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1. Introduction

Outer space fascinates young children and captures their imagination. They raise questions about and often express bewilderment at astronomical phenomena which they observe every day (e.g. Kallery, 2000). Children, in their effort to interpret these phenomena, form their own 'ideas' about the causes of these phenomena and develop their own 'notions' of the related concepts.

Internationally a large number of intensive research studies (e.g. Baxter, 1989; Nussbaum, 1979, 1985; Sharp, 1995; Vosniadou & Brewer, 1990) focusing on young children's notions of the shape of the earth, its position in space, the day/night cycle and certain related matters have identified a number of different views. Regarding the shape of the earth, some of the most frequently found views are: the 'flat earth', according to which the earth is shaped like a disk, round, rectangular or square; the 'hollow earth', according to which the earth is shaped like a sphere with two hemispheres, a lower upon which people live, and an upper one which covers the lower like a dome; the 'dual earth', according to which two earths exist, one spherical and one flat, both in space, with people living on the flat earth; and, lastly, the 'spherical earth', according to which the earth is like a ball in space and people live all over it. Regarding the phenomenon of day and night, the studies revealed that very young children regard the sun as a living body and attribute to it anthropomorphic habits, such as 'it goes to sleep', 'it hides behind trees and hills', 'it fades away'. They also attribute the day/night cycle to the rotation of the sun around the earth, which successively lights different parts of the earth, to the earth's rotation around the sun once a day or to an upward and downward motion of the sun.

Certain studies (e.g. Butterworth, Siegel, Newcombe & Dorfmann, 2002; Nobes, Moore, Martin, Clifford, Butterworth, Panagiotaki, 2003; Schoultz, Saljo, Wyndhamn, 2001), however, the methodology of which differed from others in the field, questioned both the research methods and the theoretical framework of the earlier researchers. Butterworth *et al.* (2002) and Nobes *et al.* (2003) for example, who researched children aged 4-9, argue that these children's thinking is fragmentary, and Schoultz *et al.* (2001) point out that student knowledge is context specific. They suggest that all that is necessary is to present students with appropriate information about the earth, along with conceptual tools to help them understand the spherical earth concept. These researchers began their interviews with a globe in front of the children and related all of their questions to it. The researchers found that when using the globe as a concrete point of reference for the interaction, children's views regarding the shape of the earth reported by the other studies completely disappeared. These studies were in turn criticized by other researchers (see Agan and Sneider, 2004).

The research reviewed above consists largely of studies that seek to characterize student knowledge; however, as mentioned in Harlen (1992), few studies have paid attention to the effectiveness of instruction. These studies concern mainly children of elementary and middle school grades (e.g. Diakidou and Kendeou, 2001; Hayes, Goodhew, Heit, Gillan, 2003; Sneider & Ohadi, 1998). Learning studies for children in pre-primary years are indeed limited, and address kindergarten children aged 5-6 years (e.g. Valanides, Gritsi, Kampeza & Ravanis, 2000). As far as we have been able to determine there are no learning studies on elementary astronomy topics intended for pre-primary children of ages as young as 4 years.

Opinions on what astronomy education for very young children should comprise are divided. Some of the primary goals of education in astronomy for young children are to spark their imagination and to encourage their interest in space exploration (NASA, 2003; NASA Office of Space Science, 2003, as cited in Agan and Sneider, 2004). Although educators applaud these goals they suggest that, apart from engaging, activities should also be scientifically accurate and educationally effective (Agan and Sneider, 2004). A question that has frequently been raised is the question of the age at which it is appropriate to introduce concepts such as the sphericity of the earth. Some researchers (e.g. Agan and Sneider, 2004) and the 1996 National Science Education Standards (NSES) (National Research Council, 1996) recommend that explanations of astronomical phenomena that require students to understand earth's spherical shape should be eliminated from the curriculum for grades one to three and be replaced "with activities in which students observe, record, and find patterns in the world around them". Mali and Howe (1979) point out that the danger in teaching concepts such as the sphericity of the earth in the first three grades is "that the child will be told and accept the new notions of earth…without understanding the meaning of the evidence…". However, as Sharp (1995, 1999) suggests, earth's shape and many of the other features associated with it are considered fundamental enabling concepts upon which a knowledge and understanding of the earth's other physical and astronomical attributes and phenomena, such as day and night and place in the solar system, could be constructed at an early age. Other researchers (e.g. Diakidou and Kendeou, 2001) also note that late instruction in concepts related to the earth and the day/night cycle which are part of the young child's everyday experience may lead to formation of initial conceptions that are already evident in the first grade. Additionally, the findings of a recent study (Kikas 2005) which investigated the effect of verbal and visuo-spatial abilities on the development of knowledge of the earth in children of mean age seven years and eight months suggest that it is useful to talk about elementary astronomical concepts to children of pre-school age.

In Vygotsky's view, learning is essential to cognitive development and the best time for learning something new is when a child is most receptive, provided that he or she has the assistance of a teacher or a peer (Vygotsky, 1962). 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 four to six) falls within this critical span, as learning is apprehended as a modification of neural structure and the formation of new synapses. This critical period, called 'window of opportunity', begins to close at around the age of nine (Bransford, Brown & Cocking, 2000; Gramann, 2004; Nash, 1997; Shore, 1997). However, for essential science skills, the window seems to close quite early (Begley, 1996; Eshach & Fried, 2005). Thus, as Gramann (2004) notes, maximizing opportunities for early learning must be strived for while a young child's brain development remains somewhat flexible.

The literature (e.g. Metz 1995, 1998) 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 researchers (e.g. Gelman and Markman, 1986; Ruffman, Perner, Olson & Doherty, 1993) 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. Moreover, cognitive researchers, having become much more sophisticated in probing children's capabilities, have uncovered much richer stores of knowledge and reasoning skills in young children than they expected to find (Michaels, Shouse & Schweingruber, 2008).

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). Thus, as Sharp (1995) notes, instead of abandoning concepts and phenomena which are considered too difficult for very young children, at least in the ways in which they might have been presented to them, we should seek resources, teaching styles and strategies which make learning astronomy more accessible and fun.

It was against this background that the study reported in this paper was undertaken. In this study, which was carried out in Greece, we test the effectiveness of a teaching intervention which aims at:

a) Acquainting children aged 4-6 with the concept of the sphericity of the earth.

b) Assisting these children to realize that the alternation of day and night is caused by the spherical earth's rotation on its axis.

