials and carrying out investigations, solving problems, observing and collecting data, predicting and testing ideas, classifying, and drawing conclusions. Highlighting and developing these manners of proceeding is one of the fundamental organizing principles of the curriculum.

Research design

The present work, which is aimed at diagnosing the extent to which the teaching practices employed in the pre-primary classroom support children's learning in science viewed in the context described in the introduction, attempts an analysis of typical didactical activities observed in such classrooms. The analysis will use a framework that allows us to discover whether these didactical activities promote the desired connections between theory, evidence and the material world. As was discussed earlier, connections between these entities are essential in assisting young children's understanding and scientific thinking. The process through which typical didactical activities were identified in the pre-primary science classroom is presented below, together with the framework of analysis. It should be noted that in this paper we have used the term 'science lessons' instead of the term 'science activities' more commonly employed in the context of pre-primary education, in order to avoid confusion with the word 'activities', which we reserve for 'didactical activities'.

Typical didactical activities in pre-primary science lessons

Seeking to identify discrepancies between classroom practices and the guidelines of the proposed Greek pre-primary science curriculum, Kallery and Psillos (2002) performed a three-level qualitative analysis (Strauss & Corbin 1990) of 44 classroom protocols. The protocols were produced by participant observations of science lessons carried out in pre-primary classrooms in central Northern Greece. The observations were performed during the course of one school year by the first author. The observer/researcher's role was that of a spectator (Gay, 1992). The observations were recorded on site by taking detailed field notes, since the teachers did not permit the use of recording devices (Merriam, 1988; Silverman, 1993). The observed lessons, each of 45 minutes' duration, dealt with topics from physics, biology and outer space and were carried out by 11 teachers (4 lessons each), who were implementing the proposed science curriculum. The teachers were recruited from a randomly chosen number of schools; those in our sample were those who agreed to participate in this study. The above-mentioned qualitative analysis of the classroom protocols produced findings concerning lesson organization, classroom management (discipline rules and teacher feedback), academic interactions, skills used, types of teachers' questions, etc. The analysis also revealed different didactical activities employed by early-years teachers in science lessons. In the lessons on physics topics (28 in total), early-years teachers mainly employed 10 types of didactical activities. These activities are shown in Table 1, and are those that are analysed in the present work. The reason for choosing to analyse only didactical activities identified in lessons based on physics topics is that pre-primary teachers face more difficulties and have expressed more concerns about their teaching performance with these topics than with topics relating to biology (Kallery, 2004). In general, research has shown that the teachers of the lower grades of education face more difficulties in teaching physics than other science subjects (e.g. Holroyd & Harlen, 1996).

[Insert Table 1 about here]

The framework of analysis

The framework presented below is based on the epistemology of scientific practice and is used for analysing it. It involves three major categories of entities that, as noted earlier, are – according to Hacking (1992) – internal to scientific inquiry, namely the categories of Cosmos (C), Evidence (E) and Ideas (I).

The category 'Cosmos' includes materials and artefacts, such as devices, measurement instruments, samples and instrument readings, which constitute the raw data. The category 'Evidence' includes representations of entities that have been derived either from the senses or from a systematic processing of raw data, e.g. representing them in specific ways, classifying them according to chosen criteria, comparing them with other data, etc. The category 'Ideas' includes specific theoretical entities, like systematic theory, models or concepts, methodological entities that gain certain meaning in a specific theoretical framework, like questions and hypotheses, and implicit views, i.e. views of reality, causality, the relation between the subject of the knowledge and the external world, which can influence the construction of scientific knowledge. Scientific ideas and evidence represent phenomena that are part of the real world and explain or justify one another. During the course of scientific inquiry, activities involve making connections between the entities of Cosmos, Evidence and Ideas in two-way interactions (C↔ I, C ↔ E, E ↔I). Approaching scientific inquiry practices in terms of patterns of connections between the entities of Cosmos, Evidence and Ideas (CEI) is considered to apply to educational settings as well as to professional ones. The use of the CEI framework in educational settings has the advantage of allowing a fruitful analysis of teaching-learning activities in terms of scientific practice; it does not, however, imply that the variety of possible patterns is precisely similar for students and scientists (see Psillos *et al.,* 2004).

Some of the possible connections between the three entities of the CEI framework that may occur in teaching-learning activities when it is applied in educational settings, and what these connections may imply, are shown in Table 2. These connections can be distinguished as those of interventions into the material world on the basis of an idea or specific evidence (connections I→C and E→C) and those of representations of the material world (connections I→E, E→I, C→I and C→E).

