Learning and Instruction 15 (2005) 333–351

Learning and Instruction

www.elsevier.com/locate/learninstruc

Reconsidering the role of artifacts in reasoning: Children's understanding of the globe as a model of the earth

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Abstract

This experiment investigated the effect of the presentation of a globe – the culturally accepted artifact representing the earth – on children's reasoning in elementary astronomy. Forty-four children from grades 1 and 3 were interviewed individually. First, the children were asked to make their own representations of the earth (i.e., drawings and play-dough models) and to indicate where people live on the earth. Then, the same children were presented with the globe and were asked to answer another set of questions regarding the shape of the earth and the areas where people live. The results showed an increase in the frequency of correct responses with the presentation of the globe, but also a decrease in the overall consistency of responses. Only some (the older) children could profit from the presence of the artifact to construct an internally consistent scientific model of the earth. Many children employed a mixed way of responding, sometimes basing their answers on the externally provided model and sometimes on their prior knowledge. These latter children did not seem to be aware of what they were doing. It appears that in the absence of an external, cultural model, children can form internal representations which they can distort in ways that make them consistent with their prior knowledge. But, when the cultural artifact is

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0959-4752/$ - see front matter
doi:10.1016/j.learninstruc.2005.07.004

present, such distortions are not possible with the result that children end up with internally inconsistent patterns of responses.

Keywords: Cognitive development; Development of reasoning; Constructivism; Socio/cultural approaches; Science learning

1. Introduction

Cognitive approaches to learning and instruction have been the subject of criticism by socio/cultural theorists for a number of years now (Lave, 1988; Greeno, 1997). While most educators agree that some kind of synthesis is required (e.g., Anderson, Greeno, Reder, & Simon, 2000; Vosniadou, 1996), deep differences continue to exist. One of these differences centers around what may be called "the object of analysis" in studies of human thinking and learning. Cognitive approaches focus on individuals' assumed mental representations and analyze how such representations are formed, how they are influenced by prior knowledge, and how they constrain the acquisition of new information. Socio-cultural approaches, on the other hand, advocate a discursive approach in which the object of analysis is the situated practice of people communicating using specific physical artifacts. While many socio-cultural theorists do not deny mental representations altogether, they still doubt their usefulness as an explanatory construct (e.g., Lemke, 1990; Saljo, 1996; Wertsch, 1998).

We believe that this debate is in many respects misguided since both individual and social forms of cognition are important for a theory of learning and instruction (Vosniadou, 1996). More specifically, we believe that while the physical properties of the brain prepare a child's cognitive and language development, conceptual categories and language are acquired through social participation in social contexts. Acknowledging the social nature of the acquisition and the use of knowledge does not, however, imply that we should deny individual experiences or individual representations. Knowledge must be represented in some form in the memory system, be it in the form of propositional representations or in neural networks, with the possibility that these representations will be activated, reconstructed, or recalled in particular situations to accomplish cognitive tasks. Such prior knowledge can also influence the way in which children learn to use cultural artifacts. In other words, we hypothesize that learning how to use a cultural artifact is not a process of direct cultural transmission but a constructive process during which the cultural artifact may be distorted to fit what is already known.

Recently, the debate between cognitive and socio/cultural approaches has been transported in the area of elementary astronomy, or more specifically the study of the development of children's reasoning about the earth and gravity. A series of studies by Vosniadou and her colleagues (Vosniadou, 1994a, 1994b; Vosniadou & Brewer, 1992, 1994) have shown that elementary school children have difficulty understanding the scientific concept of the earth as a rotating sphere with people living all around it on the outside. For example, in the cross-cultural studies reported by Vosniadou (1994a), many children said that the earth is round and constructed a spherical play-dough model to represent it, but later, the same children, stated that people cannot live at the "bottom" of the earth because they will fall off.

Detailed examinations of the responses of these children showed that a great deal of the apparent inconsistency could be explained by assuming that the children constructed and used in a consistent fashion a mental representation – a mental model – of the earth other than the spherical model. Five alternative models of the earth were identified in the U.S. data: the *rectangular earth*, the *disk earth*, the *dual earth*, the *hollow sphere* and the *flattened sphere*. These alternative models of the earth were interpreted to be synthetic models, because they could all be derived from a synthesis of the scientific information that the earth is a spherical, rotating, astronomical object and an initial concept of a flat, motionless, supported earth, as a physical object, with the sky and solar objects located above its top. Subsequent cross-cultural research supported the finding that children assimilate the scientific information to their prior knowledge about the earth constructing alternative models which reveal the presuppositions of flatness and support, but which are also influenced by native culture (Vosniadou, 1994a). For example, children in India constructed spherical earths that were supported by an ocean of water that were consistent with local cosmological beliefs. Similarly, children from a Samoan village used their play-dough to form a horizontal ring to depict the earth, thus seemingly capturing salient aspects of the circular organization of space in their every-day environment (see Vosniadou, 1994a; for a detailed discussion of the cross-cultural differences).