The treatment comprised three units of activities which:

- Were developed collaboratively by a researcher and early-years' teachers employing action research processes.
- Were implemented by the teachers of the work group in real classroom settings.

In the present study two sources of data will be used:

1) Teachers' recordings, made during all the stages, of the implementation of the activities and of events related to students' astronomical activities.
2) The post-instructional assessment of the students.

The rest of this paper is organised in sections, as follows: In section 2, entitled 'contextual information', aspects of the Greek pre-primary education are described. This is followed by a section on 'Methodology' (section 3), which presents the design and the approach of the activities and the approach and procedures followed for the development of the activities and for the teachers' preparation for implementing them, and describes the units of the activities in the sequence in which these were implemented and the post-instructional assessment instrument. In section 4, the implementation of the activities and collection of data are presented. Following that is section 5 ('Methodology of data analysis and results'), in which a description of the method used for analysing these data and the procedure followed is given and the findings of the analysis of these data are presented. Section 6 gives the results of the post-instructional assessment. The findings of the study are discussed in section 7, while section 8 presents the conclusions and the implications.

2. Contextual information

Greek pre-primary education is, as mentioned earlier, attended by children of ages between four and six. More specifically, there are two age groups: pre-kindergarteners, ages 3 years 8 months (they become 4 years old in December of the year they start preschool) to 5 years, and kindergarteners, ages 5-6 years. Pre-primary classes in Greece are multi-age classes.

Teachers are required to implement the National Curriculum for Pre-primary Education (2006), which proposes two kinds of activities: 'free' activities for the children, which are activities chosen and carried out by the children themselves without the teacher's direct involvement, and 'teacher-organised' activities, which are activities planned and organised by the teachers according to the objectives that have to be met. The duration of the 'teacher-organised' activities, i.e. the 'class period', is usually 30 to 40 minutes, but it can be extended depending on the structure and the type of the activity as well as on the potential of the class.

The pre-primary classroom is organised in 'corners', one of which is expected to be the 'science corner' where children can work in groups or individually either during 'teacher-organised' activities or during 'free' activities. Whole class sessions take place in a classroom area called the 'company' where children and teacher sit in a circle on low chairs or on comfortable pillows on the floor.

One of the curricular objectives of the children's initiation to the study of the natural world is the development of attitudes and of the basic science process skills such as observing, comparing, investigating, answering of questions (or solving problems) and drawing of conclusions. These, according to the teacher's guide that accompanies the curriculum, create presuppositions for the gradual development of children's abstract thought.

The choice of topics for the 'teacher-organised' activities is left to the teachers' discretion. More specifically, teachers can organise activities on topics that emerge from the children's interests or questions, or, if the children's interests do not touch upon issues which they consider important and appropriate to be introduced to pre-primary children, they can design the activities from scratch by choosing the topic, the content and the instruction materials in order to meet the objectives that they have decided upon. Topics can concern either concepts or phenomena of the natural world that children often encounter in everyday life. Very general directions as to how activities could be developed are given to the teachers in the teachers' guide. Regarding elementary astronomical concepts and events, the guide suggests the very general theme of 'what people do during the day and at night' as a possible place for their introduction; within this context, children could for example talk about the alternation of day and night and, if the teacher considers appropriate, the seasons. The discussion could also include the rotation of the earth around its axis and its movement around the sun.

The curriculum considers important both the mental and physical involvement of the children in the activities, and stresses the importance of language as a decisive factor for the development of children's scientific concepts. Scientific vocabulary can be introduced, although children are not expected to retain all the scientific terms.

3. Methodology

3.1. Design and approach of the activities

In the present study student knowledge is considered context-specific (Schoultz *et al.*, 2001). Thus, in the activities children are presented with appropriate information along with conceptual tools, such as a globe and an instructional video. In this video scientifically accepted information about the earth and its shape, its position in relation to the sun, the moon and the other planets of our solar system, the earth's two movements and the day/night cycle are presented in three episodes. The presentation is done via spoken narration accompanied by animated live video clips using 3-D models and music. Dynamic representations such as live animations can do a good job in providing a clear idea of events and phenomena. However, as very young children are rather unlikely to be familiar with or have prior knowledge of all the entities represented, spoken narration can enhance understanding of images and phenomena by filling in details that are difficult to portray in visuals (Buckley and Boulter, 2000). This influenced our decision to combine both visual and verbal modes (Boulter and Buckley, 2000) in all three episodes of the instructional video. Also, in all three video episodes the models in the animations bear structural and behavioural similarities with the real phenomena and events. However, the time scale of the evolution of the animated phenomena is not proportional to that of real phenomena (see also Boulter, 2000).

A detailed description of each episode of the video will be given in the corresponding activity in which it is used.

The design of the activities and the tailoring of the instructional video took into consideration that:

(a) Some children believe that the earth or other celestial bodies are supported in space (e.g. Vosniadou & Brewer, 1990). This finding influenced our decision to exclude the use of any artefacts in the first two units of activities. A globe is used later, in the third unit and after the concept of 'model' has been introduced. It is known that the foundations of modelling are evident in young children long before they arrive at school since they have an "appreciation of the representational qualities of toys, pictures, scale models, and video representations…. This suggests that children have rudimentary skills for modelling- a fundamental aspect of contemporary scientific practice-even before kindergarten" (Michaels, Shouse & Schweingruber, 2008). Also, as research reported by Gilbert and Boulter (1998) has shown, models are used from an early age and help children understand theories more clearly.

(b) Children may become confused by the two simultaneous movements of the earth, tending to attribute the day/night cycle to both movements rather than to the earth's rotation on its axis (Valanides, Gritsi, Kampeza & Ravanis, 2000).

c) A non-stationary sun may impose an unnecessary challenge for children of this age (Valanides, Gritsi, Kampeza & Ravanis, 2000).

The two latter findings influenced our decision to use a stationary sun and to introduce the two movements of the earth in subsequent stages in the instructional video.

d) Children must realize that the earth "appears to be flat because we only see a small part of it, and that if we could see it all, as astronauts do, we would see it as a huge sphere" (Agan and Sneider, 2004). This proposition was taken into consideration in the design and tailoring of the first episode of the instructional video, where the sphericity of the earth is first introduced. In this, the gradual change in the apparent shape of the earth from flat to spherical and vice versa are observed when the observer moves away from the ground and then when he approaches it again.

