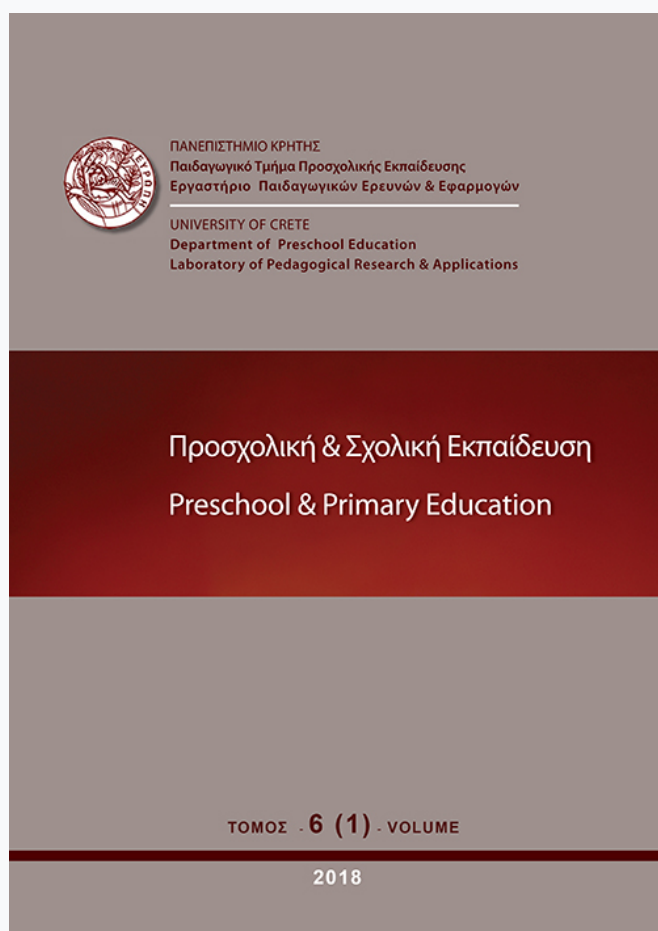


Preschool and Primary Education

Vol 6, No 1 (2018)

Early view



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doi: [10.12681/ppej.14210](https://doi.org/10.12681/ppej.14210)

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To cite this article:

Vaiopoulou, J., & Papageorgiou, G. (2018). Primary students' conceptions of the Earth: Re-examining a fundamental research hypothesis on mental models. *Preschool and Primary Education*, 6(1), 23–34.
<https://doi.org/10.12681/ppej.14210>

Primary students' conceptions of the Earth: Re-examining a fundamental research hypothesis on mental models

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Summary. Research on pupils' conceptions of the earth has proposed certain mental models within the theoretical perspective known as *coherent* or *theory-like* knowledge. Alternatively, the *fragmented* knowledge hypothesis refutes the existence of such models and proposes a different perspective. Although the relevant discussion has not converged into a definite answer, recently the debate between the two theories has been brought up for consideration by the advances in methodology and statistical analysis. In this paper pupils' conceptions of the earth were analyzed by latent class analyses. Children's ideas ($N=184$, grades 1st to 3rd) were investigated using a closed-ended questionnaire which includes illustrations corresponding to certain mental models. The results showed that pupils' conceptions of the earth are not characterized by consistency, and thus they do not support the existence of coherent mental models. Implications for theory and practice are discussed.

Keywords: Students' conceptions; earth; coherent models; fragmented knowledge

Introduction

A fundamental question in both cognitive psychology and science education concerns the ways in which children can acquire the scientific view for a variety of concepts and phenomena. Among these, the earth and its relevant concepts have been at the center of science researchers' interest many times. Vosniadou and Brewer (1992, 1994) for instance, investigated the knowledge of 6- to 11-year-old pupils on the earth via interviews, including drawings and generative questions. Data analysis of the drawings and pupils' answers led to identifying a small number of coherent mental models of the earth (Vosniadou & Brewer, 1992). Other similar studies conducted in different cultures agreed with these results (e.g., Brewer, Hendrich, & Vosniadou, 1987; Diakidoy, Vosniadou, & Hawks, 1997; Hayes, Goodhew, Heit, & Gillan, 2003). Children's emerging models of the earth were thought to be generally common, even though there were some differences reported in the studies. Thus, a hypothesis supporting the existence of particular coherent mental model was articulated, according to which children form naive, theory-like mental models about the earth before acquiring the scientific view. These models are initially formed due the influence of everyday observations and experiences, and they presuppose that the earth is flat and any object on it 'falls down'. Thus, children are led to adopting particular *initial* models, namely, the 'rectangular earth model' and the 'disk earth model', in which the earth is considered to be a flat object. However, when a child tries to incorporate additional information about the actual