Recently some researchers have challenged the above findings according to which children distort the scientific information about the earth (Ivarsson, Schoultz, & Säljö, 2002; Nobes et al., 2003; Schoultz, Säljö, & Wyndhamn, 2001; Siegal, Butterworth, & Newcombe, 2004) claiming that Vosniadou and her colleagues have not paid attention to socio/cultural influences on the development of children's understanding of elementary astronomy, and, particularly, that they have ignored the role of cultural artifacts. In two experiments that investigated elementary school children's reasoning about the earth and gravity using physical artifacts such as a globe and a map, Ivarsson et al. (2002) and Schoultz et al. (2001) argued that young children had sophisticated knowledge of the physical tools provided and could accomplish complex reasoning about the earth and gravity using them. More specifically, Schoultz et al. (2001) found that when their participants had access to a globe, they could all identify the globe as a representation of the earth, they all considered that people could live all across the earth without falling off, and 77% could refer to gravity as an explanatory concept. They concluded that the experiments by Vosniadou and colleagues underestimated children's knowledge, mainly for two reasons: first, because they did not use a physical tool, a concrete artifact. The presence of the globe as a "shared object of attention", they argued, allows children "to reflect while talking by using (the physical tool) as a prosthetic device for thinking" (p. 115). Second, because they did not pay attention to the "specific utterances the children used, in their concrete settings, using the resources available to them" (p. 45).

We agree with Schoultz et al. (2001) that the presence of the globe can facilitate children's thinking because it can, in fact, be used as a prosthetic device to help children think, fulfilling in this way its role as a cultural tool. The use of artifacts, however, is only one-way to investigate children's thinking and not the only ("correct") way. Investigating children's thinking without the use of cultural artifacts is equally legitimate and important, indeed necessary, in order to form an understanding of the different ways of reasoning that can be employed in different contexts.

As we argue in Vosniadou, Skopeliti, and Ikospentaki (2004), there can be different 'modes of knowing and ways of reasoning' in the process of learning science, from those that require students to generate their own models and reason on the basis of them, to those that require the simple manipulation of an externally given model. The presence of the globe imposes on children the culturally accepted scientific model of the earth in space, and forces them to reason on the basis of this external representation. It is clear that in this condition we would expect an increase in the number of the scientifically correct responses.

In our experiments so far, we have not been interested in finding out what children do when they are simply exposed to the scientific information about the earth and the day/night cycle. Rather, we have been interested in finding whether they fully understand this information. This is why we challenge them with open-ended, generative questions, which require them to make productive use of the scientific information to which they have been exposed, unaided by the use of external representations. We are interested in investigating children's understanding of science concepts, because we know that children often memorize science information superficially, or use it in limited contexts only − a phenomenon known as *inert knowledge* (Bereiter, 1984; Bransford, Franks, Vye, & Sherwood, 1989). Science educators have also noticed students' higher performance in tests that resemble the information taught compared to their performance in exams that pose critical questions that require generative problem solving (see Feinman, 1997). The presence of a globe simplifies children's reasoning about the earth because it communicates the presupposition that the earth is spherical, and because the children can rely on the cultural artifact to provide the expected, scientifically correct, responses.

Nevertheless, we claim that learning how to use an external cultural artifact like a globe is not an act of simple and direct cultural transmission, but a constructive act of interpretation, where the external model can still be distorted if it comes in conflict with what is already known. For this reason, we predict that some children will have difficulties reasoning about elementary astronomy, even in the presence of the globe. From our point of view, the critical question is to find out what are the sources of difficulty in students' understanding of science concepts and of science artifacts and the reasons behind the formation of misconceptions (e.g., Novak, 1987), rather than denying the existence of such difficulties.

On the issue of discourse analysis, we agree with Schoultz et al. (2001) that it is important to pay attention to the specific utterances made by people in a concrete setting, to fulfill particular purposes. Indeed, the importance of paying attention to the communicative situation in experiments, particularly with young children, is not a prerogative of the socio/cultural approach but has also been noted in the context of developmental research in the cognitive tradition (e.g., Siegal, 1997). Nevertheless, we find it difficult to agree with Schoultz et al. (2001) that the results of our astronomy experiments were produced because of our failure to pay attention to the specific utterances produced by the children in our experimental settings. Implicit here is the supposition that some kind of bias in our methods of questioning produced the alternative models of the earth. However, as we noted also in Vosniadou and Brewer (1992), this type of bias is very implausible. There cannot be any implicit assumption in our open questions that could give rise to the range of alternative models of the earth that we obtained, with the probably exception of the flat earth model, which was adopted by only two children. On the contrary, there is plenty of room of question bias, given the inclusion of the globe, in the Schoultz et al. (2001) questionnaire, leading children to the adoption of the socially accepted spherical earth model.

Second, we find the methodology of discourse analysis rather limiting particularly in situations of reasoning about the physical world. When reasoning about the physical world it is often necessary to construct a mental model (i.e., an analog mental representation that preserves the structure of the referent) that encapsulates intuitive physical knowledge and use it to answer novel generative questions (see Vosniadou, 2001, for a detailed discussion of this issue). These models provide important information about children's prior physical knowledge that needs to be taken into consideration in the discourse analysis. In our studies, we ask children to construct models of the earth either in drawings or by using play-dough and we use the information these models provide, in addition to children's discourse, to understand their sources of difficulty with scientific concepts.

We believe that this type of "mindful" discourse analysis is a much better methodology for investigating learning and reasoning processes. After all, the psychological reality of mental representations has been demonstrated experimentally in many situations (e.g., Shepard & Metzler, 1971; Kosslyn, 1994), while experiments in cognitive neuroscience have recently provided evidence for their neurological reality as well (Richter et al., 2000; Richter, Ugurbil, Georgopoulos, & Kim, 1997).

1.1. The present study

The purpose of the experiment presented in this paper is to further examine how children's prior knowledge influences the way they use a cultural artifact – the globe – to reason about the shape of the earth. More specifically, we hypothesized that many of the children who have difficulties understanding the shape of the earth without the use of the globe will still have difficulties even with the globe present. We designed an experiment that provided us with information about children's knowledge about the earth, with or without the presence of a globe. Thus, in the first part of the present experiment, the children were asked to indicate verbally, in drawing, and in play-dough models, the shape of the earth and where people live. In the second part of the interview the children were presented with a globe and were told that this is the culturally accepted model of the earth. Then, they were asked a second series of questions about the earth and where people live. In the analysis of the data special attention was paid both to the specific utterances of the children in the context in which they were produced and to their representations of the earth, as these representations were revealed by their drawings and their play-dough models.