For the structuring of the units the astronomical concepts dealt with by the activities were organised into three groups and were treated in the following sequence:

a) * Shape of the sun

* Shape of the moon

b) * Shape of the earth

* Earth's position and movement in the solar system in relation to the sun, the moon and the other planets

c) * Earth's two movements

* Day and night cycle

The concepts of the sphericity of the sun and the moon were considered key concepts for the realization of the sphericity of the earth. Thus, taking into consideration a) that scientific knowledge is based on and/or derived from observations of the natural world (Abd-El-Khalick, Bell, Lederman, 2001) and b) that kindergarten children have surprisingly sophisticated ways of thinking about the natural world based on direct experiences with the physical environment, such as observing parts or elements of it and phenomena (Michaels, Shouse & Schweingruber, 2008), the children are initiated into the activities by performing direct observations of the above two celestial bodies in the immediate vicinity of the earth. Since "explaining observations of objects beyond the earth is considered a key aspect of scientific work in the field of astronomy" (Plummer, 2008-in press), observations are followed by children's reporting, explaining and representing what they observe.

An important aspect that was taken into consideration was the interpretation of children's representations. With children's drawings it is often difficult to determine whether specific features are caused by insufficient drawing skills or drawing peculiarities or whether they indicate misunderstandings (Kikas, 2005). Thus in the activities, all children's drawings are followed by their verbal descriptions and explanations (see also Boulter, 2000).

In the present study the approach to learning can be characterized as socially constructed in the sense that the teacher's role is central in explaining the scientific concepts, children collaborate with peers sharing opinions and knowledge, and adults and children work together (e.g. Fleer, 1993; Robbins, 2005).

Within the learning context described above, whole class and group discussion was considered one of the most important aspects (e.g. Dawes, 2004) of the activities. Ogborn, Kree, Martins & McGillicuddy (1996) note that providing opportunities for discussion in science leads to greater engagement on the part of the learners and optimises learning when it is mediated and supported by others where individual thinking is developed through social interaction with teachers or more capable peers (Vygotsky, 1978).

3.2. Activities development: approach and procedures

The present work was carried out by a study group composed of a researcher/facilitator (R/F) (author of the present paper) with a background in physics and six early-years teachers. The activities were developed collaboratively by the R/F and the teachers. The advantage of this process was that it provided opportunities for the partners to bring their expertise to this collaboration (see Jones, 2008). The initial idea was to motivate the teachers by making them members of an *action research* group, meaningfully engaging them in the development of the activities and the instruction material (Kallery & Fragonikolaki, 2007). The R/F initially designed the activities. The teachers implemented them and used *action research processes* to optimise classroom practices and to gather information, which in turn was used by the group for the revision and final shaping of the activities and for tailoring an instructional video which accompanies the activities. These processes were cyclic and included the most basic steps: acting-recording, reviewing-reflecting, acting (Dick, 1997). More specifically, the development procedures comprised teachers' individual class work and group work. In class, teachers recorded their lessons and related events by audiotape and field notes and transcribed them into protocols. Teachers' reviewing and reflecting took place in group meetings and was facilitated by the R/F. Group work led teachers to joint decisions on coping with common problems and yielded alterations of the activities initially designed by the R/F. The procedure resulted in the production of a total of eight activities. However, since classes differ in their characteristics, teachers had to adapt the 'model activities' to the particularities of the class taught.

3.3. Teacher preparation

Previous research has shown that early-years teachers hold alternative conceptions of current scientific ideas related to astronomical issues (Kallery & Psillos 2001) as well as pseudoscientific beliefs about them (Kallery, 2001). Thus, taking into consideration that children's thinking is influenced by what teachers say and do (e.g. Fleer & Robbins 2003), prior to the implementation of the activities the R/F introduced the concepts and phenomena to be taught in group meetings, presenting the teachers with knowledge that was necessary for responding successfully to the implementation of the activities. At the same time the R/F answered teachers' personal questions concerning the topics of the activities and provided printed material on related children's ideas. Also, during the preparatory pre-implementation stage the group was occupied with some methodological issues such as: (a) ways in which teachers' questions can be formulated in order to be more effective, (b) possible ways for handling children's questions depending on their type (e.g. Harlen, 1996; Kallery, 2000) and (c) the avoidance of personification when answering children's questions or introducing scientific issues. According to Piaget (1951), use of anthropomorphism can foster subjectivity in young children. Since personification is often used by teachers in both the two latter cases, either consciously or unconsciously (Kallery & Psillos, 2004) and is also very often found in children's books, analysis of texts from children's books helped teachers locate and better understand animistic and anthropomorphic explanations in scientific issues, especially in those concerning astronomical phenomena.

3.4. The activities

The activities were organised in three units. A teachers' guide was created in order to make the material easy to use as well as accessible to other teachers. Taking into consideration early-years teachers' self-perceived needs in science (Kallery, 2004) and the fact that didactical activities usually adopted by early-years teachers in science activities very often do not lead to desirable outcomes (Kallery & Psillos, 2002; Kallery, Psillos & Tselfes, 2008), the guide contains detailed descriptions of all the activities of each unit as they were finally shaped by the work group and of all the materials, as well as suggestions and explicit directions on how to implement them. An introductory chapter provides teachers with the necessary scientific knowledge, which is presented in the form of answers to astronomical questions concerning issues directly related to the content of the activities. Each of the activities is designed to take one 'class period', but if necessary can be extended to one more. The structure of the units and of the activities is as follows:

Unit 1:

The first unit includes three activities focusing on children's first acquaintance with the shape and appearance of the sun and the moon. In the first activity, in whole class, the children describe the sun. The class is then divided into small groups. Each group is invited to directly observe the sun using eclipse observation filters. The teacher asks for reports and explanations from each group and records the results. Then he/she pulls the class together, and the groups report, compare and discuss their observations in whole class. This is followed by children's individual representations of the sun, as it was observed with the filters. Drawings are discussed in whole class session.

The second activity comprises children's observations of the full moon and the recording of observations in any way they want. The night observations are carried out at home with the assistance of a more capable member of the family.