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e-publisher: National Documentation Centre, National Hellenic Research Foundation
URL: <http://ejournals.epublishing.ekt.gr/index.php/education>

shape of the earth, a number of *combined* or *synthetic* models can be formed. The simplest of these, is the 'hollow sphere model', where people leave on a flat ground under a hollow sphere. Another synthetic model, more sophisticated than the previous, is the 'dual earth model', which combines a spherical earth up in the sky with a flat earth on which people live. Moving closely to a more realistic view, the 'flattened sphere model' has also been found, in which children consider the earth as an object which is round on the sides but having flat areas on the top and bottom, so people can stand and live. Finally, the 'no-gravity sphere model' considers the earth as a sphere, but without any sense of gravity. All these models seem to be hierarchical with a stepwise progression, at the end of which a child can reach the scientific model (Samarapungavan, Vosniadou, & Brewer, 1996; Vosniadou, 1994).

Using similar research tools, contemporary research in the same field of pupils' mental models has shown that the proposed models, *initial* and *synthetic*, although the most prevalent, are not the only ones and many variations are reported across cultures (Nobes, Moore, Martin, Clifford, Butterworth, Panagiotaki & Siegal, 2003; Samarapungavan, et al., 1996). Thus, some of the cross-cultural studies provided clues of inconsistent knowledge, shifting towards the 'fragmented knowledge perspective'. For instance, studies initially attempting to verify the above results, by using three-dimensional model selection tasks and forced-choice questions (Nobes et al., 2003; Panagiotaki, Nobes, & Banerjee, 2006; Siegal, Butterworth & Newcombe, 2004) or using picture selection tasks instead of drawings and open questions (Nobes, Martin & Panagiotaki, 2005; Straatemeier, van der Maas & Jansen, 2008) have reached different conclusions. The findings of these studies suggested that children's knowledge of the earth is not *coherent* and *theory-like*, but *inconsistent*, supporting the fragmented knowledge hypothesis. According to the 'fragmentation view', children's knowledge consists of fragments, that is, 'pieces of knowledge' known as *p-prims* that are loosely interconnected and are organized accordingly when conceptual understanding is attained (diSessa, 1988; diSessa, Gillespie & Esterly, 2004; Harrison, Grayson & Treagust, 1999).

The debate between the 'coherent mental models' and the 'fragmented knowledge' hypotheses has important theoretical and practical implications. First, the nature of children's naïve knowledge determines the processes of conceptual development, and second, it significantly contributes to the development of methods appropriate to teach the corresponding scientific concepts. Nevertheless, the debate has continued for decades, since both hypotheses appear to have empirical support. Moreover, methodological problems have been pointed out concerning the use of open-ended questions and children's drawings. Instead, pictures with 3-D models and closed-ended questions were proposed as better means for data collection (Panagiotaki, et al., 2006; Straatemeier et al., 2008). The present work aims to contribute to this dialogue by re-examining pupils' knowledge about the earth using forced-choice questions and a robust statistical methodology for data analysis. This methodology is based on a specific research tool for earth models that has been already proposed and applied in a different cultural environment and population (Straatemeier et al., 2008). In the light of the striking findings, this work attempts to verify them by investigating the coherent mental models on the earth, if any, among Greek primary school pupils of the first, second and third grades.

Methodological considerations: The Latent Class Analysis

In the context of the theoretical debate described above, some methodological issues arise concerning both data collection and analysis. As a number of researchers suggest (Panagiotaki, et al., 2006; Straatemeier et al., 2008) different methodological approaches accounted for discrepant findings. For example, studies supporting the coherent mental model (e.g. Siegal et al., 2004; Vosniadou, Skopeliti & Ikospentaki, 2004) are based on

interviews, drawings and open-ended questions. On the other hand, research evidence based on 3D models or pictures selection tasks and forced-choice questions advocates the fragmented knowledge (Nobes et al., 2003, 2005; Panagiotaki et al., 2006; Siegal et al., 2004; Straatemeier et al., 2008).