2. Method

2.1. Participants

Our sample consisted of 42 children, all students in a middle-class elementary school in Athens, Greece. Twenty students were from Grade 1, with ages ranging from 5 years and 6 months to 7 years (mean age, 6 years and 1 month) and the remaining 22 from Grade 3, with ages ranging from 7 years and 6 months to 10 years (mean age, 8 years and 5 months).

2.2. Procedure

The children were interviewed individually in a private room in their school by two experimenters. One of the experimenters conducted the interview while the other kept detailed notes and photographed children's models. The interviews lasted for approximately 20–25 min and were both audio-recorded and video-taped.

2.3. Materials

A questionnaire (shown in Tables 1 and 2) was constructed based on the original questionnaire used in the Vosniadou and Brewer (1992) study. In the first part of the questionnaire (Questions 1–8) we tried to determine as accurately as possible how the children represented the earth without the help of artifacts. This part included verbal questions (Questions 1 & 2), requests for drawings (Questions 3, 4 & 5), and the construction of play-dough models (Questions 6, 7 & 8). The children were given wood-colouring pens and felt-tipped pens to make their drawings and coloured play-dough to construct their models.

In the second part of the questionnaire (Questions 9–14), the drawings and play-dough models of the earth that the child had constructed were removed from the testing area and the child was presented with a 90 cm diameter globe. We were interested in finding out (a) whether the children would be able to reason with the globe in an internally consistent manner, and (b) if they had constructed an alternative model of the earth in Question Set I, whether they would be able to adequately justify the differences between their original representations of the earth and the globe in Question Set II.

Table 1
Question Set I: frequency/percent of responses in the various response categories *before* the use of the globe

Questions	Response categories	Grade 1	Grade 3
Q1(a): Can you tell me what is the shape of the earth? *Q1(b) (For round earth response only)*: If the earth is round, does it look like a circle or a ball?	(1) Round like a ball (2)[a]	7 (35%)	15 (68%)
	(2) Round like a circle (1)	10 (50%)	6 (27%)
	(3) Flat (0)	3 (15%)	1 (5%)
Q2: Here is the picture of a house. This house is on the earth, isn't it? How come here the earth looks flat but before you said it is round?	(1) The earth looks flat because it is very big, or because it has many flat pieces on it, or looks flat from space (2)	4 (20%)	7 (32%)
	(2) It is flat inside, or flat where people live (1)	1 (5%)	5 (23%)
	(3) I made a mistake. The earth is flat (0)	1 (5%)	–
	(4) Was not asked, because the child had said the earth is flat (0)	3 (15%)	1 (5%)
	(5) Unclear response, or Do not know (0)	11 (55%)	8 (36%)
Q3: Could you make a drawing of the earth?	(1) Circle (2)	15 (75%)	21 (95%)
	(2) Square/rectangular (0)	4 (20%)	1 (5%)
	(3) Circle inside a square (0)	1 (5%)	–
Q4: Show me where you think the people live on the earth.	(1) Everywhere outside the circle and/or everywhere inside the circle (2)	12 (60%)	13 (59%)
	(2) Only on the top of the circle, outside (1)	2 (10%)	–
	(3) Inside the circle at the center, or at the bottom of the circle (1)	3 (15%)	6 (27%)
	(4) On the top and on the bottom of the circle, outside (1)	–	1(5%)
	(5) On another earth (1)	–	2 (9%)
	(6) On flat earth (0)	3 (15%)	–
Q5: Show me where you think the sky and the stars are located.	(1) All around the circle, outside (2)	2 (10%)	8 (36%)
	(2) Only above the top of the circle, outside (1)	9 (45%)	8 (36%)
	(3) On the top of the circle, inside (1)	5 (25%)	4 (18%)
	(4) Between the two earths (1)	–	1 (5%)
	(5) Above a flat earth (0)	4 (20%)	1 (5%)
Q6: Can you make a model of the earth using this play-dough?	(1) Sphere (2)	2 (10%)	13 (58%)
	(2) Elliptical sphere (2)	1 (5%)	–
	(3) Vertical ring (1)	5 (25%)	2 (9%)
	(4) Horizontal ring (1)	4 (20%)	4 (18%)
	(5) Disk (1)	4 (20%)	1 (5%)
	(6) Flattened sphere (1)	–	1 (5%)
	(7) Flat/square (0)	4 (20%)	–
	(8) Uncertain model (0)	–	1 (5%)

(*continued on next page*)

Table 1 (*continued*)

Questions	Response categories	Grade 1	Grade 3
Q7: Show me in your model where you think the people live.	(1) Everywhere outside the sphere, or everywhere outside and inside the sphere (2)	5 (25%)	6 (27%)
	(2) Only on the top of the model (1)	6 (30%)	5 (23%)
	(3) Inside the model (1)	6 (30%)	7 (32%)
	(4) On the top and on the bottom of the model, outside (1)	–	1 (5%)
	(5) On the top part of a flat model (0)	3 (15%)	2 (9%)
Q8: Show me in your model where you think the sky is located.	(1) All around the sphere, outside (2)	2 (10%)	7 (32%)
	(2) Only above the top of the model (1)	9 (45%)	9 (41%)
	(3) Inside the model (1)	6 (30%)	4 (18%)
	(4) Between the two earths (1)	–	1 (5%)
	(5) On top part of a flat model (0)	3 (15%)	1 (5%)

[a] Scoring (2) indicates agreement with the scientifically expected answers, (1) indicates an alternative model of the earth, and (0) indicates a flat model.