The third activity is carried out in whole class. The children present the results of their night observations and compare them with those of the others. Finally, the shape of the sun as it was observed with the filters and the shape of the full moon are compared and similarities are identified and discussed.

Unit 2:

The second unit comprises three activities. The objective of this unit is to introduce and familiarize children with the shape of the earth and its movements as well as with the shape and the movements of other celestial bodies (planets and moon) of the solar system. In the first activity children's initial ideas about the shape of the earth are investigated. The activity entitled "The shape of the earth" begins with artwork. The children are invited to draw the shape of the earth and explain and reason about their drawings. The teacher categorizes children's drawings depending on the shape of the earth and the explanations given by them. Then, using a real picture of the earth, he/she introduces the new knowledge, explaining that this picture of the earth has been taken by astronauts and this is what the earth looks like when seen from space. The children's drawings are discussed in comparison with this picture. In the discussion the teacher emphasizes that 'the earth which we live on and which looks flat to somebody who stands on it, is the same earth that the astronauts see as a sphere when they are in space, far away from it'. This discussion is a useful introduction to what the children will see in the first episode of the video.

The second activity starts with a review discussion of the shape of the sun, moon and earth (as shown in the above-mentioned picture), in comparison to each other. Next the teacher introduces, in a form of a question, a new piece of knowledge necessary for following the video: 'Did you know that the earth moves in space?'. Children are given time to express their own opinions and discuss them in class. The activity continues with the playing of the first episode of the video. In this episode children observe the spherical shape of the earth, its movements, the relative positions of the sun, earth, moon and other planets as well as their movements. These are presented through a story of a space trip (see narratives in appendix). More specifically the video begins with the boarding of a space shuttle by a group of astronauts and continues with its launching. During its lift-off and ascent the video focuses on the land surface of the earth. This gives the children the chance to observe the gradual change in the shape of the earth from flat to spherical as the spaceship moves away from it. Next, the video shows and draws children's attention first to the rotating spherical earth and then to its movement around the sun accompanied by the moon. Then it places the earth in its real position in relation to other planets within the solar system and shows it rotating together with the other planets and the moon around the sun, which, as noted earlier, is kept stationary. During the return of the spaceship, as it approaches the earth the video focuses again on the gradual changes in its apparent shape, showing it finally becoming flat again.

In the third activity, children are invited to draw the celestial bodies they observed in the video and to render graphically the movement they execute. Children present and explain their work in whole class. During these presentations the identity of the celestial bodies drawn by the children is discussed, as are their shape and their movements.

Unit 3:

The third unit comprises two activities in which children are engaged in the study of the phenomenon of day and night. The aim is for the children to realize which of the earth's two movements causes the alternation of day and night. In the first activity, in whole class, children are asked to describe the gradual change of light intensity on the earth during the 24-hour cycle and express in detail their opinions on what they think are the reasons why these changes occur. The children's opinions are extensively discussed before the second episode of the video is shown. In this episode the two movements of the earth are introduced successively: first it shows the earth turning around on its own axis and then it shows the rotating earth revolving around the sun. It is important that during this episode, the teacher focuses the children's attention on two points: (1) the part of the earth that is facing the sun has daylight while the other is in the dark and (2) the earth is moving around the sun and not vice versa. The screening of the video is followed by children's descriptions of the earth's two movements. The children are then invited to show, in any way they want, the movement of the earth that they think is the one that makes different places on the earth have day or night. Next, the teacher shows a picture of the earth lighted on one side and invites children to express their opinions on why they think half of the earth is dark and half is lighted. Children comment on each other's explanations. It is recommended that during this discussion the relevant episode of the video be repeated.

In the first part of the second activity the teacher, using a wooden and a real apple, introduces the concept of the "model" and works on children's realization of the difference between the 'real' and the 'model'. Next, the globe is presented to the children. The teacher explains that, just like the wooden apple, the globe represents the earth, i.e. is a model of the 'real earth'. In the second part of this activity children work in small groups. They use the globe and an electric lamp or a torch to investigate and find out 'how night will come in a place that has day'. Each group presents their findings, which are discussed in whole class. This is followed by the showing of the last episode of the video. In this episode, which animates the earth's movements and shows the changes of light on it, the outside observer has the chance to 'enter' the totally dark side of the earth as it rotates on its own axis while moving around the sun. The activity closes with children's individual artwork. They are asked to draw the sun and the earth in appropriate positions, to sketch the orbit of the earth, to shadow the part of the earth they believe has night and to colour with bright colours the part that has day. The children present and discuss their work in whole class.

3.5. Post-instructional assessment

The assessment was designed to be carried out in two separate phases. The first two units are assessed in the first phase and the third unit in the second phase. As very young children often cannot correctly express their ideas, the assessment tasks comprise, in addition to oral descriptions, children's construction of play-dough models and handling of these models and artefacts.

Phase 1 assessment tasks:

In phase one the child is given play-dough of two different colours, yellow and blue. The child is asked:

a) To construct 'the sun' and 'the earth'.

b) To identify the celestial bodies, i.e. to show which represents the sun and which the earth.

c) To first explain orally and then show which of the two bodies is the one that moves, and next to first describe and then show, by moving the corresponding model, how this particular body moves. This makes it possible to diagnose whether what was described orally has been understood to a degree that can also be demonstrated.

Phase 2 assessment tasks:

The second phase of the assessment comprises the following tasks:

a) The child is initially given a picture of the earth half lighted and a picture of the sun. He/she is asked to place the sun in the correct position in order to have the effect shown on the picture of the earth.

b) The child is given a torch and a globe on which a place has been marked by the teacher. He/she is asked to "make" this place "have day" and explain why, and afterwards to show how night will come to a place indicated by the child and identified as having day.

c) The child is asked to show which of the movements of the earth creates the alternation of day and night and then to explain why.

4. Implementation and data collection

The activities were implemented by the teachers in their own pre-primary classes in six different public schools in central Northern Greece and in a sample of 104 children of different social and cultural backgrounds. All the classes were multi-age except one, which was attended only by kindergarteners. It should be noted that at the time of the implementation of the activities children's ages ranged from 4 years 4 months to 5 years 8 months. The activities constituted part of the regular pre-primary school week timetable. As noted earlier, in the activities children worked in small groups, in whole class and individually, depending on the type of activity. The full moon observations were carried out at home, where children, with the assistance of a more capable member of the family (e.g. a parent), observed the night sky and recorded their observations.