Although arguments in favor of both methods of collecting data can be articulated, the first approach, using drawings and open-ended questions, possesses a major disadvantage originating from the researchers' difficulty in consistently interpreting children's immature sketches (Nobes et al., 2003, 2005). Further to this, a main issue in this research area is the method of classification. That is, the method used to determine the mental model in which a child would be classified, is based on his/her responses. The prevailing approach is the *Rule Assessment Methodology* (RAM) (Siegler, 1976, 1981) used in many studies on mental models (Johnson, 1998; Vosniadou, 1994; Vosniadou & Brewer, 1992). According to RAM, the degree of correspondence between the expected and the observed responses determines the classification of each participant into a hypothesized model. The magnitude of the deviation between expected and observed responses that could be accepted for this classification is a matter of consensus.

The disadvantages of RAM are associated with the arbitrariness of the accepted criterion of fit (e.g. 80% or 90%) which may be changed by the number of items used in the questionnaire. In addition, there is no statistical test to provide a fit index for the proposed classification (Jansen & van der Maas, 1997), and only the predetermined mental models can be detected. Contemporary multivariate statistical methodology offers an alternative classification method which is appropriate for detecting mental models as entities or variables at the nominal scale (Clogg, 1995; Dayton, 1998). One of them is the *Latent Class Analysis* (LCA), which is implemented when both manifest and latent variables are categorical. LCA employs algorithms which can identify distinct groups within a set of data. These groups, namely *Latent Classes* (LCs), are clusters where the subjects hypothetically belong to, being qualitatively different from each other. These LCs, which are derived from appropriate data under certain conditions, might be the mental models under investigation.

The LCs are proposed by means of statistical criteria based on conditional probabilities. A *conditional probability* is the probability of providing a certain response to an item, given that the subject belongs to the specific LC, i.e. mental model (Magidson & Vermunt, 2001). If the resulting class account is correct, a limited number of LCs with conditional probabilities consistent with these classes should be found. If LCA procedure converges to a single-class model, then students' knowledge based on their responses cannot be classified into qualitatively different mental models. LCA, contrary to other cluster analysis procedures, offers statistical measures indicating how well the LC model accounts for the data, and it actually tests whether the specific proposed mental models are statistically supported by the data.

Methodology

Research question and hypotheses

The present study investigates the nature of knowledge about the earth acquired by Greek primary school pupils (grades 1 to 3). The main research question is whether the knowledge is coherent or fragmented, while also investigating the effect of *age* and *gender*. In this context, two hypotheses could be articulated:

- Pupils' knowledge is fragmented. This hypothesis is the null hypothesis (Ho) in the present statistical framework of analysis.

- Pupils' knowledge is coherent or theory-like. This is the alternative (H_1) hypothesis, which supports the mental-model perspective.

Thus, the statistical inference focuses on the rejection of the H_0 , which may or may not support the existence of mental models.

The sample

The study was conducted with the participation of 184 elementary school pupils (ages 6-8, $M = 6.99$, $SD = 0.87$). The children were from three different age groups corresponding to the first grade ($n=70$), the second ($n=45$) and the third ($n=69$), 98 of which were male and 86 females. Participants were all the pupils of 12 classes, each of which belonged to a different school in Macedonia, Northern Greece. Pupils were of varied socioeconomic backgrounds and living conditions.

Instrument and procedures

Pupils filled in a closed-ended questionnaire concerning the shape of the earth and relevant phenomena under the supervision of a researcher and the classroom teacher. The choice of participants was based on non-probability convenience sampling, engaging those who belonged to schools in which there was access and willingness to cooperate. The choice of a closed-ended questionnaire was made to avoid the disadvantages of the alternatives shown by Nobes and Panagiotaki (2007) who demonstrated the difficulties arising for students at young ages. The instrument was the EARTH-2 questionnaire (see appendix), designed and used in previous research (Straatemeier et al., 2008). It is a structured, nonverbal, forced-choice test that can be easily administered, whereas the use of complex coding systems is not required. The EARTH-2 includes a number of illustrations, each one depicting a number of items which describe the most prevalent models found in earlier studies with samples from Western countries (Vosniadou & Brewer, 1992; Vosniadou et al., 2004). In each item the participants examine corresponding pictures and choose the one which best fits what they have in mind. The questionnaire is freely available on the internet and was translated into Greek by two experts. An example of an item and the corresponding illustrations is shown in the Appendix. The validity issue for the present instrument, measuring students' understanding of a specific domain, focuses on the content validity, which is established by judgement and expertise (Mertens, 2005). It is also significant to note that each possible choice illustrated in EARTH-2 is clearly linked to a corresponding mental model found in earlier relevant studies (e.g. Vosniadou & Brewer, 1992; Vosniadou et al., 2004). Moreover, the use of closed-ended questions with illustrations, instead of open-ended items and drawings, enhances the validity because it eliminates the mediatory step of the researcher's interpretation (Nobes & Panagiotaki, 2007; Straatemeier et al., 2008). Reliability measures by usual means, such as Cronbach's alpha, cannot be applied in the present study, since the latent variables involved in the mental processes under study are unidimensional (Kline, 1999). The internal consistency is the main concern of the present endeavour and it is investigated as a reflection of the coherency of the hypothesized models.

