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The development of scientific knowledge of the Earth

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Investigation of children's knowledge of the Earth can reveal much about the origins, content and structure of scientific knowledge, and the processes of conceptual change and development. Vosniadou and Brewer (1992, 1994) claim that children construct coherent mental models of a flat, flattened, or hollow Earth based on a framework theory and intuitive constraints of flatness and support. To examine this account, 62 children, aged 5–10 years, and 31 adults ranked 16 pictures according to how well they were thought to represent the Earth. Even young children showed scientific knowledge of the shape of the Earth. There was little or no evidence of naïve mental models, indicating that any intuitions or constraints must be very weak. Instead, before they acquire the scientific view, children's knowledge of the Earth appears to be incoherent and fragmented.

The scientific view of the Earth is in many aspects counter-intuitive and contradictory to everyday observations: for example, the Earth appears flat but is actually spherical; it seems stationary but spins and orbits the sun; and people can live in Australia without falling off. These discrepancies between facts on the one hand, and observations and intuitions on the other, mean that research into children's understanding of the Earth can provide a number of important insights concerning the origins, content and structure of children's scientific knowledge, and the processes of conceptual development. If young children believe that the Earth is flat and that people can fall off, they must construct these naïve (non-scientific) 'theories' themselves, based on their own observations and intuitions, since it is unlikely that they will have been taught such things. Alternatively, if children either hold the scientific view of the Earth, or have no view at all, their observations and intuitions cannot be very influential. Their concepts or theories must be acquired from their culture through, for example, parents, schools and the media.

The usual method of investigation of children's understanding of the Earth has involved asking them to draw pictures of, and answer questions about, the Earth. Children tend to produce very intriguing pictures and responses, including the *flat*

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Earth, which is a disk or rectangle with people living only on top; the *hollow Earth*, with people living inside; the *flattened sphere*, with people on top; and the *dual Earth*, with one Earth being flat and the other round and in the sky (e.g. Nussbaum & Novak, 1976; Sneider & Pulos, 1983; Vosniadou & Brewer, 1992). These have been investigated in a number of cultures (e.g. Diakidoy, Vosniadou, & Hawks, 1997; Samarapungavan, Vosniadou, & Brewer, 1996; Vosniadou, 1994; Vosniadou & Brewer, 1992, 1994) and have been interpreted by Vosniadou and her colleagues as revealing that children construct naïve, theory-like 'mental models' of the Earth.

The mental model account

Vosniadou claims that, since naïve mental models are very unlikely to have been received from the culture, they demonstrate that young children's concepts of the Earth are strongly influenced by intuitive constraints ('entrenched presuppositions') of flatness and support, according to which the ground is flat, and all unsupported things fall downwards. These constraints are reinforced by children's observations of their local environment, and organized in a framework theory of naïve physics (Vosniadou & Ioannides, 1998). 'Initial' mental models are therefore flat Earths. As children become increasingly influenced by culture through, for example, school and the media, they are said to have 'synthetic' models such as the flattened, hollow, and dual Earths. These are hybrids that combine children's intuitions with the scientific information they have acquired. According to Vosniadou, it is only in late childhood that children relinquish their intuitions and acquire the scientific model.

The mental model account of children's conceptions of the Earth is consistent with and supports the 'theory theory' of cognitive development (Brewer & Samarapungavan, 1991; Carey, 1985; Gopnik & Wellman, 1992; Wellman, 1990). Theory-theorists propose that children construct their own conceptual systems which are 'theories' because they are organized and coherent and are used to explain, interpret, and make predictions about the world. According to Wellman and Gelman (1998, pp. 537–538),

> Conceivably, children could just learn from their elders the relevant facts. However, children's understanding reveals the imprint of their larger coherent theories of physical objects . . . Vosniadou and Brewer's studies demonstrate the coherence of children's physical beliefs by showing their conceptual systematicity even in cases where children's conclusions are wrong, at odds with, or only partly adjusted to adult beliefs and input.

In common with theory theory, Vosniadou's mental model account places emphasis on the individual child constructing her own mental models, first on the basis of observations and intuitions, and then gradually incorporating scientific information. Vosniadou and her colleagues do, therefore, recognize the role of culture in the development of a scientific concept of the Earth (see Diakidoy *et al.*, 1997, for discussion of their 'cultural mediation hypothesis'). But, for these researchers, the role of cultural information about the Earth in early childhood is negligible, owing to the overwhelming strength of children's own constraints through which experiences of the flat and supported local environment are interpreted:

> We view the process of acquiring knowledge about the physical world as one in which children construct an initial understanding of the observed world based on their everyday experience. Over time, children are exposed to the adult culture's theories of the physical world and must restructure their naïve beliefs in ways that take the new information into consideration (Samarapungavan *et al.*, 1996, pp. 491–492).

The mental model account also shares with theory theory the view that cognitive development occurs through a process of conceptual change (Carey, 1985, 1995). As in the domains of biology and physics, it is claimed that learning about the Earth occurs primarily through a series of conceptual revolutions resembling scientific paradigm shifts (Kuhn, 1962). Thus, the development of children's knowledge of the Earth and astronomy is said to be closely analogous to the historical shifts from the ancient flat Earth view, through Ptolomy's geocentric theory, to the Copernican heliocentric model (Gellatly, 1997; Vosniadou & Brewer, 1992).