[Insert Table 2 about here]

In what follows we attempt an analysis and description of the didactical activities identified, in terms of connections between the entities C, E, I. This analysis will allow us to detect the type of connections between Cosmos, Evidence and Ideas embedded in these activities. We also examine the character of the analysed didactical activities within the context of the science lessons in the pre-primary classrooms, and give representative examples. To enable the reader to form an integrated idea, all the examples have been drawn from lessons dealing with the same phenomenon. We chose the phenomenon of 'floating and sinking' because it is a popular topic in pre-primary education and was the subject of a considerable number of the lessons analysed (25% of these, and 16% of the total data). Taking into consideration the possible connections between the three entities C, E and I that may occur in teaching-learning activities, and what these connections may imply when the CEI model is applied in educational settings (see Table 2), the above didactical activities can be analysed as follows:

Analysis and discussion of didactical activities

Reading a book and showing its pictures aims at creating representations relevant to the subject treated in the book. In the first activity, namely 'Teacher reads a book and shows its pictures to the pupils', the teachers aimed at creating in the children representations of the real/natural world in which the phenomenon may occur. For example, in a "floating and sinking" lesson the teacher reads a book and shows the class a picture in which a child in a bathtub is holding an empty bucket and trying to sink it by pushing it downwards in the water. But the bucket, being full of air, does not sink. During this activity the children responded by recalling evidence from their own experiences, such as "we float in the water when we put our life jackets on". The children's reactions indicated that they had been mentally transported into worlds with which they had interacted in the past. It can, therefore, be considered that this didactical activity was effective in helping the children form connections between the entities Cosmos and Evidence drawn from their own experiences (C→E). Connections between the entities Cosmos and Evidence were also promoted by experimental demonstrations in which the teachers sought to elicit children's observations of evidence from pieces of the material world (C→E).

Similar connections were promoted by the third didactical activity, 'Teacher asks for descriptions of events or phenomena'. Here the children, asked to describe events or phenomena, linked pieces of Cosmos with Evidence that they either observed at the time of the activity or recalled from previous experiences. For example, in a floating and sinking lesson, the teacher placed different objects in the water and asked pupils to describe what was happening to them. In doing so they linked pieces of Cosmos, namely the objects the teachers used, with Evidence, that is, that the objects had either sunk or floated (C→E).

Predictions about expected evidence are based on ideas representing a process (Ideas→Evidence). In productive scientific activities, this type of connection is promoted in children if their predictions are based on a hypothesis or on prior knowledge necessary for creating a rational base for making these predictions (Harlen, 1996). In the lessons analysed, however, the children's predictions were not justified in terms of a hypothesis or evidence, and therefore remained guesses. For example, in a floating and sinking lesson the teacher, carrying out demonstration experiments, asked the children to make predictions about the behaviour of the objects that she was going to put into the water, but did not give them an opportunity to experiment first with instruction materials specifically designed to create the appropriate knowledge base for making those particular predictions. In one instance, one of the materials she was going to use in the water was plasticine. The teacher moulded a small quantity of plasticine into a small ball, and then asked the children to predict its behaviour in the water. Some children guessed correctly that "it will sink", and some did not. Some children explained their guesses by using evidence: "it will float because it is small" (E→E). Next, the teacher changed the shape of the object - she made it flat - and once more asked for predictions. Again, some children guessed correctly - "it will sink" - and some did not; and again some children used the new evidence produced by the teachers' intervention to explain their guess: "it will float because it has a larger surface" (E→E).

In other "floating and sinking" lessons carried out by different teachers, the use of mostly randomly chosen ordinary objects made of a combination of materials precluded predictions of expected evidence based on ideas (i.e. variables affecting the objects' behaviour in water, e.g. concepts such as shape, size, material) and resulted, once again, in mere guesses from the children. Furthermore, this practice of simply testing children's guesses resulted only in proving some of them right and some wrong, without addressing their existing ideas.

The explanation of evidence is linked to ideas. One explains evidence based on one's own ideas, thus associating Evidence with Ideas (E→I). In the lessons analysed, the teachers asked for explanations and provided their own explanations of the evidence produced at each individual stage of the experimental demonstrations. To explain evidence the children used other evidence, alternative ideas (not the generally accepted scientific ones) and anthropomorphic ideas. Teachers, to explain evidence, also used other evidence, scientific ideas, alternative ideas and anthropomorphic ideas (see Kallery & Psillos, 2001).