As planned, the teachers audio-recorded the lessons and transcribed them into protocols. These protocols were supplemented by the teachers with descriptions of events that took place during activities, with comments and personal experiences. The teachers, observing the children on a regular basis, were able to keep field notes on their astronomy-related activities during 'free' time. Additionally, they kept notes of parents' reports about children's reactions relating to both the astronomical activities that were carried at home (i.e. full moon observations) and those at school.

5. Methodology of data analysis and results

The analysis was informed by the aim of the study (Merriam, 1998) and, in the case of the lesson protocols, was carried out using as indicative categories those in which the astronomical concepts dealt with by the activities were organised (see 'design of the study'). In the first stage the procedure used identification of regularities–things that happened frequently. Patterns and regularities were then transformed into subcategories into which, following a constant comparative technique, related items were sorted. Subcategories were given a name reflecting the most dominant findings sorted in them.

Teachers' lesson protocols and notes were analysed by the R/F. In order to validate interpretations, member checks – 'taking data and interpretations back to people from whom they were derived and asking them if the results are plausible' - were used throughout the study (Guba & Lincoln, 1981, Meriam 1988). Thus findings and interpretations were discussed with each individual teacher whose data they came from, in order to ensure plausibility. Peer examination was also employed: i.e. each of the collaborators was asked to comment on the findings as they emerged (Merriam, 1998).

The analysis sought to identify procedures, teaching acts and events indicating how the concepts dealt by the activities were gradually approached, at the same time providing information on children's reactions and response to the treatment. (Note: Quotes - Children are denoted with a 'C' and teachers with a 'T'.)

a) Shape of the sun and shape of the moon

Children were surprised on the one hand at the appearance of the sun and on the other at its size and colour when they looked through the filters, which showed a distinct white light sun image. Teachers reported that *"at the beginning several of them did not want to accept that what they were looking at was the sun. It was so different from their mental image of what the sun looks like"*.

C*: Wow!! Is it really the sun? I see something small, white and round. Let me wear them* [the filters] *once more to see if it really is the sun.*

C: *It is white and doesn't have rays around it. It is glorious!*

Some children, who been able to see the sun's contour clearly, started wondering whether what they were looking at was the moon:

C: *I am looking at the sun. But is it really the sun? It doesn't have rays around it and looks like the moon*. [Takes the filters of for a moment and puts them back again], *Yes it is the sun.*

C: *I see the sun. It looks like the moon. It is totally round, just like a white ball. Dear, how much I like it!*

At the end children drew representations of the sun. They pictured it white and the surrounding space dark, just as they saw it through the filters.

During the observations, children used the words round, circle, sphere and ball to describe the shape of the sun. Teachers recorded children's reactions and terminology and used them as a starting point for discussions regarding the shape of the sun. They also showed the children a flat circle and a ball and had them identify the similarities and the differences. During these discussions, children who used the word circle were often corrected by some peers: *"You don't say it right. It is a sphere"*.

The children also reported their night observations of the shape and colour of the moon. Some of them had kept a diary with drawings and written text, often dictated to their parents as illustrated by: *"Tonight the moon is very bright. It is half. The sky is very dark blue. There are clouds passing in front of the moon which look like smoke".* And a few days later: *"Today the moon is much bigger. It is white and round. It is just like a white ball".*

When teachers asked pupils to compare the shape of the sun as it looked through the filters with that of the full moon, children easily identified similarities between the two bodies regarding their shape.

C: *They are both spheres*

C: *Well, I was telling my mummy that even when you see the moon looking like a slice or half a circle, it really is a sphere too* [meaning that the other one is the sun].

One of the teachers, in her report, writes: *"In whole-class discussion children with one voice said that both bodies look alike and are spheres".*

These results indicate that the pupils were able to observe the sun and moon carefully and at least begin to appreciate that they are both spheres.

b) Understanding the apparent flatness of the Earth

The children's drawings indicated that initially they had one of three views:

i) The flat Earth

C: *I drew it as I see it when I go out*

C: *I cannot see the whole earth, but only where I stand and there it is straight* [meaning flat]

ii) The dual Earth: a flat earth and a spherical earth were drawn on the same picture

C: *There is a 'straight'* [flat] *earth and a spherical. We live on the 'straight'.*

iii) The spherical Earth

To introduce the spherical shape of the earth teachers used three pictures: a picture of the earth as it looks from space explaining that *"this is how one would see it if one could look at it from a distance as the astronauts can"*, a picture of the full moon and a picture of the sun as they had seen it with the filters. When the shapes of these celestial bodies were discussed in comparison to each other, the children identified their resemblance:

C: *Our earth is round*

C: *The shape of the moon is round*

C: *The sun is also round, just like the moon*

The teachers pointed out: *"We are very small and the earth is very big. We are standing on it and so we cannot see the whole earth as we would be able to see it if we were in space, far away from it. We can see only a small part of it and this is why we think it is flat – it looks flat to us"*. This concept was also dealt with in the first episode of the video. Children were invited to follow a group of astronauts on their trip in space. Teachers played the episode at least twice, freezing it at crucial points in order to give children the chance to observe and comment on them:

C: *Look it is getting smaller and smaller* [talking about things on the ground]

C: *Wow!! It is going up in the sky*

C: *Not in the sky, in space*

C: *Look, it* [the earth] *is becoming round*

C: *There, now it is completely round*

C: *Yes, it was straight* [means flat] *and then it became round.*

And after a while during the spaceship's return:

C: *Now that it* [the spaceship] *is coming closer it is becoming straight* [flat] *again.*

Later, when teachers invited children to draw representations of the earth, the majority of them pictured it spherical. Teachers then probed children's ideas:

T: *If we go outside and look around are we going to see the earth spherical like you made it in your drawings?*

C: *No, only when you see it from space it looks spherical*

C: It is round [making the shape of a sphere with his palms] *but to us it looks flat.*

C: *The earth is round like a ball. But it is flat here, where we stand* [hitting the ground with his foot].