2.4. Scoring

Children's responses to each question were categorized in ways that made it possible to retain information that could be diagnostic of alternative representations of the earth. Two of the three authors of the paper scored half of the data independently. Then they met and agreed on a scoring key. Using the scoring key, they scored independently the remaining half of the data, met again, discussed the scoring and revised the scoring key as needed after agreement had been achieved. Subsequently, the third author used the scoring key to independently score the same data. At the end the whole team met to discuss any disagreements. The agreement between the initial scoring of the two researchers and that of the independent scoring of the third author was very high (96%). All disagreements were discussed until a common score had been achieved on all the items.

3. Results

3.1. Analysis at the individual question level

3.1.1. Question Set I: before the use of the globe

Table 1 shows the frequency and percent of responses in the various response categories in Question Set I. Most children said the earth is "round" in Q1a, but 50% of the 1st graders thought that the earth is "round like a circle" and not "round like a ball" in response to Q1b. Only a few of the children who said that the earth is round in Q1 could adequately explain the appearance-reality conflict Q2 (20% of the 1st graders and 32% of the 3rd graders). When asked to draw the earth almost all of the children drew a circle and only four 1st graders (20%) drew a square/rectangle

Table 2
Question Set II: frequency/percent of responses in the various response categories *after* the use of the globe

Questions	Response	Grade 1	Grade 3
Q9: Here is a globe. Why does the earth appears to be round here but before you made it as……? *(use description of child's model)*	(1) The child was not asked, because he/she had made a ball (2)[a]	3/20 (15%)	12/22 (54%)
	(2) I have made a mistake. The earth is round (2)	5 (25%)	1 (5%)
	(3) The earth is round, but it looks flat. I could not make it round with the play-dough (2)	4 (20%)	5 (23%)
	(4) People make the earth spherical in order to represent all the countries (1)	2 (10%)	1 (5%)
	(5) There is another earth, where people live and it looks like my model (1)	–	1 (5%)
	(6) The earth looks like the one I made (1)	2 (10%)	–
	(7) Do not know (0)	4 (20%)	2 (9%)
Q10: If you walked for many days in a straight line, where would you end up? Is there an end/edge to the earth?	(1) No, there is no end/edge (2)	7 (35%)	15 (68%)
	(2) Yes, there is an end/edge (0)	13 (65%)	7 (32%)
Q11: *(Asked on for the children said that there is an end/edge to Q10)* Could you fall off that end/edge? Why/Why not?	(1) Not asked (2)	7 (35%)	15 (68%)
	(2) No, because of gravity (2)	1 (5%)	–
	(3) No, because of other (unscientific) reasons (1)	–	2 (9%)
	(4) Yes (0)	12 (60%)	5 (23%)
Q12: Can people live down here, at the South Pole?	(1) Yes (2)	16 (80%)	18 (82%)
	(2) No (0)	3 (15%)	4 (18%)
	(3) Do not know (0)	1 (5%)	–
Q13: If there was a little girl who lived down here, and she held a ball and the ball fell from her hands, where would the ball go? Show me.	(1) Towards the earth (2)	12 (60%)	14 (64%)
	(2) Outwards from the earth (0)	5 (25%)	4 (18%)
	(3) Not asked (the child had said "no" to Q12) (0)	3 (15%)	4 (18%)
Q14: This globe is supported by something. Do you think that there is something that supports the earth?	(1) No (2)	13 (65%)	19 (86%)
	(2) Yes (0)	6 (30%)	3 (14%)
	(3) Do not know (0)	1 (5%)	–
Q15a: Finally, what do you think is the real shape of the earth?	(1) Retains initial model (sphere)	14 (70%)	19 (86%)
	(2) Retains initial model (alternative)	12 (60%)	6 (27%)
	(3) Changes initial model	6 (30%)	3 (14%)
Q15b: *(If the child said that he/she had changed model)* Make a model of the earth as you now think it is.	(1) Sphere	6/6 (100%)	3/3 (100%)

[a] Scoring (2) indicates agreement with the scientifically expected answers, (1) indicates an alternative model of the earth, and (0) indicates a flat model.

earth. The majority of the children drew the people inside the circle. Only a few of the children thought that people live everywhere on the sphere, outside. Only 10% of the 1st graders and 36% of the 3rd graders drew the sky and the stars all around the circle. Also only 10% of the 1st graders constructed spherical models of the earth using play-dough, in contrast to 58% of the 3rd graders. The remaining children constructed alternative models of the earth using play-dough. Most of the children thought that people live either above the top of the sphere (30% 1st graders and 23% 3rd graders) or inside the sphere (30% 1st graders and 32% 3rd graders). Finally, as with their drawings, very few children indicated that the sky and stars are all around the spherical model of the earth (10% 1st graders and 32% 3rd graders). Most of them thought that the sky was only above the top of their model.

Children's responses to the questions were marked as 2 for responses consistent with the scientifically expected answer, 1 for responses consistent with an alternative model of the earth, and with 0 for responses consistent with the model of a flat earth. A one-way ANOVA on these data showed main effects for grade ($F\,(1,40) = 5,867$, $p < 0.05$). As expected, the frequency of scientifically correct responses increased with age with the 3rd graders having a higher mean score compared to the 1st graders.