In explanations of evidence using other evidence, teachers and children essentially made links within the same entity (E→E). This is evident in the representative passages of dialogues from "floating and sinking" lessons presented below.

[The teacher places an object in the water]

Child: It floats. (Evidence)

[The teacher takes the object out of the water and gives it to the children to examine].

Teacher: Why [does it float]? Is it heavy or light?

Child: It is light. (Evidence)

Teacher: Yes, it floats because it is light. (E→E)

[The teacher chooses a very small object and gives it to the children. The children examine it, passing it from one to the next. Then the teacher places it in the water].

Child: It goes down. (Evidence)

Teacher: Why did it go down?

Child: It is small. (Evidence)

Teacher: [It is small], that's why it goes down (E→E)

[The teacher brings a bucket into the classroom and fills it with water almost to the brim. She puts in the water a glass bottle with a thick base. The bottle floats, its upper part above and its lower part beneath the surface]:

Teacher: See, things made of glass sink, but this one floats (Evidence) because there is a lot of water [in the bucket]. (Evidence) (E→E).

It should be noted here that the entities heavy, light, small, much, etc. have the status of evidence (E) because they represent semi-quantitative estimations of physical quantities (e.g. weight, volume, mass, etc.) that, as becomes obvious from the reported data, are derived from the senses (see section '*framework of analysis*'). This distinguishes these explanations, using evidence, from those using ideas, which are presented below. Also, in the instances reported above, this type of explanation (E→E) can be linked with alternative ideas (E→E→I) about floating and sinking consistent with those held by children and adults as reported in the literature (e.g. Biddulph & Osborn, 1984; Havu & Aho, 1999; Kallery & Psillos, 2001), although in the present case this could not be detected since the explanations ended with the reporting of evidence.

In explanations of evidence using ideas, children linked evidence with their own alternative ideas. Children's alternative ideas can be especially useful for the teacher, allowing her to set up experiments in which the children can test them out. This provides new evidence, stimulating children to link them with the material world and with existing ideas in trying to explain them, and probably challenging these ideas, and thereby providing opportunities for conceptual conflict and, later, for exchanging them with scientific ones. In the lessons analysed, however, no experimentation through which the children could test their ideas took place. It is interesting to note that the teachers, in explaining evidence, adopted several of the children's alternative ideas:

[To explain why an object made of iron sinks]:

Child: I think there is magnetism in the bottom of the bucket, that's why it sinks.

Teacher: [Addressing the child] That is a very good answer.

[Addressing the rest of the children] He is right; there is something at the bottom that pulls things made of iron.

This example illustrates how children, trying to make sense of new events but due to their limited experience having limited ideas available, use what seems to them most reasonable, modifying it to accommodate their observation. However, an equally good alternative explanation, which would allow them to make links between the observed evidence and new ideas, was not available to them. Providing opportunities for new explanations has to be done scientifically, if the result is to be of any value in making sense of experience (Harlen, 1996).

Anthropomorphic explanations of evidence were, in some of the lessons, initially introduced and promoted by the teachers (see Kallery & Psillos 2004); these were readily adopted by the children. Some examples of anthropomorphic explanations are: "A ghost or a robot is pushing objects when they float" or "The water likes [the objects] and it doesn't drown them". Anthropomorphic ideas, however, are not productive. As noted earlier, scientific activities involve connections between the entities Cosmos, Evidence and Ideas, in two-way interactions. No repeatable interventions in the material world based on anthropomorphic ideas are possible. Nor, based on such ideas, can testable predictions about expected evidence be made or explanations of evidence produced by interventions into the real world be given.

In classification activities teachers asked children to classify objects on the basis of observable behaviour or properties, e.g. as to whether they floated or sank, melted if heated, were transparent or opaque, were magnetic, etc., and/or on the basis of predicted behaviour.