These findings show that the children initially identified the resemblance of the shape of the earth, as this is seen from space, with those of the sun and moon (already appreciated by them as spherical). They then observed the flat earth gradually changing to spherical when the observer moved away from the ground and back to flat when approaching it, and begin to understand that its flatness is only apparent.

c) Earth's position and movement in the solar system

The concepts of the earth's movement and position in the solar system in relation to the sun, moon and the other planets were also dealt with in the first episode of the video, in which the observer initially watches the earth moving around the sun and then the planets, and among them the earth, in their respective positions, performing their motion around the sun. After the screening of the video the teachers held whole class discussions during which the children dramatized the earth's movements: "*Thomas was the sun and Eugenia was the earth. She turned around herself and moved around Thomas, the sun*".

Later children drew representations in which they sketched the orbit of the earth with respect to the sun. In some drawing the whole solar system is pictured (Figures 1 and 2) and in others only the three bodies – sun, earth and moon (Figure 3).

Insert figures 1, 2, 3 about here.

Drawings such as the one shown in Figure 2 were criticized by the other peers for giving the sun an anthropomorphic appearance.

Graphical representations and dramatizations reveal that children were able to form the notion of how the solar system is structured and most importantly of the position and of the movement of the earth in relation to the sun.

d) Explaining day and night

Describing the changes of light intensity on the earth over 24 hours, children gave mainly two different explanations about this phenomenon. One of them attributes the phenomenon to the variation of the sun's 'strength':

C: *Because at the beginning the sun is not very strong and then it becomes stronger, but then, when the day passes, it loses its strength*

The other to the sun's motion in the sky:

C: *Because the sun moves in the sky. Slowly he goes higher and higher and then slowly he goes away*

When teachers asked children explicitly *"why we have day and night"* most of them, additionally to those reported above, gave explanations such as:

C: *So we can sleep*

C: *Because the sun goes to another country*

C: *Because the earth rotates around the sun, and when the sun lights it has day and when it doesn't light it has night*

Few children gave explanations of the following type:

C: *The earth turns around itself and only on one side is dawning. The other side has night*

Children's ideas were discussed in whole class.

To initiate children to the concept of the earth's rotation on its axis, in some schools, teachers had children play with a spinning top and watch its motion.

The concept of the earth's rotation on its axis was dealt with in the second episode of the video, in which, as noted earlier, the two movements of the earth are introduced successively starting with the earth's rotation on its axis and followed by the revolution of the rotating earth around the sun. The teachers played the episode twice, freezing it at crucial points and used questions to focus children's attention:

T: *Watch, is the whole earth lighted?*

C: *Only the part that the sun's light falls on is lighted*

T: *What about the side that does not face the sun?*

C: *This is dark*

C: *The light goes only on the part that is opposite the sun, the other half has night.*

To investigate 'how night will come in a place that has day', teachers provided children with globes and torches or with models of the sun-earth system and had them work in small groups (Figure 4).

Insert Figure 4 about here

Most of the groups presented and explained their findings in class. Below is one of the most accurate presentations:

"The earth turns around itself [the group shows how]. *The place which is opposite the sun has day. But it* [the earth] *turns* [they show the movement], *the place that has light 'leaves' and goes in the back. It is not opposite the sun any more and so it has night. Afterwards,* [they continue rotating the globe] *it comes back and is again opposite the sun and has light again. It becomes day again"*.

Children drew or used collage in their representations of the phenomenon. In a large proportion of children's work the part of the earth that is not facing the sun is coloured black while the one facing it is coloured with different bright colours (see Figures 5 and 6).

Insert Figures 5, 6 about here

The above reported findings indicate that children had the chance to observe and discuss the effects of the axial rotation of the earth. Their graphical representations and their explanations of them reveal that they have understood where a place should be positioned in relation to the sun in order to have day or night. In their investigations children had the chance, using the concrete 3-D models, to reproduce the movements of the earth observed in the animated event and ascertain for themselves the effects of the rotation on its axis. Children's presentations show that, at least at the level of models, they had understood the process of how and why day and night alternate in a place.

Results from teachers' field notes

Teachers' field notes showed that, long after the intervention, pupils enacted and recalled the activities for themselves, either when peer tutoring (they were observed explaining earth's movements to newcomers in the class) or in other activities throughout the new school year:

We were discussing about seasons when the subject of the earth's movements came up. My pupils from the previous year started explaining that the earth makes two movements. They kept on stressing it over and over again, as if they wanted to make it believable to the other pupils that the earth, apart from moving around the sun, makes turns, as they called it, around itself, and continued reminding everybody of this movement during the whole discussion.

6. Post-instructional assessment results

In all schools, both phases of the assessment were carried out at least two weeks after the end of the assessed activities. Teachers audio-recorded and photographed the assessment for each individual child. The data were analysed by the researcher. The analysis gave results for four different issues indicated by the design of the post-instructional assessment (see section 3.5.): (1) Shape of the sun and the earth, (2) Earth's movement around the sun (movement a), (3) Earth's movement around its axis (movement b) and (4) Day/night cycle. The results indicated that:

In the first phase, 92% of the 104 children assessed responded correctly by modelling earth (with blue play-dough) and sun (with yellow play-dough) as spheres while 8% of them modelled the earth as flat and the sun as spherical. The 92% of the children who modelled earth and sun as spheres included a few children who moulded the earth a little larger than the sun. These came from a school in which there was no discussion of the relative sizes of the celestial bodies.

A percentage of 89.4 correctly showed movement (a) by rolling the blue sphere around the yellow and 85.6% correctly showed movement (b) as well. One of the children belonging to the latter percentage is shown in Figure 7.

In their explanations of movement (b) children used interesting expressions like *"The earth turns around itself like a ballet dancer"*.

Some of the children wanted to show the movement of the moon as well.

C: [After he had shown the two movements of the earth] *Teacher I want to show the moon too*

T: *OK you can take a piece of play-dough to make the moon*

[The child chooses brown play-dough, constructs a ball noticeably smaller than the earth, and places it next to the earth].