If correct, this account has important implications for science education. Vosniadou and her colleagues (Vosniadou, 1991, 1994; Vosniadou & Ioannides, 1998) argue that, despite the wealth of information made available by the culture, the process of acquiring scientific knowledge of the Earth is necessarily difficult and slow because children's early intuitions are so strong. This resistance to instruction, they claim, demonstrates the existence and strength of intuitions and naïve theories that constrain conceptual change.

It follows that, while children have such strongly held intuitions that contradict scientific theory, teachers' principal task should be to challenge children's intuitions. According to Vosniadou and her colleagues, it is only when these have been overcome that scientific information can be assimilated:

> the restructuring of prior knowledge is usually achieved in a slow and gradual fashion, and . . . requires the reinterpretation of certain beliefs, which individuals construct on the basis of their everyday experience. In order to promote restructuring, instruction should aim at making students aware of their entrenched beliefs and at providing them with a different explanatory framework to replace the one they have constructed on the basis of their phenomenal experience (Vosniadou, 1992, p. 347).

Problems with the mental model account

The mental model theorists' studies have been criticized on a number of grounds (e.g. Nobes *et al.*, 2003; Panagiotaki, 2003; Schoultz, Säljö, & Wyndhamn, 2001; Siegal, Butterworth, & Newcombe, 2004). One problem stems from their reliance on drawings. Children are poor at drawing three-dimensional objects and have difficulty combining perspectives (Blades & Spencer, 1994; Ingram & Butterworth, 1989; Karmiloff-Smith, 1992). Being unable to draw a sphere, it is possible that many choose instead to draw a flat, hollow, or dual Earth because these are more easily represented on paper. It has also been shown that when children draw, they display an 'orientation bias' that leads them to orient objects such as the human figure to a vertical or horizontal baseline (Pemberton, 1990; Wilson & Wilson, 1982). Instead of constraints of flatness and support, it may be this bias that accounts for children's drawings of people standing on a flat line in their pictures of initial and synthetic Earths.

Furthermore, even in late childhood, comprehension is better than production of realism in pictures: in preference to their own drawings (e.g. of human figures), children choose pictures that depict the true appearance of objects (Fayol, Barrouillet, & Chevrot, 1995; Jolley, Knox, & Foster, 2000; Kosslyn, Heldmeyer, & Locklear, 1977). The fact that children draw initial and synthetic models does not mean that they believe these drawings to represent reality.

In a recent study of adults' drawings of the Earth, Nobes and Panagiotaki (2003) found that, in response to the same instructions given by Vosniadou to children, approximately 25% of the participants depicted the Earth as flat, hollow, or dual. These pictures were strikingly similar to children's drawings of so-called initial and synthetic Earths. Yet follow-up interviews revealed that, as expected, all adults were fully aware of the actual shape of the Earth. These findings show that even adults often misinterpret the apparently simple task of drawing the Earth, and strongly suggest that these drawings – whether by adults or children – are poor representations of people's actual beliefs.

A second possible problem with Vosniadou and her colleagues' methods is that their questions may mislead children, with the result that researchers will misrepresent children's concepts. Vosniadou and Brewer (1992) describe how to interpret children's often ambiguous responses; they rephrased the same questions and asked similar questions within the same interviews. This use of repeated questioning can lead children to change their answers because they assume that their first answers must have been incorrect (Donaldson, 1978; Siegal, 1997; Siegal *et al.*, 1988). Moreover, children may base their responses on their answers to previous questions in an attempt to appear consistent, thereby giving the impression that their views are more coherent (and therefore theory-like) than is actually the case. This is particularly likely to occur when children are asked questions about their own drawings: children might seek to justify their art rather than their beliefs. For example, children who have no views on where people live, or who believe that people live around the Earth, might refer to their own drawing of a flattened Earth and therefore say that people can live only on top. Similarly, when children were asked by the mental model theorists to choose 3D models instead of to draw (Samarapungavan *et al.*, 1996), they were first asked to make their own clay models (another productive task, and one which is possibly even more difficult than drawing). Much of the apparent consistency reported in this study between their model making and model selection might be accounted for by children basing their selection on the clay model they had already made, rather than on any mental model.

A third possible problem concerns the mental model theorists' method of analysis of their findings (Nobes *et al.*, 2003). Their approach has been to inspect their data for coherent patterns of responses, construct and define from these a number of possible mental models, and then go back to their data to determine its consistency with these definitions. Theirs is therefore a circular, inductive method of analysis. Deductive validation with separate samples is required to ensure that any apparent mental models do actually occur in children's minds, not only in those of the researchers.

The fragmentation account

A number of recent studies have used different methods and found different results from the mental model theorists. Instead of being asked to draw or make models, children have been prompted to choose between 3D models and asked forced-choice instead of open-ended questions (Nobes *et al.*, 2003; Siegal *et al.*, 2004). Schoultz *et al.* (2001) asked children about a globe. All these studies found little or no evidence of initial or synthetic mental models. Instead, scientific knowledge was shown to be present from an early age. Findings from these studies have therefore led to a very different view from Vosniadou's concerning children's knowledge of the Earth: rather than having strong intuitions that influence their concepts, young children's knowledge of the Earth is 'fragmented' and incoherent (Nobes *et al.*, 2003; Siegal *et al.*, 2004). As diSessa (1988, p. 52) has argued, 'intuitive physics consists of a rather large number of fragments rather than one or even any small number of integrated structures one might call "theories".'