To classify objects on the basis of observable behaviour or properties one has first to observe objects (Cosmos) and collect evidence linking Cosmos with Evidence (C→E). Then, based on this evidence, one intervenes in Cosmos and organizes it to suit the desired purpose (E→C). The classification of objects may, moreover, also involve ideas. This type of object classification is based on variables such as size, shape, material, weight, etc., which influence the behaviour of objects in specific phenomena; and it is central to concept formation (e.g. Funk *et al.*, 1985; Lind, 1999) and phenomena understanding, since it presupposes the formation of the specific concepts (Ideas) on which it is based (e.g. Lind, 1999; Piaget & Inhelder, 1958; Smith, Carey & Wiser, 1985). In this type of classification one first collects evidence through observation of the objects (C→E), then, looking for regular patterns, links evidence with the existing ideas (concepts) (E→I) and, finally, based on these, intervenes in Cosmos and organizes it to suit some purpose (I→C). For example, whether an object made of a single material will float or sink depends on the relation of the density of its material to that of the water. Therefore, having children classify solid objects of a variety of sizes and (single) materials first on the basis of their material and then, after testing them in the water, on the basis of their behaviour in it, would assist them in acquiring the idea that floating or sinking is not dependent on the size of the object but on the material of which it is made. This kind of classification (involving ideas) may also provide opportunities for interventions into the material world (I→C). Children, guided by teachers' questions, can intervene in Cosmos, changing the category in which these objects were classified by changing one of the variables that influenced their classification. For example, changing the shape (another concept) (I) of a ball of plasticine [solid object] (C) into a boat [hollow object] that floats (planned intervention into the material world based on the idea 'shape': I→C) substantially improves the way of looking at the phenomenon by making children use a new concept (shape). This process gives them the opportunity to make connections between the newly constructed (by them) Cosmos (boat) and the new evidence (it floats) (the object no longer belongs to the category of objects that sink but has become a floating object, due to the new shape that it has been given) (C→E). This process also involves the use of the new concepts 'solid' and 'hollow', which may not be scientific, like density, but "indicate important descriptive elements of this scientific concept" (Havu – Nuutinen 2005, p.274) and thus contribute to the formation of the scientific concept of density and the role it plays in the phenomenon of floating and sinking. According to Thagard (1992, as quoted by Havu – Nuutinen 2005), adding new concepts (I) is important for the development of scientific knowledge.

In the lessons analysed, classifications were mainly of the former type. For example, in the floating and sinking lessons the use of mostly ordinary objects made of a combination of materials allowed classification based only on their behaviour in the water. This may also be the reason why most of the attempted classifications based on the predicted behaviour of the objects were not successful. In a few lessons, isolated classification of objects based on some kind of variable (mainly shape or size) was carried out, but was not related to the study of phenomena which these variables may influence. Also, in several cases, classification of the former type was carried out with significant teacher intervention, and consequently it was difficult to judge whether in these cases the children had successfully formed the connections promoted by this type of classification.

Problem-solving questions asked children to find ways to intervene in the material world in order to produce desired evidence. For example, in a "floating and sinking" lesson a teacher asked pupils to find a way to make a floating object sink:

Teacher: Can you find a way to make it sink? I want it to stay down.

In such types of interventions children develop ideas on which they will base their planning of their interventions into the material world for successfully producing the desired results (evidence). In this process, children first make links between the desired evidence and their ideas (E→I) and then, based on those ideas, are required to intervene in Cosmos, modifying or rearranging it in order to produce the desired solution, i.e. making links between the entities I and C (I→C). However, in the lessons analysed, problem-solving questions represented a very small percentage of all questions asked by the teachers. Children mostly intervened in the material world using a 'trial and error' tactic focusing chiefly on the expected evidence (they pushed the object down, they kept it in the water for some time, etc.). Additionally, in some of the lessons in which teachers posed problem-solving questions, they did not give the pupils a chance to experiment towards producing possible solutions.

Presentation of theoretical scientific ideas or concepts is often an attempt to establish or re-establish connections between scientific ideas or scientific concepts (I→I). In theoretical explanations of phenomena, newly introduced scientific ideas or concepts must, if they are to be meaningful and comprehensible to the learners, be linked to ideas or concepts that have been used in explanation of evidence produced during the individual stages of the experimental study of the phenomena. In the lessons analysed, however, teachers often attempted theoretical explanations of the phenomena being studied using abstract concepts or ideas that were not relevant to those used in the explanation of evidence produced by the experimental demonstrations. For example, in floating and sinking lessons teachers used new concepts and ideas such as force or upthrust to explain the phenomenon.

Teacher: Well, the water has a force inside it, the upthrust. This force can lift some things but not others.

Teacher: Now let's see. Why some things don't sink? What pushes things up?

Child: "Mumos" (the ghost) [This was the idea that was used during experimental demonstrations to explain the flotation of some of the objects].