Statistical analysis

The LCA which was chosen as the most appropriate method to answer the main research question was implemented as a confirmatory approach. The LatentGOLD_5.1 software was used, which runs cluster analysis on the basis of conditional probabilities. The software provides a number of model fit indicators such as, the number of parameters (Npar), likelihood ratio statistic (L^2), Bayesian Information Criterion (BIC), Akaike's Information Criterion (AIC), degrees of freedom (df) and bootstrapped p -value. The p -value should be

greater than 0.05, the number of parameters has to be the smaller and the BIC criterion has to be the lowest.

Results

Pupils' responses as categorical variables directly provided a marking scheme at the nominal level which was used for the Latent Class Analysis. In addition, a scoring at the ordinal level was used for statistical analysis. In this marking scheme, children received one point for choosing the 'disk model', two points for the 'hollow model' or the 'dual earth model', three points for the 'flattened model' or the 'no-gravity sphere model', and four points for choosing the 'scientific model'. This marking scheme is justified by the fact that the hypothesized mental models are hierarchical. The same marking scheme was used by Straatemeier et al. (2008) in an analogous inquiry. The mean scores were calculated and used to test hypotheses related to the effect of age and gender.

Table 1 shows the percentages of the pupils' responses to the EARTH-2 questionnaire items allocated to various mental models. The internal consistency of the responses, using the ordinal marking scheme expressed by Cronbach's α , was 0.70. As Table 1 shows, a high percentage of pupils preferred the scientific model, especially in items concerning the shape of the earth. Quite high frequencies are also appeared in the no-gravity model, which means that pupils who recognize the earth as a sphere do not necessarily understand the gravity concept. Also, there are high frequencies for the flat-earth model in the items referring to the day/night cycle, which suggests that pupils had not understood the cycle.

In order to test the effect of *gender* and *age* on pupils' scores, an analysis of covariance was carried out with *gender* as independent variable and *age* as covariate. Both the effect of *age* [$F(1, 181) = 12.75, p < 0.001, \eta^2 = 0.07$] and *gender* [$F(1, 181) = 5.80, p < 0.05, \eta^2 = 0.03$] were statistically significant. Moreover, the nonparametric Kruskal-Wallis test supports the effect of *age* ($p < 0.01$) and the Mann-Whitney test the effect of *gender* ($p < 0.05$). Boys and elder pupils achieved higher scores.

Latent class analysis

Participants' responses were introduced to the LCA procedure and the results using the nine items are shown in Table 2.

Among all LC model-solutions the 2-cluster model-solution appears to be statistically significant ($p = 0.068$), the most parsimonious and the best fitting one. The two LCs account for 61.1% and 38.9% of the sample respectively. In each LC a conditional probability is assigned for an item, that is, the probability for an item to be answered in line with one of the hypothesized mental models, given that the subject is a member of this class. Figures 1 and 2 show these conditional probabilities for the two emerged latent classes respectively. If a LC represents a coherent mental model, then the conditional probabilities in all items should be close to unity and in line with only one hypothesized mental model. If not, the conditional probabilities would be heterogeneous, corresponding to answers from various mental models. Figures 1 and 2 show that the resulted LCs do not coincide with any of the hypothesized mental models. Although the scientific model is present in both LCs, it seems to dominate in LC1. Many pupils of this group (LC1) have attained the correct conception of the earth. On the contrary, LC2 appears more heterogeneous in terms of responses linked to different mental models. For example, in Figure 2 the item Q2 has been answered, with the probability of 0.27 within the scientific model, with probability of 0.26 within the disk earth model and with probability of 0.31 within the hollow earth model. Thus, children's knowledge

appears to be fragmented, not showing any coherence as mental-model theory has hypothesized.

Table 1 Percentages of the children's responses to the EARTH-2 questionnaire items.