In a number of ways the fragmentation account of acquisition of knowledge of the Earth is similar to, and consistent with, socio-historical accounts of cognitive development in which the child is seen as a novice, or apprentice, who gains expertise through acquisition of the tools of the culture (see, for example, Chi, 1978; Gellatly, 1997; Rogoff, 1990; Vygotsky, 1978; Wellman & Gelman, 1998; Wertsch, 1998). First, in this domain children's initial state is ignorance. They have no beliefs, intuitions or theories about the Earth – either correct or incorrect – they simply do not know. Second, acquisition of this knowledge is seen as a process of gradual enrichment, or weak restructuring, as the child develops from novice to expert, as opposed to the cognitive revolutions or strong restructuring said by theory-theorists to underlie conceptual change. Third, the sources of information about the Earth are cultural (e.g. parents, schools and the media) rather than innate, intuitive or observational. And fourth, this information is communicated piecemeal, and stored fragment by fragment until the coherent cultural theory has been acquired.

Regarding science education, according to the fragmentation account there are no strong intuitions and misconceptions in this domain to be overcome, and the acquisition of scientific knowledge of the Earth, although gradual and challenging, can occur relatively early and without resistance or constraint. The role of the teacher is to provide cultural information and enable the child to make sense of this information.

Testing the contrasting accounts

There are therefore two very different sets of findings and conclusions concerning children's understanding of the Earth. The mental model account has been based largely on the evidence of children's drawings, whereas the recent critics have used 3D models. As discussed above, there are reasons to suspect that there are problems with the mental model theorists' methods that might account for these discrepancies. It is also possible that there are problems with the studies that used 3D models. Whereas drawing and open-ended questions allow children an infinite number of responses (albeit constrained by the limitations and biases of drawings), the use of only three 3D models and questions with only two possible answers in the model selection tasks (Nobes *et al.*, 2003; Siegal *et al.*, 2004) and only one 3D model (the globe) in the Schoultz *et al.* (2001) study could restrict responses so that, if a child had a view of the Earth that was not represented by the 3D models and possible answers, their choices would not adequately represent their view.

In this study we sought to re-examine the debate between the proponents of the mental model and fragmentation accounts by using neither drawings nor 3D model selection. Children and adults were presented simultaneously with a wide choice of pictures that they were asked to rank in order of how well they represented the Earth. Each of the pictures represented three of the Earth's properties on which previous studies (e.g. Nobes *et al.*, 2003; Samarapungavan *et al.*, 1996; Siegal *et al.*, 2004; Vosniadou & Brewer, 1992) have focused: the Earth's shape, the location of people, and the position of the sky. This deductive, quantitative approach precluded the need to use children's drawings, repeated questioning or circular coding schemes, and hence reduced to a minimum the possibility of ambiguity or misinterpretation of researchers' questions or of participants' responses.

Our recent work on adults' drawings of the Earth (Nobes & Panagiotaki, 2003) prompted us to include adults in the present study to validate its method, since if they failed to understand the task, so too would children. The adults also provided a range of scientific responses to the task with which children's responses could be compared in order to assess the extent to which they were adult-like and scientific.

Three issues were addressed. First, do children have intuitions of flatness and support, as Vosniadou and her colleagues claim? If so, children should prefer pictures in which the Earth is flattened or hollow, and the people and sky are on top or inside. In contrast, according to the fragmentation account, children do not have strong intuitions. Following the fragmentation account, it was predicted that children would either choose pictures in which the Earth is spherical and in which the people and sky are all around (because they already have one or more of these scientific fragments of knowledge), or they would show no preference (because they do not have these fragments and so guess). That is, there would be no preference for any of the intuitive forms of the three properties.

Second, do children have coherent mental models? If the mental model account is correct, there should be groups of children that are distinguishable by their rankings of pictures. Each of these groups should choose the pictures in ways that indicate that they have the mental models that Vosniadou and her colleagues claim to have documented. For example, children with the flat-Earth mental model should all rank the pictures in one way (with the pictures showing the flat Earth and people and sky on top preferred to other pictures), and children with the hollow-Earth mental model should all rank the pictures in another way (with pictures showing the hollow Earth and people and sky inside preferred to other pictures). In contrast, according to the fragmentation account there are no non-scientific mental models. It was therefore predicted that there would be no distinct groups of participants whose responses indicated coherence except for those who had a scientific understanding of the Earth.

The third issue was developmental: in what ways do participants' rankings of pictures change with age? According to the mental models account, most young children's choices of pictures should indicate that they have initial (flat) mental models. In middle childhood there should be high proportions of synthetic (e.g. hollow or flattened) mental models, and only by late childhood or beyond should the majority have scientific mental models. Again following the fragmentation view, adults and older children were expected to be more likely than younger children to choose pictures showing scientific forms of the properties of the Earth, and to show more evidence of the coherent scientific model. Young children who lacked this knowledge should have neither intuitive nor synthetic mental models, but only be able to make inconsistent guesses about the Earth and its properties.