3.1.2. Question Set II: after the use of the globe

A similar method of scoring was followed for the second part of the questionnaire (Questions 9–15, Table 2). In this part of the interview, children's play-dough models of the earth were removed and the experimenter presented the globe. If the children had constructed an alternative model of the earth, the experimenter asked them to explain the difference between their model and the globe (Q9).

In response to Q9 five 1st graders and one 3rd grader immediately changed their responses and said "I made a mistake, the earth is round". The remaining children justified their models in different ways, as shown in Table 2. Some said that the earth is round but it looks flat, others that people live on flat pieces of land, and a few said that there is another earth that looks flat!

Q10 and Q11 asked children if there was an end/edge to the earth and whether they could fall off this end/edge. Most of the 3rd graders (68%) said that there was no end/edge to the earth, but only few of the first grade children (35%) thought so. The great majority of the 1st graders said that there is an end/edge to the earth (65%) and that one could potentially fall off this edge (60%) even with the globe present.

On Questions 12 and 13, there were practically no age differences in children's responses, contrary to all the other questions in the questionnaire where the older children gave more scientifically correct responses than the younger children. The majority of the children in both grades said that people can live "down here at the South Pole" in response to Q12 (80% of the 1st graders and 82% of the 3rd graders). In response to Q13, which asked children indicate the position of a ball that fell from the hands of a little girl living "down there" (at the bottom of the earth), most of the children responded correctly that the ball would fall on the earth, next to the little girl (60% of the 1st graders and 64% of the 3rd graders). It is interesting to note that many children bended and looked at the bottom part of the globe to make sure that there was a country "down there" before giving their response.

Most children said that the earth is not supported by something (65% of the 1st graders and 86% of the 3rd graders) in Q14. In Q15a and Q15b, which asked children to indicate again what they believed was the real shape of the earth, 10% of the first graders and 59% of the third graders, respectively, retained their initial, spherical model while 60% of the 1st graders and 27% of the 3rd graders retained their initial non-spherical models. Only six 1st graders and three 3rd graders changed their initial, alternative models to a spherical earth.

The response categories in the second part of the questionnaire were scored in ways similar to those for the first part and were subjected to a one-way ANOVA. The results showed main effects for grade ($F\,(1,40) = 5{,}043$, $p < 0.05$), with the 3rd graders having a higher mean score than the 1st graders.

3.1.3. Question Sets I & II

The total scores of Question Set I and Question Set II were subjected to a two-way mixed ANOVA with grade as a between subjects factor and question set as a within subjects factor. The results showed main effects for grade [$F\,(1,40) = 8{,}304$, $p < 0.01$] and for question set [$F\,(1,40) = 11{,}575$, $p < 0.05$]. As shown in Fig. 1, Question Set II produced a statistically significant higher mean score of responses than Question Set I, while the grade differences were retained. This result indicated that the presence of the globe resulted in increases in the frequency of correct responses particularly for the older children.

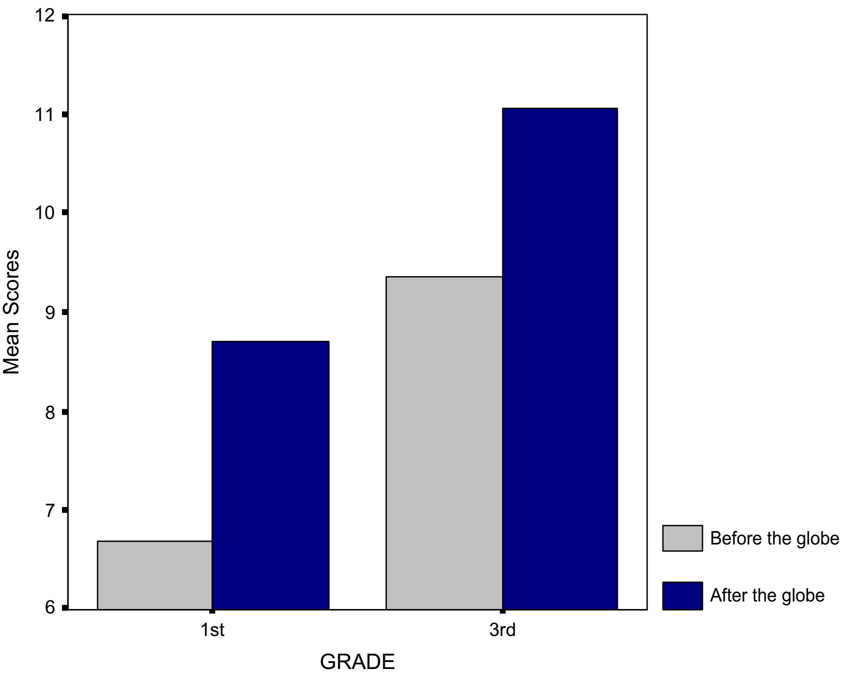

Fig. 1. Mean scores of responses as a function of grade and question set.

3.2. Analysis at the overall level

3.2.1. Internal consistency

Children's responses were categorized again, this time in earth shape models. The categorization was based on the internal consistency of their responses in Question Sets I & II independently, using the criteria described in Table 3. The criteria for placement in a model category were defined on the basis of prior research, and *not* on the basis of the obtained responses. The scoring was based both on children's verbal responses and on their representations (i.e., drawings and play-dough models), and particular attention was paid to the internal consistency of responses.

Two experimenters scored the data independently and placed the children in the different model categories. Reliability was high (95%). All disagreements were discussed and resolved.