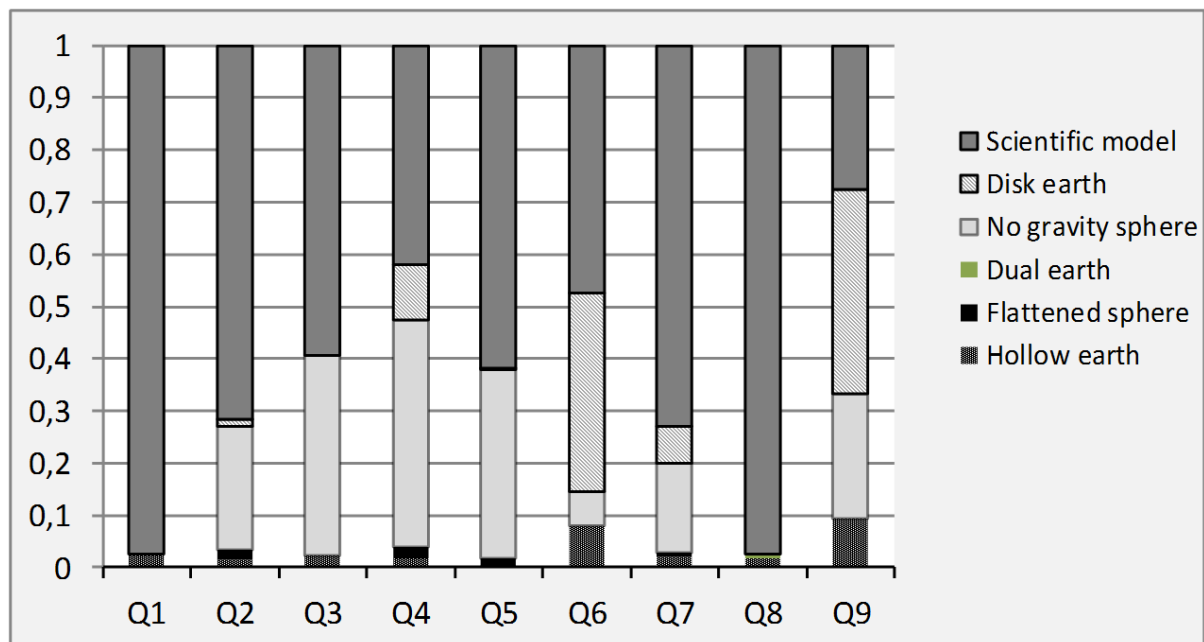
Question	Hypothesized Mental Models						Scientific
	Flat earth		Hollow	Dual	Flattened	No gravity	
1. What does the earth look like?	1.1		2.2	2.2	-	-	94.6
2. Which picture shows best where people live on the earth?	12.0		13.0	-	1.1	19.6	54.3
3. Which picture shows best where the clouds are?	9.8		16.3	-	0.5	31.5	41.8
4. Which picture shows best what happens when a giant kicks a ball real hard?	Falls off the earth 7.1	Does not fall off the earth 10.9	6.5	-	5.4	34.8	35.3
5. Which picture shows best where the trees are on the earth?	12.0		14.1		1.1	30.4	42.4
6. Where is the sun at night?	Cloud 3.8	Sundown 42.9	7.6	-	-	6.0	39.7
7. What happens when you walk along a straight line for a very long time?	Falls off the earth 3.3	Does not fall off the earth 9.8	10.3	-	1.1	16.8	58.7
8. Which picture resembles the earth best?	1.1		4.9	0.5	0.5	-	92.9
9. Which picture shows best how night falls?	Cloud 10.3	Sundown 40.8	8.7	-	-	19.0	21.2

Note: the symbol '-' corresponds to a mental model not represented in an item

Table 2 Results of the various LC factor models fitted to all 9 items.

	LL	BIC(LL)	Npar	L ²	df	p-value	Class.Err.
1-Cluster	-1804.22	3801.388	37	1774.61	147	0.000	0.000
2-Cluster*	-1688.28	3767.674*	75	1542.729	109	0.068*	0.011
3-Cluster	-1617.21	3823.715	113	1400.601	71	0.000	0.029
4-Cluster	-1566.86	3921.178	151	1299.897	33	0.000	0.046
5-Cluster	-1535.18	4055.991	189	1236.543	-5	0.000	0.029

*Indicates the most parsimonious and best fitting model: Npar, number of parameters; L², likelihood ratio statistic; BIC, Bayesian Information Criterion; AIC Akaike's Information Criterion; df, degrees of freedom; bootstrapped *p*-value; classification error.