Method

Sample

The participants were 10 boys and 9 girls aged 5–6 years ($M = 6.45$, $SD = .28$), 12 boys and 9 girls aged 7–8 years ($M = 8.76$, $SD = .46$), 10 boys and 12 girls aged 9–10 years ($M = 10.30$, $SD = .37$), and 13 men and 18 women ($M = 25.74$, $SD = 6.14$). The children were from three primary schools and were principally from middle and lower-middle class backgrounds. The adults were undergraduate and postgraduate university students.

Design

Participants ranked 16 pictures, each of which depicted a unique combination of forms (levels) of three properties (factors) of the Earth: shape, of which there were four forms (sphere, flattened sphere, hollow and disk); location of people, with two forms (around and on top); and location of sky, with two forms (around and on top).

The participants' mean rankings for each form of each property were calculated from their rankings of each picture on which that form appeared (minimum, or least preferred = 1; maximum, or most preferred = 16) in order to test the extent to which each participant considered each form to accurately represent the Earth. These mean rankings were also categorized in terms of each participant's preferred form (the form with highest ranking) of each property.

Materials

The 16 coloured picture cards all measured 10 cm × 10 cm (Fig. 1). Each picture showed a different version of the Earth with one of the four shapes, one of the two locations for people,[1] and one of the two locations for the sky. All combinations of these three key properties of the Earth were thus systematically varied across the pictures. Included among the pictures were representations of the main mental models that Vosniadou and colleagues claim to have found. For example, the flat Earth was represented in the picture in which the Earth was a flat disk, the people were on top and the sky was on top. The pictures were constructed using Corel Photo Paint from digital pictures of the 3D models and Lego people used in previous studies (Martin, 2005; Nobes *et al.*, 2003). They were adapted from pictures used in previous studies (Martin, 2003; Panagiotaki, 2003) and piloted to ensure that children and adults understood what they depicted. All forms of all properties were deliberately symbolic (as opposed to photographic) to avoid participants selecting pictures that they recognized rather than understood.

Procedure

Participants were interviewed individually in a quiet room of their school or university. The 16 cards were placed in random positions, picture-up and correctly orientated on a table in full view of the participant. The experimenter explained that the cards showed various images of the Earth. With reference to the cards, she then pointed out and explained each form of each of the three properties of the Earth (shape, location of people, location of sky). For example, pointing to a card that depicted the Earth as a flat disk, she said, 'Some children think that the Earth looks flat like a disk or pancake, like this' or, pointing to a card that depicted the people living all around the Earth she said 'some children think that people live all around the Earth, like this'. To ensure comprehension, the experimenter then asked the participant to describe four randomly selected pictures in terms of the shape and locations of the people and sky (i.e. 'In this picture can you tell me what is the shape of the Earth? Where are the people? Where is the sky?'). If the experimenter was not confident that the participant fully understood the pictures, this checking procedure was repeated with more cards.

[1] *In the hollow Earth pictures, all people were inside. Those corresponding to people being around the earth (i.e. unsupported) were arranged around the inner circumference, oriented towards its centre. Those corresponding to people being 'on top' (i.e. supported), stood on the lower part of the inner circumference, oriented vertically.*

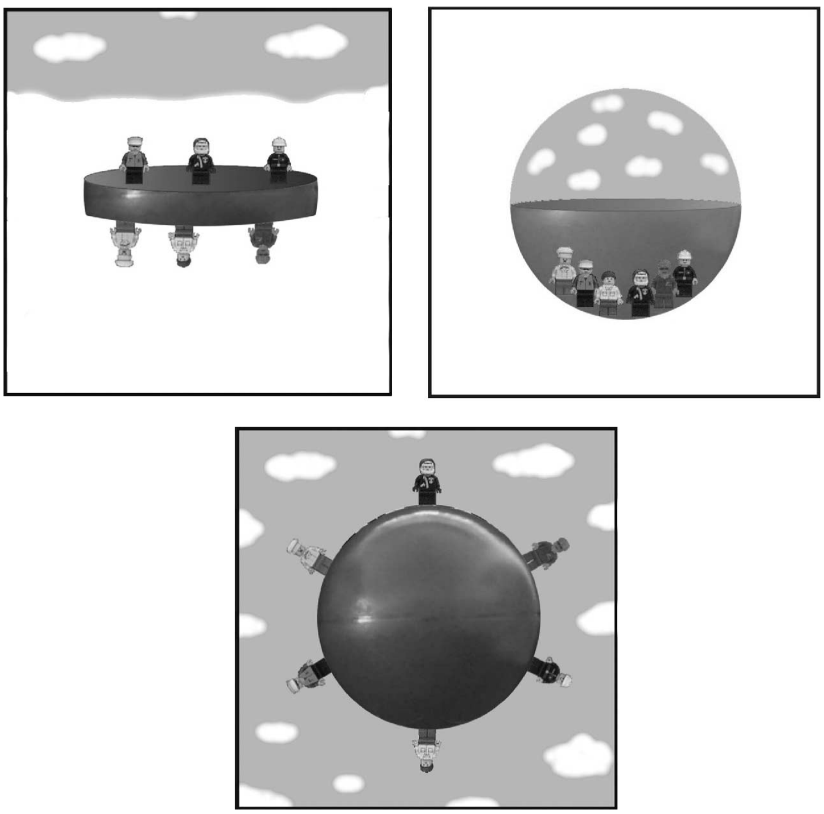

Figure 1. Examples of the pictures: flat Earth with people around and sky on top; hollow Earth with people supported and sky inside; spherical Earth with people and sky around.