Teacher: No, no, I will tell you. It is because there are forces in the water. You see, many forces are pushing up on things with large surfaces, while other things have small surfaces.

These ideas or concepts were not related to the explanations used during the experiments. As noted earlier, in these lessons teachers and children explained evidence either using other evidence or alternative and anthropomorphic ideas.

It should be noted here that in some countries the balanced-forces concept of floating and sinking is used in preference to the density concept. However, for children of pre-primary level, the concept of upthrust, which is related to the idea of forces, is difficult to demonstrate. At this level of education, using the density approach – even though the term density itself is not directly used but, as noted earlier, is replaced by concepts that indicate descriptive elements of density – allows the phenomenon to be described in terms of volume and mass. For pre-primary children this means considering the floating and sinking objects from viewpoints like hollowness, shape, size and weight (see also Havu-Nuutinen, 2005). In Greece, while in the elementary science curriculum the density approach is dominant, no explicit suggestions are made in the pre-primary science curriculum guidelines as to which approach early-years teachers should follow. This choice is left to the teachers themselves.

Finally, in drawing conclusions one has to interpret the evidence collected from Cosmos (C→E) by linking it to ideas (E→I). Interpretation involves looking for patterns or trends in observations or results of experimentation (evidence) that might be regular and would hold in other cases. In the case of floating and sinking, for example, testing different objects made of the same material (e.g. a toothpick, a large wooden block, a wooden doll, etc.) in the water produces the same evidence: none of them sinks. It is then possible to connect the evidence (does not sink) with the idea 'material' (made of wood). At the same time, an association has been made between two variables, material and size. Making the hypothesis that the variable affecting whether solid objects float or sink is their material and not their size, and testing that association against more data (evidence coming from solid objects made of different materials), can -with caution- lead to an idea-based conclusion (Harlen, 1996).

In the lessons analysed, as noted earlier, the selected instruction materials (Cosmos) did not, for the most part, provide opportunities for identifying and associating different variables affecting phenomena. Conclusions were drawn by teachers on the basis of explanations of evidence using other evidence, anthropomorphic or alternative ideas and theoretical ideas that were not previously associated with the phenomena being studied.

Teacher: So, things made of iron that are hollow don't sink. Why they don't sink is because they are hollow. What pushes them upwards? "Mumos" [the ghost] does.

Teacher: So things made of iron like the pin sink. The pin sinks because it has a small surface and only few forces are pushing it upwards.

Summary and conclusions

Summarizing the findings of the present study, the analysis of teaching-learning activities revealed that, out of all the possible connections between Ideas, Evidence and Cosmos, only certain specific types were promoted, namely connections involving the entities Cosmos and Evidence. Most of them were connections of the type C→E, and few of the type E→C. Some same-entity connections (E→E) were also identified. As was mentioned earlier (see framework of analysis), possible connections between the entities C,E,I can be distinguished as those of interventions into the material world on the basis of an idea or specific evidence (connections I→C and E→C) and those of representations of the material world (connections I→E, E→I, C→I and C→E). Thus, it seems that, in the lessons of our sample, scientific activity was mainly confined to the representational level, with limited intervention practices into the material world. Such interventions were based on evidence collected, while interventions based on ideas were not identified in these lessons.

The specific character of the connections revealed by the analysis of didactical activities suggests that scientific investigation was not promoted in the science lessons of our sample. Investigations, assuming a significant role as an inquiry approach to science education (Minstrel & van Zee, 2000), provide children with opportunities to both represent and intervene in the material world, and therefore enable them to potentially form several connections among the entities C,E,I. It can be claimed that the two types of connections C→E and E→C that were promoted in the lessons of our sample, if evaluated in the context of scientific inquiry, are of only limited value. Nor can the same-entity connections (E-E) identified in the explanation of evidence be considered as productive. These particular links can neither foster the development of ideas nor support the formation of hypotheses, although connections between evidential data can be fruitful when accompanied by analogical reasoning. Other fruitful same-entity connections, those between ideas (I-I), could be of value if, as noted earlier, they were successfully used in establishing or re-establishing connections between scientific ideas or scientific concepts.