T: *Can you show me now how the moon moves?*

C: *Yes like that, around the earth* [rolls the brown ball around the blue one]. *But I cannot do all of them* [the two movements of the earth and that of the moon] *at the same time.*

Insert Figure 7 about here

In the second phase 99 children were assessed, since there were absences in some of the schools. Regarding the phenomenon of day and night, 13.2% gave oral explanations that can be characterized either as 'egocentric' (e.g. the night comes for us to sleep) or 'irrelevant' (e.g. if we didn't have day and night, astronauts wouldn't go to see the sun) and answers that attributed the phenomenon to the rotation of the earth around the sun. 86.8% of the children assessed responded correctly. In the initial part these children placed the picture of the sun in the correct position and then showed correctly how the night will come in a place that has day and confidently showed the movement of the earth that results in the alternation of day and night. An example of the explanations children gave is the following: *"The place now has day because it is opposite the sun and it is lighted.* [The child rotates the globe] *now the place has night because it is not opposite the sun and it is not lighted".*

It should be noted that the percentage of children whose answers were not considered 'correct' included children who did not respond, either by not answering or by not demonstrating.

The percentages of the answers characterized as correct for both phases of the assessment are presented in Table 1.

Insert Table 1 about here

7. Discussion

The findings of the analysis of the classroom experiences provide an insight into how the children gradually proceeded in the realization of the shape of the earth, articulated an understanding of the position and movements of the earth in the solar system in relation to other celestial bodies, and clarified their ideas of how day and night alternate, comprehending this phenomenon as the result of the rotation of the earth on its own axis.

The results of the post-instructional evaluation indicate high percentages of awareness among the pre-primary children of the concepts and events dealt with by the activities. Additionally, children's enacting and peer tutoring long after the activities indicate storage of the new knowledge in the long-term memory and easy retrieval of it.

Children's awareness and acquisition of the new knowledge are also clearly reflected by all the types of representations they used during the stages of the instructional procedures and the post-instructional evaluation: their verbal descriptions and/or explanations, their gestural representations, their concrete 3D material model constructions and their graphical representations (Boulter & Buckley, 2000) of the earth's shape, its place in the solar system and both of its movements within it. This latter type of representations in particular, i.e. the children's drawings, such as those presented in the figures accompanying this work, when examined in comparison with the aspects of representations shown in the video episodes, indicate significant similarities between children's models and the events and phenomena represented in the video (Boulter, 2000). The children's gains of knowledge and understanding are also revealed by their narrative explanations and descriptions of the alternation of day/night phenomenon, as well as by aspects of their interaction in their communication with peers and teachers (see also Boulter, 2000; Boulter, Prain and Armitage 1998).

The encouraging results of the present learning study can be attributed to a combination of different factors, each of which we consider to have influenced the others, which may have contributed significantly to the success of the present intervention. More concretely these factors can be related to:

The structuring and sequence of the units: Each unit was built with specific learning objectives. Concepts were organised and treated in specific sequence that had the potential to give meaning to events and phenomena, giving precedence to those considered key concepts.

The design of the activities: Taking into consideration findings of different research studies enabled us to avoid factors that might have imposed unnecessary cognitive load on children of these early ages and factors that might have been confusing. These factors could be potential constraints on clarifying ideas about particular phenomena. With regard to the teaching strategy suggested in the activities, two aspects may be considered as of crucial importance: the proposed continued use of children's mixed mode representations after each new experience they were exposed to, and the consistent and systematic use of whole class discussions throughout the intervention. The latter was thought to create the potential on the one hand for clarifying thoughts through discussion of ideas and on the other for continuous testing of the expressed by each child models against those of the others and against the actual events, providing opportunities for producing acceptable models (Boulter *et al.*, 1998).

The specifically tailored conceptual tools: The video, in which a combination of representational modes was used, gave children a chance to observe animated real events and phenomena and compare and relate them to their direct observations of the real world.

The instructional handling of the model activities by the teachers in the science classroom: The findings of the analysis of the classroom data reveal that the teachers have followed closely the procedures described in the model activities. However, in order to conduct the lessons and engage the children in the activities, the teachers had to decide for themselves certain important dimensions of teaching. A significant variable that often characterizes teaching style is the teachers' questions (Harlen, 1996). During the implementation of the activities teachers used a series of linked questions, a small sample of which is provided in the present paper. These were used in different aspects of their instruction, to lead children or, in the discursive interactions, to question what they were thinking and what they believed, encouraging them to make the basis for their explanations more explicit (see also Boulter *et al.*, 1998). Another interesting initiative taken by some teachers was the use of orrery models such as the spinning top, targeting children's initiation to the idea of earth's rotation on its axis and the mechanical sun-earth system shown in the picture in Figure 4. This last, although its concrete elements were not in the correct spatial and dimensional relationship (Buckley and Boulter, 2000), constituted a useful tool for children's investigation of the alternation of day and night since at the time of its use they had already enough knowledge and experience of the differences between 'real' and 'model' not to be confused (see design of the activities).

The teachers' ways of handling the activities in the classroom can be attributed to the manner in which their preparation was conducted. Their participation in group work where they had the chance to exchange ideas, answer personal questions and jointly find solutions to problems assisted them in effectively adapting the model activities to the particularities of their classes. Group work made teachers' class work easier and more effective, and enabled them to create interesting learning situations for the children as well as a classroom atmosphere and conditions fostering children's motivation and interest for the subject. This and children's learning results are in turn two of the factors that played a crucial role in raising teachers' enthusiasm and in making their systematic and long-term participation in the group possible.

The selected approach to learning: Children's engagement in multiple science activity structures including observing, investigating, manipulating models that helped them explain the phenomena they observed, representing and communicating. The interactions between children and between children and teachers that were favoured by the instructional practice adopted and the discussions and classroom talk that, as was noted above, was an invariable part of all the activities helped them not only to clarify their ideas but also to exhibit infrequently mentioned attitudes such as curiosity, respect for evidence and 'search for truth' (Harlen, 1992). Another factor that may have supported children's learning was *the involvement of the family*. The extension of the activities to the home gave children more opportunities to communicate science to their parents (Fleer, 1996), when carrying out the night observations and being helped in formulating their report. The latter is important for children's better understanding. As Michaels, Shouse & Schweingruber (2008) note, children can learn about the world by talking with their families and apply their understanding when they try to describe their experiences or persuade other people about what is right or what is wrong.

The methodology adopted for the development of the activities: The collaborative development of the activities by a researcher/facilitator specialist in the subject and early-years teachers and the use of action research processes proved very useful in shaping the activities and for optimising classroom practices. Action research is considered by many researchers as one of the most useful ways of increasing the effectiveness of instructional treatment and informing the creation of effective instructional materials (e.g. Agan & Sneider, 2004; Sahasewiyon, 2004).