As shown in Table 4, the use of the globe resulted in an increase in spherical earth responses and a decrease in alternative models of the earth. Most of the children were placed in a well-defined category in Question Set I, before the use of the globe. Only three 1st graders and two 3rd graders were placed in the mixed category. But, after the use of the globe, the number of children placed in the mixed category increased remarkably (13 1st graders and 10 3rd graders). These findings can be best seen in the graphical representation shown in Fig. 2. A chi-square comparing the frequency of sphere, alternative, and mixed models in Question Sets I and II, gave statistically significant results [$x^2(2) = 36{,}455$, $p < 0.001$)].

To conclude, before the use of the globe 90% of the children (38/42) from both age groups gave internally consistent responses and were assigned to a model category. After the use of the globe, the frequency of internally consistent models decreased, with only 45% of the children being assigned to a model category, as shown in Table 5.

3.2.2. 'Mindful' discourse analysis

In what follows we analyze two examples from the transcribed child–experimenter exchanges. The analysis is based not only on what the children said, but also on the models they had constructed and the artifacts that they had in front of them. We believe that these examples can shed some light on the nature of the difficulties that children can have with a cultural artifact that represents the earth when their own, independent, representations are inconsistent with the artifact. The first example comes from George, a third grader who believed that people live inside the earth and formed the model of a hollow sphere in the first part of the interview. The excerpt comes from Question Set II, with the globe present.

- E: If you walked for many days, where would you end up?
- C: To the places above the earth and below the earth.
- E: Is there an end/edge to the earth?
- C: Yes, at the top and bottom part.
- E: Can you fall off this end?
- C: No, you cannot.

Table 3
Criteria for placement in model category

Model categories	Question Set I	Question Set II
(1) Sphere	Scientifically correct responses to all the questions in Table 1 (marked as 2).	Scientifically correct responses to all the questions in Table 2 (marked as 2).
(2) Sphere without gravity	Scientifically correct responses to all the questions in Table 1, except those that have to do with gravity (Q4/R2, Q5/R2). We expect the children to say that people and solar objects are located only on the top or above the spherical model. (Q7/R2, Q8/R2).	Scientifically consistent responses to Q9, 10, 11, 14 & 15. To Q12 & 13 we expect responses indicating that people cannot live "down here" at the South Pole (Q12 & 13/R2).
(3) Hollow sphere	We expect the children to say that the earth is round like a ball/circle but that it is flat inside (Q2/R2), that people live inside the earth at the bottom (Q4/R3) and that the sky is inside the circle (Q5/R3). We expect sphere or vertical ring play-dough models with the people living inside it (Q7/R3).	Scientifically correct responses to questions 9, 10, 11, 14 & 15. We expect the children to say that people cannot live outside the earth but only inside (Q12/R2, Q13/R3). Sometimes children with a hollow sphere model say that people can fall off the end/edge of the earth, if they can get there using a space-craft.
(4) Dual earth	We expect the children to say that the earth is round like a ball but indicate that people live on another earth which is flat (Q4/R5). We expect them to show the sky to be located between the two earths (Q5/R4, Q8/R4).	We expect the children to accept the spherical shape of the earth in Q9 but their responses to Q10 & 11 to indicate that there is an end/edge and that people cannot live "down here" at the South Pole (Q12/R2, Q13/R3). Also other verbal indications that there are two earths.
(5) Flattened sphere	We expect children to indicate that the earth is round like a sphere but it is flattened on top and on bottom (Q6/R6) and that people live on the top and on the bottom of the model (Q4/R4, Q7/R4). The sky is located all around the earth (Q8/R1).	We expect children to insist that the earth is round like a sphere but it is flattened on top and on bottom and probably that there is an end to earth (Q10/R2) at the side of the sphere, from where people may fall, because they cannot stand there (Q11/R4). Children with a flattened sphere model say that people live on the bottom of the globe, at the South Pole (Q12/R1).
(6) Disk	The children indicate that the earth is flat, draw people inside or on the circle (Q4/R2 & R3) and also draw the sky and solar objects above the circle only (Q5/R2). They make a disk or a horizontal ring with people living on the top part of the model (Q6/R4, R5, Q7/R2).	We expect children with a disk model to insist that the shape of the earth is that of a disk (Q15/R2) and answer all other questions consistent with a flat earth model (marked as 0).
(7) Flat earth	The children say that the earth is flat and that people live on the top of a flat surface (Q4/R6, Q7/R5). The sky is located only on top part of the flat model (Q5/R5, Q8/R5).	We expect children to believe that the shape of the earth is vertical/square (Q15/R2) and to answer all questions consistent with a flat earth model (marked as 0).
(8) Mixed	Children are internally inconsistent to their response and cannot be assigned to any of the above mentioned categories.	Children are internally inconsistent to their response and cannot be assigned to any of the above mentioned categories.

- E: Why not?
- C: Because you are inside the earth.
- E: Can people live down here, at the South Pole?
- C: (looks to see if there is a country there) Yes, they can.
- E: If this little girl stood here and held a ball in her hands, and the ball fell, in which direction would it fall?
- C: It will fall far away, below the earth.
- E: Finally, what is the real shape of the earth?
- C: It is like a globe.
- E: And where do the people live?
- C: Everywhere on the earth, all around and also inside.

In this example, George answers in a manner consistent with his hollow sphere model, until the question about the South Pole. Since there is no doubt about the existence of the South Pole at the "bottom" of the earth, (which George can see in front of his eyes in the globe), George cannot but agree that people can live there. He therefore adds to his hollow sphere the information that people also live all around the earth, on the outside, creating in this way an internally inconsistent model.

The next example comes from Nicole, a first grader who had given a flat earth model in Question Set I.