In general, connections involving ideas were not identified in the lessons of our sample. Missing links between evidence (E) and theory (I) and between ideas (I) and the material world (C), which are usually achieved through idea-based interventions in cosmos, suggest that scientific understanding did not take place. As noted earlier, in scientific contexts, scientific reasoning and understanding involving both procedural and conceptual aspects give rise to 'scientific' knowledge. Taken as a whole, the findings of our analysis of the didactical activities suggest that the pre-primary science lessons are fragmentary in character. The use of theoretical ideas or concepts that were not related to the others used in the lessons or to ones that children may have developed earlier in their lives does not seem to satisfy the objective of establishing a relation between new scientific knowledge and previously acquired or new experiences (Lind, 1999) (see introduction). Also, although some of the basic science process skills that lead to the promotion of the above-mentioned links between the entities Cosmos and Evidence were used in the lessons, others, which are necessary when conducting a scientific inquiry (Funk *et al.*, 1985; Harlen, 1996), were not. Casual instruction materials (Cosmos) that did not provide opportunities for variable manipulation (identification, association, alteration, etc.) (see Eshach & Fried, 2005; Havu-Nuutinen, 2005) suggest lessons lacking conceptual objectives. As discussed earlier, variable manipulation, as one of the skills fundamental to conducting scientific inquiry, provides opportunities for idea-based interventions in the material world, and thus promotes connections between the entities Cosmos (C) and Evidence (E) and that of Ideas (I). The teaching seemed intended merely to pile up unconnected episodes, resembling simple processes of exposition, with random results. The findings also point out missing links between the entities featured by the analysis framework that are essential for the development of scientific inquiry in science lessons.

From the methodological point of view, an epistemological analysis of didactical activities in science provides opportunities for describing them in a unifying language and thus obtaining a deep insight into their nature and meaning. Performing an analysis using the specific theoretical framework allowed us to give a more general interpretation, guiding the diagnosis of the factors that led to our conclusions. Most importantly, however, mapping the connections between the entities C,E,I potentially provides useful insights for planning interventions that can enrich science lessons specifically designed for pre-primary education in the desired connections that are missing, or improve those that are promoted, and thus supports attempts to meet the desired pre-primary education objectives described in the introduction to this paper. In order to implement such lessons, however, teaching practices need to be improved. A considerable contribution in this direction can be made by improving teachers' epistemological understanding, focusing on (a) developing teachers' ability to recognize the difference between a scientific and an empirical approach to issues related to the natural world, and (b) developing teachers' ability on the one hand to correlate evidence with scientific ideas when explaining natural phenomena and, on the other, to use scientific ideas for planning interventions into the material world in order to enhance children's understanding during the course of scientific inquiry. The latter aspect requires that early-years teachers have a good conceptual understanding of simple but fundamental concepts and phenomena of the natural world, appropriately adapted to their needs and level, which will provide them with a coherent framework in the areas of science that they deal with in their everyday professional work.

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Legends:

Table 1. Typical didactical activities in pre-primary physics lessons.

Table 2. Possible connections between the entities Cosmos, Evidence and Ideas when the CEI model is applied in educational settings.

Table 1.

When studying a phenomenon, the

1. Teacher reads a book and shows its pictures to the pupils
2. Teacher carries out experimental demonstrations
3. Teacher asks children for descriptions
4. Teacher asks children for predictions
5. Teacher asks children for explanations
6. Teachers provides explanations herself
7. Teacher asks the children to classify objects
8. Teacher poses problem-solving questions
9. Teacher introduces theoretical concepts or ideas to explain the phenomenon being studied.
10. Teacher draws conclusions

Table 2.

Possible connections between C,E,I	**Where connections may occur**
C→E	The linking of a piece of Cosmos with a piece of Evidence. This is made in descriptions of what is happening in Cosmos in terms of observed or recalled Evidence.
E→C	The linking of Evidence with a piece of Cosmos. This is made when constructing, intervening or modifying a specific segment of the material world on the basis of a specific piece of evidence
I→E	The linking of Ideas with expected Evidence. This is made in predictions of Evidence based on one's own ideas.
E→I	The linking of Evidence with Ideas. This is made when

	explaining specific Evidence in terms of some specific Ideas. These Ideas can be scientific or common.
I→C	The linking of Ideas with Cosmos. This is made in interventions to the material world. Using scientific ideas, one may construct a specific piece of Cosmos with specific characteristics.
C→I	The linking of Cosmos with Ideas. This is made when describing a piece of Cosmos on the basis of one's own Ideas.

Table 1.

When studying a phenomenon, the

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C→I	The linking of Cosmos with Ideas. This is made when describing a piece of Cosmos on the basis of one's own Ideas.