The existence of a well-documented teachers' guide that teachers could consult during practice each time they needed assistance concerning their knowledge of content or procedures. The need for a guide containing suggestions and explicit directions on how to develop and carry out science activities was stressed by the early-years teachers in a study investigating their self-perceived needs in science, who considered it to be a tool that would contribute to the improvement of their work in science (Kallery, 2004).

8. Conclusions and implications

The findings of the present study support the view that astronomical concepts and phenomena such as the sphericity of the earth and the alternation of day and night, which are considered difficult for very young children, can become more accessible if they are presented with resources, strategies and teaching styles that motivate them, arouse their interest and reduce their learning difficulties (Sharp, 1995; 1999).

The concepts, events and phenomena selected for study by the pre-primary children are considered by many researchers and educators to be of fundamental importance. As the treatment was successful both in making children aware of these fundamental concepts and events and for raising their motivation and interest for astronomy, a strategic placement of the tested intervention in the pre-primary school curriculum is worthwhile. This can be feasible, since the activities were implemented in public school classes and as a part of the regular preschool timetable, and is bolstered by the fact that the classes in which the units were implemented were composed of children of different social and cultural backgrounds, as most classes in Greek schools are nowadays. The strong links between early-years astronomy and other aspects of the curriculum are also worth exploiting (Sharp, 1995). Unfortunately it was not possible to explore the maintenance of the learning outcomes for the children of the kindergarten age group, since these children went on to primary school the following year. In Greece, primary school belongs to a different level of education from pre-primary school, and the two are completely separate. As noted earlier, only the pre-kindergarteners' awareness and understanding of the astronomical concepts and events treated by the activities were recorded by the teachers in the year that followed the activities, and these, as the findings of the analysis of their notes indicated, were quite encouraging. Nevertheless, this preschool level instruction should be followed at the immediately following age levels in primary school with units of gradually more advanced concepts, returning frequently to the children's ideas about how their understanding of the earth's shape and movements apply to new phenomena (see also Sneider and Ohadi, 1998).

The present study raises issues for further research. One issue that it would be valuable to investigate is the extent to which changing one or more of those factors that were considered to have contributed significantly to the success of the present intervention may alter the reported results. For example, the early-years teachers who implemented the activities had undergone a special preparation. It might be interesting, in follow-up studies, to include pupils whose teachers had read the teachers' guide prepared in our study but who received no special training.

Finally, within the limits of the present study, the current outcomes suggest that the approach outlined in this paper could have a wider application for the initiation of very young children to fundamental concepts and phenomena of other areas of science, such as phenomena related to the properties of matter, for instance floating and sinking, thermal phenomena and phenomena related to gravity and motion, which our action research group is currently working on.

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Appendix

The narratives of the video episodes

Episode 1.

The day the spaceship was going to be launched, from the base beside the lake, Paul got into his boat and went to watch. The astronauts waved to the people and entered the spaceship. Soon the spaceship lifted off, and as it went up the astronauts could see Paul getting farther and farther away.

From space the astronauts could still see the earth. It looked like a sphere that was rotating.

They could see other things, too. They could see the moon turning around the earth and the earth turning around the sun.

Looking beyond the earth the astronauts could also see the other planets, which, together with the earth, were all rotating around the sun.

After a fascinating trip in space, it was time to return to earth. The day that the spaceship was going to land, Paul went back to the same place to watch. As the spaceship approached the earth, the astronauts could once again see Paul in his boat.

Episode 2.

The earth turns around on its own axis, like a spinning top. At the same time, it also rotates around the sun. The sun lights the places on the earth that are facing it. These places have day. When these places have day, the places on the other side of the earth, which are facing away from the sun, have night.

Episode 3.

The earth rotates around the sun. At the same time, it turns around on its own axis, like a spinning top. The sun lights the places on the earth that are facing it. These places have day. When these places have day, the places on the other side of the earth, which are facing away from the sun, have night.

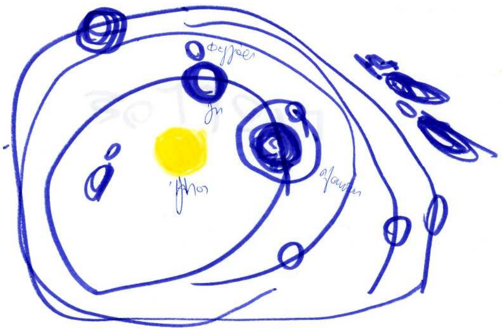

Figure 1.

Figure 2.

Figure 3.

Figure 4.

Figure 5.

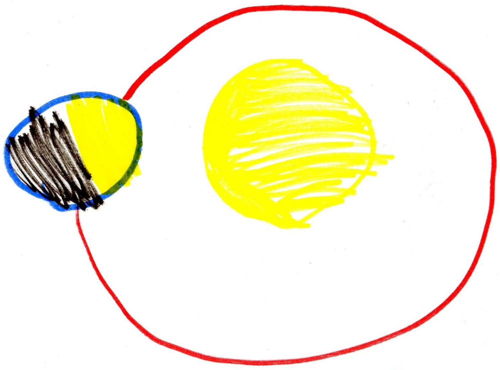

Figure 6.

Figure 7.

Figure Legends

Figure 1. The solar system. Names of planets were written by teachers as dictated by the children.

Figure 2. The solar system. The moon is placed next to the earth. The notes on the picture dictated by the child and written by the teacher read: "The earth rotates around itself and around the sun. The moon rotates around the earth".

Figure 3. Sun, earth and moon and the orbits of the last two.

Figure 4. Investigating the phenomenon of day and night.

Figure 5. Relative positions of sun and earth: places facing the sun have day.

Figure 6. The explanation given by this child was: "The earth turns around the sun and around itself. The places that are opposite the sun have day".

Figure 7. This boy used his middle finger to rotate the blue ball around itself while rolling it around the yellow one (sun) which he holds still.

Table 1. Percentage of children who responded correctly in the assessment tasks

	Shape of the earth and the sun	Movement (a)	Movement (a) and (b)	Day/Night
Number of students assessed	104	104	104	99
Number of 'correct' answers	96	93	89	86
Total % of 'Correct' answers	92.3 %	89.4%	85.6%	86.8 %