Next, the experimenter asked the participant to look at all the cards and tell her whether any two pictures were identical. If a participant pointed to two pictures that he/she thought were the same, the experimenter explained the differences between them. This procedure was repeated until the participant understood that each card was unique. The participant was then asked: 'Which of these pictures looks most like the Earth?' The selected card was placed at the top right corner of the table, still in full view. The participant was then asked to repeat the procedure from the remaining cards until all had been placed in a row, from 'least like the Earth' on the participant's left to 'most like the Earth' on their right. The participant was then asked to look carefully at their row of cards and, if desired, to change the position of any in their own time.

All the adults and older children, and the large majority of the younger children, understood the pictures and completed the task quickly and easily. The two 5- to 6-year-olds who appeared not to understand were replaced and excluded from the analysis.

Results

The first issue (whether children have intuitions of flatness and support) was addressed by testing the influence on the rankings of the pictures of each of the three properties, the participants' ages, and any interactions between these factors. A mixed

4 (shape of Earth) × 2 (location of people) × 2 (location of sky) × 4 (age group of participant) ANOVA[2] with repeated measures on shape of Earth, location of people and location of sky was carried out on rankings of the 16 pictures.

The ANOVA revealed a significant main effect for shape, $F(3, 87) = 65.69, p < .001$, partial $\eta^2 = .69$, indicating that shape accounted for 69% of the variance, and an interaction between age group and shape, $F(9, 267) = 2.27, p = .02$, partial $\eta^2 = .07$. Table 1 shows each age group's mean ranking (minimum = unlike the Earth, maximum = like the Earth) of each form of each property.[3] Mean ranks above the midpoint (8.5) indicate preference for a form, and vice versa. Even the 5- to 6-year-olds judged the sphere to be more like the Earth than any of the other shapes. While the 5- to 6-year-olds did not distinguish between these other shapes, the older children and adults chose first the sphere and then the flattened sphere, but did not distinguish between the hollow or disk shapes.

There was also a main effect for location of people, $F(1, 89) = 11.96$, $p = .001$, partial $\eta^2 = .12$, and an interaction between location of people and age group, $F(3, 89) = 2.93$, $p = .04$, partial $\eta^2 = .09$. Adults' average rankings of pictures with people around the Earth were significantly higher than their rankings of pictures with people on top. The children's average rankings were also in this direction, but not significantly so.

The main effect for location of sky was also significant, $F(1, 89) = 26.32, p < .001$, partial $\eta^2 = .23$, and the interaction between location of sky and age group approached significance, $F(3, 89) = 2.65$, $p = .053$, partial $\eta^2 = .08$. While the mean ranking of pictures with the sky around the Earth was higher in all age groups than for those with the sky on top, this distinction was only significant among the 7- to 8-year-olds and adults.

The first issue was also addressed by investigating individuals' first choices of forms of each of the three properties of the Earth. Each participant was categorized according to their highest ranked form of each property (Table 2). The majority of 5- to 6-year-olds ranked the pictures with the spherical Earth above all other shapes. Over four-fifths of the older children, and almost three-quarters of the adults showed a clear preference for this shape.

The 5- to 6-year-olds showed no preference for the locations (around or on top) of people or of the sky, but two-thirds of the 7- to 10-year-olds, and about 90% of the adults, ranked the pictures with people around above those with people only on top, and pictures with sky around above those with sky on top.

To address the second issue (whether participants had mental models), a hierarchical cluster analysis was run on all participants' ranked choices of the 16 cards. This revealed eight clusters of participants, within each of which all members had similar responses to the picture-ranking task. The clusters are described in terms of mean ranking of each form of each property in Table 3 and of age group in Table 4.

Two-thirds of the sample (63 participants) were in Cluster 1. They ranked the sphere above other shapes and favoured the pictures with people and sky around the Earth. This group's picture selections therefore indicated a scientific understanding of the

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[2]*The use of ANOVA with rank ordinal data is discussed by, for example, Keppel and Zedeck (1989) and Tabachnick and Fidell (1996).*

[3]*Since there were four cards with each shape, the minimum mean ranking for each shape was 2.5 (being the average of ranks 1, 2, 3 and 4) and the maximum was 14.5. Similarly, there were eight cards with each location of people, and with each location of sky. The minima for these properties were therefore 4.5, and the maxima 12.5.*

Table 1. Ranking (midpoint = 8.5) of forms of properties of the Earth by age group