- E: If you walked for many days where would you end up?
- C: I would go back to where I started.
- E: Is there an end/edge to the earth?
- C: Yes, there is.
- E: Can you fall from this end/edge?
- C: Yes, it is in the bottom part of the earth and you cannot stand there.
- E: Can people live down here at the South Pole?
- C: (the child looks at the bottom part of the globe to see if there is a country there) – Yes, there is a country there.
- E: Just before you told me that people cannot live down there

Table 4
Frequency/percent of children placed in the different model categories

Model categories	Question Set I: before the use of the globe		Question Set II: after the use of the globe	
	1st Grade	3rd Grade	1st Grade	3rd Grade
(1) Sphere	3 (15%)	6 (27%)	4 (20%)	10 (45%)
(2) Sphere without gravity	1 (5%)	3 (13%)	2 (10%)	2 (9%)
(3) Hollow sphere	4 (20%)	6 (27%)	–	–
(4) Dual earth	–	2 (9%)	–	–
(5) Flattened sphere	–	1 (5%)	–	–
(6) Disk	6 (30%)	1 (5%)	1 (5%)	–
(7) Flat earth	3 (15%)	1 (5%)	–	–
(8) Mixed	3 (15%)	2 (9%)	13 (70%)	10 (45%)

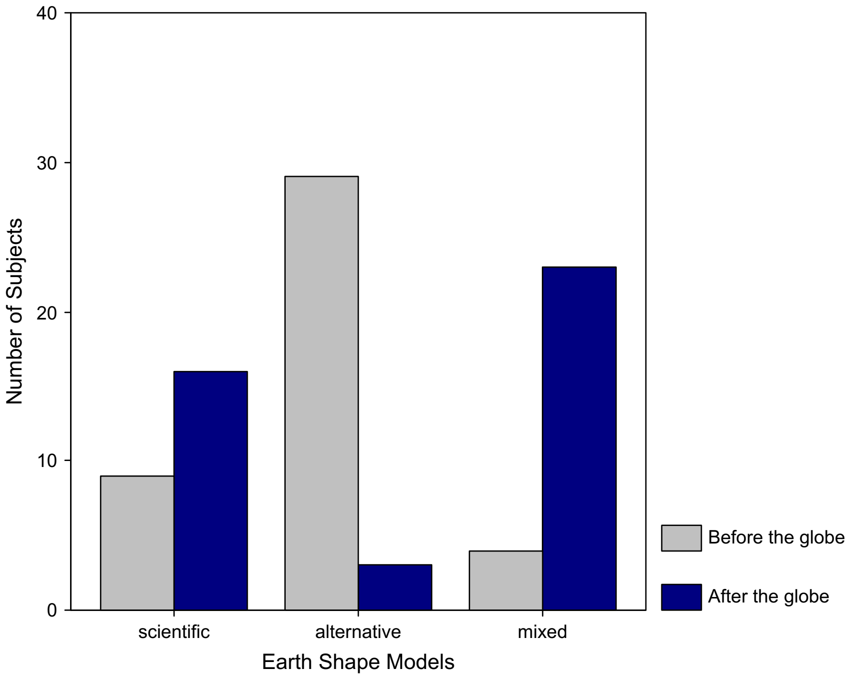

Fig. 2. Number of subjects in the different earth model categories ($n = 42$) before and after the presentation of the globe.

- C: No, they do – (looks again at the South Pole to make sure).
- E: Finally, what is the real shape of the earth?
- C: Finally, it is like a globe
- E: Where do the people live?
- C: Finally, the people live everywhere

Nicole had problems understanding how people can live at the bottom of the earth. Looking at the globe, however, she could not but agree with the implicit presupposition that people can indeed live 'down there,' at the South Pole. At the end, she changed her response to adopt the spherical earth model, ending up with an internally inconsistent response pattern.

3.2.3. Children's awareness of changes in their responses

In this analysis we tried to determine how aware the children were of the possible changes in their responses in the first and second parts of the questionnaire, (a) by asking them to indicate what they believed was the real shape of the earth at the end of the interview (Q15), and (b) by comparing their models at Question Set I and Question Set II. First, responses to Q15 were scored as "Did not Change" if the children said that they did not change their model at Question Set I (before the

Table 5
Frequency and percent of internal consistency before and after the use of the globe

	Before the use of the globe	After the use of the globe
Assigned to a model category	38/42 (90%)	19/42 (45%)
Mixed	4/42 (10%)	23/42 (55%)

presentation of the globe) and as "Changed" if they said they changed. As shown in Table 6, a total of *33 out of 42 children said that they did not change* their model and only *9 out of 42 said that they changed*. We also scored children's overall responses to Question Set II ("what the children did in Question II") as "Did not Change" if they were consistent with the child's initial model of the earth and as "Changed" if they were not. When we examined what children did in Question II, vs. what they said they did, *we found that a total of 33 out of 42 children changed their responses and only 9 out of 42 did not change*. In other words, the result in this case was the reverse of what we found when we examined children's verbal responses only! Only 18 children out of the 42 were consistent between what they said in Q15 and what they did in Question Set II: 9 said that they changed and indeed they did, 9 said that they did not change and indeed they did not, and the remaining 24 children (73%) said that they did not change but in fact they did. Therefore, we can conclude that 73% of the children *did* change their responses in some way after the presentation of the globe, without being aware of doing so.

4. Discussion

The findings of the first part of this experiment (Question Set I) replicated the previous results by Vosniadou & Brewer (1992, 1994) and Vosniadou (1994a), as well as those by Vosniadou et al. (2004). The older children gave a greater number of scientifically correct responses than the younger children. In addition, most of the children gave an internally consistent pattern of overall responses, making it possible for us to assign them to a well-defined model of the earth.