**Figure 1** Conditional probabilities for Latent Class 1 (61.1 %, dominance of scientific model).

Moreover, an association of gender and age with the two LCs was tested. The literature has shown unclear results as far as the effect of gender on children's knowledge about the earth is concerned, while the effect favors elder children (Nobes et al., 2003, 2005; Panagiotaki et al., 2006; Siegal et al., 2004; Straatemeier et al., 2008). Figure 3 shows the proportion of pupils per LC in each grade level, and Figure 4 shows the proportion of pupils per LC of each gender. It appears that the probability of attaining the science view model of the earth increases with age, a result that is in accordance with previous reports, while it is greater for boys, a finding that agrees with Panagiotaki et al. (2006).

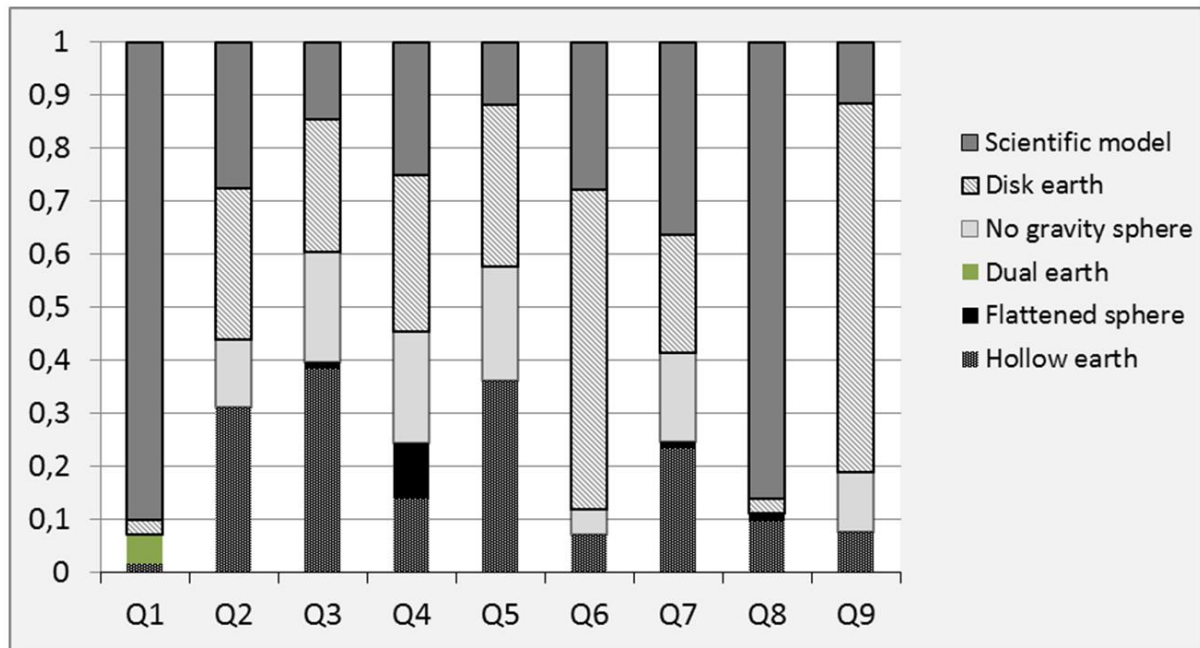


Figure 2 Conditional probabilities for Latent Class 2 (38.9 %, fragmented knowledge).

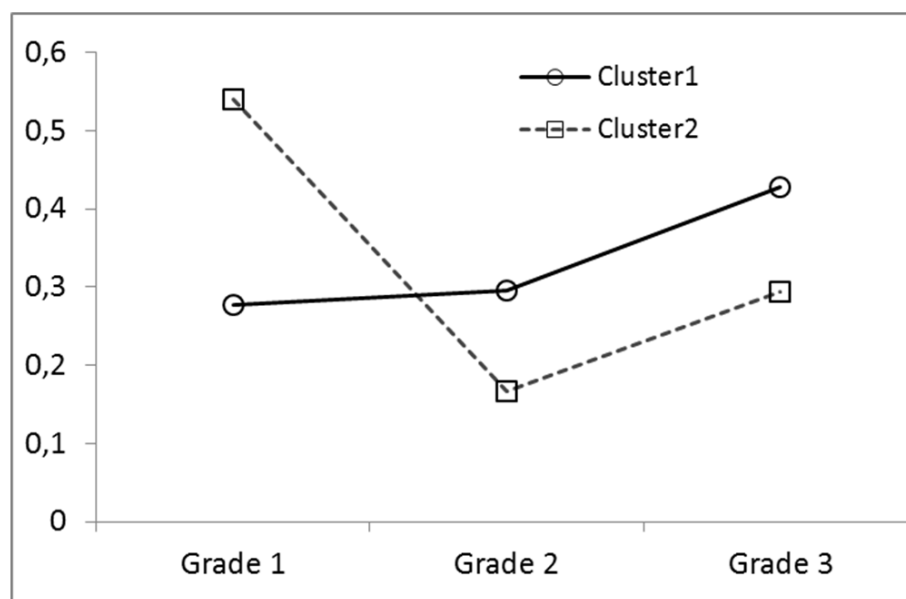


Figure 3 Proportion of children per latent class by grade. The percentage of elder children is greater in the LC1 where the scientific model prevails.