	5- to 6-year-olds				7- to 8-year-olds				9- to 10-year-olds				Adults			
			95% CI				95% CI				95% CI				95% CI	
Property	*M*	*SD*	LB	UB	*M*	*SD*	LB	UB	*M*	*SD*	LB	UB	*M*	*SD*	LB	UB
Shape																
Sphere	11.03	0.54	9.95	12.10	12.23	0.52	11.20	13.25	12.47	0.50	11.46	13.47	12.40	0.42	11.55	13.24
Flat sphere	8.18	0.47	7.26	9.11	9.27	0.44	8.39	10.16	10.18	0.43	9.32	11.04	10.51	0.37	9.78	11.23
Hollow	7.78	0.61	6.56	8.99	6.51	0.58	5.36	7.67	6.32	0.57	5.19	7.45	5.19	0.48	4.23	6.14
Disk	7.01	0.61	5.80	8.23	5.99	0.58	4.84	7.14	5.03	0.57	3.91	6.16	5.91	0.48	4.96	6.86
Location of people																
Around	8.63	0.23	8.17	9.08	8.62	0.22	8.19	9.05	8.88	0.21	8.46	9.30	9.33	0.18	8.97	9.68
On top	8.37	0.23	7.92	8.83	8.38	0.22	7.95	8.81	8.12	0.21	7.70	8.54	7.67	0.18	7.32	8.03
Location of sky																
Around	8.84	0.35	8.14	9.53	9.87	0.33	9.21	10.53	8.90	0.32	8.26	9.55	9.67	0.27	9.13	10.21
On top	8.16	0.35	7.47	8.86	7.13	0.33	6.47	7.79	8.10	0.32	7.45	8.74	7.33	0.27	6.79	7.87

Note. CI = Confidence Interval, LB = Lower Bound, UB = Upper Bound. Minimum mean rank of each shape = 2.5, maximum = 14.5. Minimum mean rank of each location of people, and of sky = 4.5, maximum = 12.5.

Table 2. First choices of forms of properties of the Earth, by age group

	5- to 6-year-olds		7- to 8-year-olds		9- to 10-year-olds		Adults		All	
Property	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%
Shape										
Sphere	10	52.63	18	85.71	18	81.82	23	74.19	69	74.19
Flattened sphere	2	10.53	1	4.76	2	9.09	2	6.45	7	7.53
Hollow	1	5.26	2	9.52	2	9.09	3	9.68	8	8.60
Disk	4	21.05	0	0.00	0	0.00	0	0.00	4	4.30
No clear preference[a]	2	10.53	0	0.00	0	0.00	3	9.68	5	5.38
Location of people										
Around	9	47.37	14	66.67	16	72.73	27	87.10	66	70.97
On top	8	42.11	5	23.81	6	27.27	4	12.90	23	24.73
No clear preference[a]	2	10.53	2	9.52	0	0.00	0	0.00	4	4.30
Location of sky										
Around	8	42.11	14	66.67	15	68.18	28	90.32	65	69.89
On top	7	36.84	5	23.81	6	27.27	3	9.68	21	22.58
No clear preference[a]	4	21.05	2	9.52	1	4.55	0	0.00	7	7.53

[a] Participants whose top two or more mean rankings of forms of the property were equal.

Earth. Almost half of the youngest children chose this distribution of cards, and the proportion increased with age to over four-fifths of the adults.

Cluster 2 also ranked pictures depicting the sphere with the sky and people around above the alternatives, and so these 12 participants were also classified as having a scientific understanding of the Earth. They differed from Cluster 1 in that they more clearly distinguished between pictures according to the position of the sky, and less clearly in terms of the shape of the Earth. It appears that for members of this group the location of the sky was more salient than was the shape of the Earth. More than a quarter of the children aged 7–8 years were included in this cluster, and there were other members from the three other age groups.

Cluster 3 did not differentiate the pictures according to location of sky or of people. These six participants, including three 5- to 6-year-olds and one adult, preferred both the sphere and the hollow Earth to the other shapes, suggesting that for this group, the only criterion by which they ranked the pictures was whether the Earth was spherical.

The four participants – including two 5- to 6-year-olds and an adult – in Cluster 4 preferred the pictures in which the sky was around the Earth and the people were on top. They also considered the picture showing a hollow Earth with people and sky around to be a good representation of the Earth, but otherwise showed no strong preference for any shape.

Cluster 5 favoured pictures in which the Earth was either a disk or hollow. Overall, they did not distinguish between pictures according to the location of the people or of the sky. However, these three young children ranked the pictures with the disk and the people on top higher than all other cards.

Cluster 6 also did not differentiate between pictures according to the location of the people or the sky. These two young children had a strong preference for both the sphere and for the disk.

Table 3. Mean ranking of forms of each property of the Earth by cluster of participants

Property	1: Scientific, focus on shape		2: Scientific, focus on sky		3: Sphere and hollow		4: Sky around, people on top		5: Disk and hollow		6: Sphere and disk		7: Sphere, sky on top		8: People around	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Shape																
Sphere	13.26	1.25	9.58	1.65	12.08	1.19	7.75	0.98	5.92	0.52	12.50	2.83	9.75	2.12	8.50	0.00
Flattened sphere	10.67	1.47	8.67	1.17	6.42	1.08	7.88	2.77	5.92	2.10	4.75	3.18	9.13	0.53	8.50	0.00
Hollow	5.08	2.01	7.85	1.90	10.54	2.71	10.19	3.17	10.17	0.58	5.50	1.41	7.88	2.65	8.50	0.00
Disk	4.99	2.20	7.90	1.43	4.96	2.24	8.19	1.11	12.00	2.38	11.25	1.06	7.25	1.06	8.50	0.00
Location of sky																
Around	9.13	0.95	12.23	0.51	8.27	0.34	9.56	1.05	8.42	1.13	8.69	0.09	4.63	0.18	9.00	0.00
On top	7.87	0.95	4.77	0.51	8.73	0.34	7.44	1.05	8.58	1.13	8.31	0.09	12.38	0.18	8.00	0.00
Location of people																
Around	9.09	0.80	9.15	0.73	8.29	0.57	6.41	1.02	8.46	0.81	8.38	0.88	8.56	0.62	12.50	0.00
On top	7.91	0.80	7.85	0.73	8.71	0.57	10.59	1.02	8.54	0.81	8.63	0.88	8.44	0.62	4.50	0.00