It should be emphasized here that children's models of the earth are not figments of our imagination. They are based on children's own external representations of the earth in their drawings and in their play-dough models. Furthermore, our method of scoring takes into consideration these representations only if they are consistent with each other (i.e., if the drawings are consistent with the play-dough models) as well as with children's overall verbal statements.

Table 6
Comparison between what the children said in Q15 and what they did in Question Set II

Children's responses to Q15	What the children did in Question Set II		Total
	Changed	Did not change	
Changed	9	–	9
Did not change	24	9	33
Total	33	9	42

The presentation of the globe in Question Set II, affected children's responses in three ways: at the individual response level, there was an increase in the overall number of scientifically correct responses given by the same children. This was indicated by the main effect for question set in the ANOVA comparing the mean scores for Question Set I and Question Set II, shown in Fig. 1. At the overall response level, there was a marked decrease in the internal consistency of responses, with "mixed" responses almost completely replacing children's alternative models of the earth obtained in the first part of the questionnaire. Finally, the children seemed to be unaware of the changes in their responses and the fact that they gave internally inconsistent responses after the presentation of the globe.

One possible explanation for the increase in the number of scientific responses with the presentation of the globe is that the children adopted the externally provided representation and reasoned on the basis of it. Indeed the presence of the globe had an immediate effect on some of the responses of the children, the responses which could be read from the model and did not require many inferences to be drawn. Characteristic is the example of Q12 "Can people live down here at the South Pole?" The great majority of the children responded affirmatively to this question, placing the little girl "at the bottom" of the globe, at the South Pole. In this case many children bended to look under the globe to see if there was indeed a country there. Seeing the South Pole, they then answered that yes, people could live "down there". The magnitude of the Yes response (16/20 and 18/22 for the 1st and the 3rd grade, respectively) under this condition was noticeable, given the fact that only 5 out of 22, 1st graders and 6 out of 22 3rd graders of the same sample had given a Yes response to the same question in Question Set I, when their own play-dough models were used.

Children's responses in Question Set II were not, however, always consistent with the spherical earth model. For example, when asked Q10 about the end/edge of the earth, 65% of the 1st graders and 32% of the 3rd graders answered that there is indeed an end/edge to the earth, even though they had the globe in front of them. A possible explanation of the difference in responses between Q10 and Q12 is that only in the latter the answer can be read directly from the model but not in the former. A superficial interpretation of the globe could possibly justify a reading consistent with the end/edge response (interpreting the end as the sides or bottom of the globe) in Q10. In Q12, however, the actual presence of the South Pole at the bottom of the globe, together with children's previous knowledge that people can get to the South Pole without falling off, makes the scientific conclusion more obvious. These findings agree with our argument that the presence of the globe does not by itself solve the problem of understanding the spherical shape of the earth and that the cultural artifact is interpreted in light of what the children already know.

When we take into consideration children's overall responses we find that there is an increase in the number of internally consistent *sphere* models (from 27% in QS I to 45% in QS II). This effect is particularly noticeable in the case of the older children who profit more from the presence of the globe. The remaining children, many of who had formed internally consistent, alternative models of the earth in Question Set I, gave inconsistent, "mixed" responses, in Question Set II. Moreover, most of these children did not seem to be aware of the inconsistency in their responses.

These findings suggest the following. First, only some (the older) children can profit from the presence of the artifact to construct an internally consistent scientific model of the earth. Second, many children employ a mixed way of responding, sometimes basing their answers on the externally provided model and sometimes on their prior knowledge. Third, these latter children are not aware that by doing so they are becoming internally inconsistent. It appears that in the absence of an external, cultural model, children can form internal representations which they can distort in ways that make them consistent with their prior knowledge. But, when the cultural artifact is present, such distortions are not possible. Children reason on the basis of the externally provided artifact when this is unavoidable, but when the answer cannot be derived directly from the external model they rely on prior knowledge. The children do not seem to be aware of this process that somehow distorts their rationality producing internal inconsistency.

The above support our argument that the *mere* presence of the cultural artifact does not solve the problem of science teaching, although they do not agree with our prediction that the cultural artifact would be distorted. The cultural artifact in the present study was taken into consideration when the answers to the questions we asked the children could be derived directly from it. When the children needed to use the artifact generatively, to draw new inferences, they did not do so. Rather, they relied on their prior knowledge. It is clear that the children need extensive instruction with the artifact to learn how to use it. George and Nicole and the other children in our sample, need an *explanation* of why it is possible for people to live down there, at the South Pole. An explanation that will help them reconcile their previous knowledge and beliefs about the earth with the presumptions afforded by the cultural artifact. In the absence of an understanding of why people do not fall off at the "bottom" of the earth, the children will repeat the same mistakes again, when the artifact is not present.

However, explanations do not have place in a radical socio/cultural approach. They make sense only in a theory that assumes that children think, and believe, and have internal representations. This is why we believe that we still need to pay attention to students' prior knowledge and internal representations and why a simple discourse analysis will not do the job. Methodologically, what is needed is a 'mindful' discourse analysis where attention is paid not only to communicative but also to cognitive factors, in order to understand student's difficulties in learning science concepts. The radical socio/cultural approach with its denial of mentalism and the lack of a cognitive analysis prevents us from understanding children's difficulties with cultural artifacts and ends up replacing understanding and explanation with social coercion.

Acknowledgments

We are deeply grateful to the administrators, teachers, and children who made this research possible. This publication is part of a PhD dissertation which is financially supported by the grant IRAKLEITOS-Fellowships for Research of NKUA- from the Greek Ministry of Education.

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