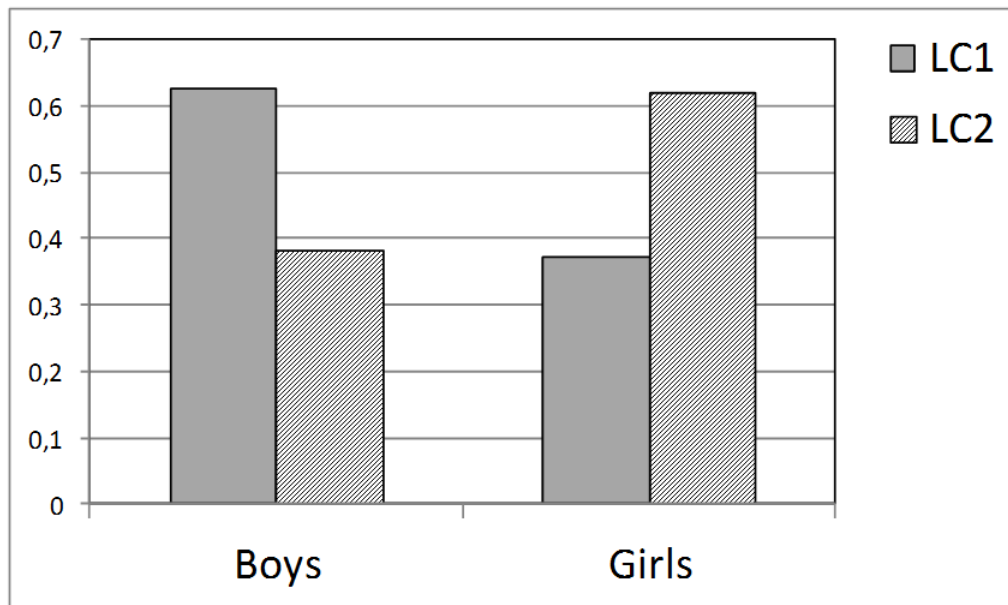


Figure 4 Proportion of children per latent class by gender. The percentage of boys is greater in the LC1 where the scientific model prevails.

Discussion and conclusions

The findings of the present research show that children aged 6-8 have, to a significant degree, acquired scientific knowledge about the earth, or they are close to it. However, even though they acknowledge the sphere shape of the earth, they have not completely understood the concepts of gravity and the day/night cycle. Also, although pupils chose pictures representing either *initial* (flat) or *synthetic* mental models, their percentages varied considerably across questions. The percentages of pupils with presuppositions of flatness are very small. However, since the same pupils who responded to a particular item choosing the flat model, could also choose another model in a different item, it seems that these presuppositions could be fragments of naïve knowledge that co-occur with pieces of knowledge closer to scientific knowledge.

The present work is limited by a number of factors, including: a) the relatively medium sample size, even though bootstrapping techniques were employed by LCA, b) the non-probability convenience sampling, since participants belonged to schools in which there was access and a willingness to cooperate and c) the limitation arising from a possible violation of the independence-measurement assumption, which nevertheless concerns all relevant pieces of research. However, despite the above limitations, the robust statistical methodology supports the conclusion that the null hypothesis (H_0) of fragmented knowledge could not be rejected. The results are in line with previous research findings using LCA on children's knowledge about the earth (Straatemeier et al., 2008).

The outcomes of the present research have a number of implications for both theory and educational practice. Regarding the former, these findings further support the perspective positing that children's understanding about the earth is not affected by intuitive constraints that lead to the formation of stable and coherent naïve mental models before they acquire the scientific model. Thus, the knowledge of children appears to be 'theory free' and it consists of unsystematic and fragmented pieces of information, which are organized accordingly, forming different responses under various circumstances. Children's responses are created on the spot, and they can vary under different conditions, demonstrating their sensitivity and their dependence on the context (Siegal, Waters & Dinwiddy, 1988).