Table 4. Composition of clusters by age group

Age	1: Scientific, focus on shape *N*	%	2: Scientific, focus on sky *N*	%	3: Sphere and hollow *N*	%	4: Sky around, people on top *N*	%	5: Disk and hollow *N*	%	6: Sphere and disk *N*	%	7: Sphere, sky on top *N*	%	8: People around *N*	%	Total *N*
5–6 yrs	9	47.37	1	5.26	3	15.79	2	10.53	2	10.53	1	5.26	0	0.00	1	5.26	19
7–8 yrs	12	57.14	6	28.57	1	4.76	0	0.00	1	4.76	1	4.76	0	0.00	0	0.00	21
9–10 yrs	16	72.73	2	9.09	1	4.55	1	4.55	0	0.00	0	0.00	2	9.09	0	0.00	22
Adults	26	83.87	3	9.68	1	3.23	1	3.23	0	0.00	0	0.00	0	0.00	0	0.00	31
Total	63	67.74	12	12.90	6	6.45	4	4.30	3	3.23	2	2.15	2	2.15	1	1.08	93

Both the 9- to 10-year-olds in Cluster 7 had a scientific view of the shape of the Earth, but their judgments of the pictures were based primarily on whether the sky was on top. Their rankings were not influenced by the location of the people.

Cluster 8 consisted of one 5- to 6-year-old whose principal criterion was that people live all over the Earth rather than only on top. Among those cards with people around, he preferred those with the sky around and, first the sphere, second the flattened sphere, third the disk, and last the hollow Earth. This would suggest a scientific view of all three properties and an emphasis on people rather than on shape (Cluster 1) or sky (Cluster 2). However, among those cards with people on top, his order of preference for shape was the opposite (i.e. first the hollow, second the disk, third the flattened sphere and last the sphere), and he was not concerned with the location of the sky.

Discussion

If the mental model account is correct, and there are strong constraints or intuitions of flatness, young children should consider pictures depicting a disk, hollow or flattened sphere to be more accurate representations of the Earth than pictures of a sphere. This was not found to be the case. Even children aged 5–6 years showed a clear preference for the spherical Earth. Consistent with the first hypothesis and the findings of studies using 3D models (e.g. Nobes *et al.*, 2003; Schoultz *et al.*, 2001; Siegal *et al.*, 2004), even young children demonstrated scientific knowledge of the shape of the Earth.

Similarly, if there is a strong constraint of support, children should believe that people and the sky are only on top of the Earth. No evidence for such a belief was found. Instead, it appears that by 7–8 years most children already know that the people and sky are around the Earth. Those children who do not know have no view (that is, they have neither conception nor misconception), and so do not choose pictures according to these criteria.

The second issue (whether there are groups of participants whose responses correspond to Vosniadou's mental models) was addressed using cluster analysis. This revealed that four-fifths of the sample, including the large majority of adults and 7- to 10-year-olds, and over half of the youngest children, had scientific views of the Earth in terms of the three criteria used here. Some focused on the position of the sky (Cluster 2) but for most the shape was the most salient property (Cluster 1). These findings show that, by 7–8 years, the large majority of British children already have adult-like scientific knowledge of these properties of the Earth.

Of the remaining participants, it is likely that at least some gave non-scientific responses because they did not understand the task. For most, the locations of the sky and people were irrelevant. Of the eight clusters, only two – with a total of just five members – bore any resemblance to any of the naïve mental models proposed by Vosniadou and her colleagues. Members of Cluster 5 favoured the pictures in which the Earth was a disk with people on top, suggesting that they had flat-Earth mental models. However, they had no preference concerning the position of the sky, nor any overall preference for people being on top, indicating a lack of coherence.

The other cluster whose picture rankings might have resembled a naïve mental model was Cluster 6. These children's preference both for pictures of spherical and flat Earths might be interpreted as indicating a dual-Earth mental model. On the other hand, it might also have been based on their knowledge that the Earth is both (locally) flat and (globally) spherical. Moreover, if they did have a coherent dual-Earth mental model, they would have been expected to prefer pictures with the people and sky on top, but this was not the case.

These findings differ substantially from Vosniadou and Brewer's (1992). They reported that 50% of their Grades 1 and 3 children had non-scientific mental models, 27.5% had scientific mental models, and 22.5% gave mixed (inconsistent) responses. In contrast, a majority even of the 5- to 6-year-olds in the present study selected pictures that indicated scientific views of the Earth that were similar or identical to those of adults. All of the remaining children gave inconsistent responses: none gave responses that indicated any of the naïve mental models by all three criteria. Our findings support the second hypothesis: most children have some scientific knowledge of the Earth, and when they do not have a particular fragment of knowledge (concerning, for example, the location of the sky), they guess. It is likely that these random guesses sometimes give the impression of coherence because, by chance, they sometimes appear consistent with one another.

The absence of evidence for non-scientific mental models in the present data is unlikely to result from our method being less sensitive to children's understanding than Vosniadou and her colleagues' method: on the contrary, the picture ranking task used here, elicited substantially more scientific responses than did the drawing task used by the mental model theorists. This is consistent with the points outlined in the introduction concerning the problems associated with children's drawings and responses to repeated questions. It supports the claim (e.g. Nobes *et al.*, 2003; Schoultz *et al.*, 2001; Siegal *et al.*, 2004) that naïve mental models are methodological artifacts of the drawing task and of the analyses employed by the mental model theorists.

The third issue examined here was developmental. The findings supported the hypotheses that the extent of scientific knowledge and the proportion of participants with the coherent scientific model would increase with age. There was no indication that the development of knowledge of the Earth involves first initial and then synthetic mental models, before the scientific model supersedes these in late childhood.

Children's knowledge that the Earth is a sphere around which are people and sky cannot have been acquired from intuitions or observations. It must have been culturally communicated. These findings are therefore consistent with those of previous studies (e.g. Nobes *et al.*, 2003; Siegal *et al.*, 2004) that have used very different methods and support an enculturational view of knowledge acquisition in this domain. The lack of coherence in young children's knowledge is consistent with the notion that cultural information is communicated piecemeal to children and that this knowledge remains fragmented until the coherent cultural view is acquired. Its fragmented, incoherent content and structure mean that children do not have anything like a naïve theory or 'mental model' of the Earth. The only theory that children acquire is the scientific theory that culture communicates, presumably through linguistic and visual means by school, parents, and the media. While young children might have strong constraints and construct their own intuitive theories in domains such as those of biology (e.g. Hatano & Inagaki, 1994; Slaughter, Jaakkola, & Carey, 1999), physics (e.g. McCloskey, 1983), and understanding others' minds (e.g. Wellman, 1990), this does not appear to be the case in the development of knowledge of the Earth. As Siegal *et al.* (2004, p. 25) point out, cosmology differs from 'aspects of biology such as the edible-inedible distinction or bodily contamination in that children are not constrained to seek and receive information on the shape of the earth and the day-night cycle.' Instead, the Earth is one of many phenomena that cannot be tested experientially, such as the past and the future, life after death, the stars and the sun. According to Harris (2000, p. 165), in the absence of empirical feedback, 'children use that alternative, species-specific mode of information gathering – discussion and conversation – to seek enlightenment. In such contexts, they are likely to learn about, and come to rely on, the collective representations of their culture concerning the nature of numerous phenomena.'

A limitation of the present study is that, despite the extensive piloting of the stimuli, and the experimenter's careful instructions to participants, the task of sorting 16 pictures may have been too demanding for some of the participants. This might have led to their failure to represent their mental models. However, the large majority of the participants found the task easy. The fact that over 50% of the youngest children, and 80% of the older children gave adult-like scientific responses, shows that at least for these children, the meaning of the task was clear, since the chances of anyone giving such a response by guessing are extremely low. If this explanation of our results were correct, it would follow that only those few children who did not understand the task had naïve mental models (or strong intuitions), and it is far from clear why this might be the case.

Another possible problem with the present study is that the task might not be conducive to the construction of mental models. As Vosniadou and Brewer (1992, pp. 575–576) point out, it is unclear whether mental models are 'pre-compiled theories which are stored in long-term memory', or 'constructed by the children on the spot'. If the latter is the case, perhaps this construction does not occur in some situations (such as 3D model choice and picture selection), but does in others (the drawing task). While it is not clear why this might be so, this possibility cannot be discounted. But Vosniadou and Brewer continue: 'regardless of how this issue is resolved . . . there are some stable underlying conceptual structures which constrain the range of possible mental models that children can form'. For this reason, we consider the lack of evidence found in the present study for any 'underlying conceptual structures' (i.e. intuitive 'entrenched presuppositions') that constrain children's understanding of the Earth to be at least as informative as the failure to find any naïve mental models.

Further research is required to examine the reasons for the discrepancies between the findings of the mental model theorists' work and those of this and other recent research. In particular, the proposal that children's drawings are poor representations of their knowledge and views needs to be tested. This research might involve the use of several tasks (e.g. drawing, model-making, 3D model choice, and picture selection) with the same individuals, and asking them to explain any inconsistencies in their responses to the various tasks.

In summary, these findings indicate that even young children have some knowledge of the scientific view of the Earth. The large majority of children showed no evidence of intuitions or constraints of flatness or support. None appeared to have naïve mental models in which all three properties of the Earth were coherent. If there were any constraints or framework theory of physics (Wellman & Gelman, 1998), their influence in this domain of knowledge must therefore be weak. The possibility that a small number of children construct initial or synthetic mental models cannot be discounted, but their prevalence is very much lower than Vosniadou and her colleagues' findings suggest. Moreover, any constraints or framework theory must be easily displaced by cultural knowledge because the knowledge held by even the youngest children shows that there can be little resistance to instruction of scientific knowledge in this domain. The existence of counter-intuitive scientific knowledge from an early age, and the lack of coherence in this knowledge before the scientific model is acquired, are consistent with the fragmentation account of children's understanding of the Earth.

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