In addition, the present findings also have implications for educational practice. Since there are no coherent naïve mental models of the earth, the acquisition of relevant scientific knowledge can be attained by providing the appropriate information to children so as to help them organize the corresponding pieces of knowledge. Thus, science teachers have to understand that any learning difficulties do not originate from the resistance of the naïve mental models *per se*, but from the incapacity of mental processes to organize the fragmented knowledge into scientific views. This is the central point where teachers should be focused when organizing their lessons. Since the fragmented knowledge hypothesis seems to be gaining ground, generally teaching methodologies and science curricula should be also reconsidered, becoming a focal issue in education.

Given the advantages of the contemporary methodological tools, such as LCA, over alternative categorization procedures, it is imperative to state that the dispute between coherent versus fragmented knowledge should be reexamined. Thus, new rounds of discussion might be started on this issue, since this discussion concerns not only the specific subject matter, but a large number of concepts and phenomena in science education. Since different theories lead to different pedagogical practice, there is a growing interest in elucidating basic aspects of conceptual change theories (Kirbulut & Beeth, 2013; Stamovlasis, Papageorgiou & Tsitsipis, 2013; Turcotte, 2012). Also, LCA associated with a robust methodology is a powerful tool for investigating the instructional conditions and ways in which pieces of knowledge are organised and structured into large constellations of meaning approaching the science view. This will allow conceptual change theories to acquire a better understanding of learning and developmental processes, and support science education with teaching assets that do not rely on metaphors, but on valid theories grounded on empirical evidence.

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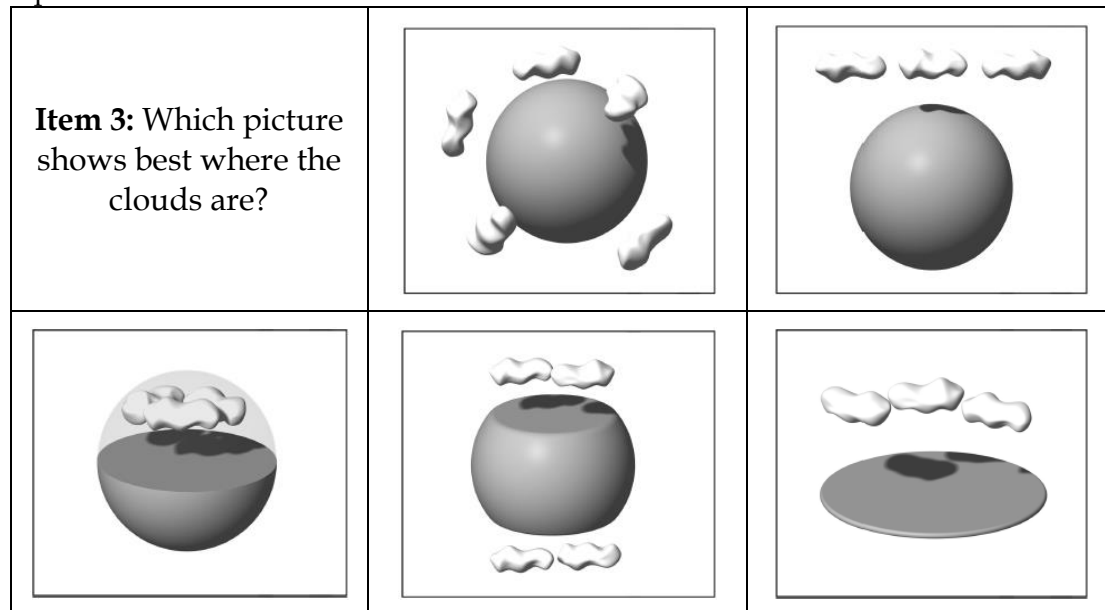
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Appendix

EARTH-2: The instrument was developed by Straatemeier et al. (2008) for children 4 years old or older and it includes 9 items, each of which includes a question and five or six three dimensional pictures. The pictures represent the six models that were found in previous studies: disk earth, hollow earth, dual earth, flattened sphere, no gravity sphere, and the scientific model. The items of the EARTH-2 questionnaire concern the shape of the earth, gravity, and the day/night cycle. An example of a test item (Item 3) is shown in the figure below. The questions of the items are presented in Table 1. The complete EARTH-2 can be viewed at <http://bit.ly/2qBABTs>.

Example of an illustration used in item 3



(The complete EARTH-2 can be viewed at <http://bit.ly/2qBABTs>)

Received: 17.7.2017, Revised: 8.10.2017, Approved: 2.11.2017