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Children's understanding of the earth in a multicultural community: mental models or fragments of knowledge?

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Abstract

*Children's understanding of properties of the earth was investigated by interviewing Asian and white British classmates aged 4–8 years (*N = 167*). Two issues were explored: whether they held mental models of the earth (Vosniadou & Brewer, 1992) or instead had fragmented knowledge (di Sessa, 1988); and the influence of the children's different cultural backgrounds. Children selected from a set of plastic models and answered forced-choice questions. Using this methodology, there were no significant differences in the overall performance of Asian and white children after language skills were partialled out. Even young children showed an emerging knowledge of some properties of the earth, but the distributions of their combinations of responses provided no evidence that they had mental models. Instead, these distributions closely resembled those that would be expected if children's knowledge in this domain were fragmented. Possible reasons for the differences between these findings and those of previous research are discussed.*

Introduction

Acquiring an understanding of the earth's properties cannot be accomplished solely through a process of direct observation and individual construction. Appearances, such as the world's apparent flatness, can be deceptive; and facts, such as the possibility of living in the Southern Hemisphere without falling off, are counterintuitive. To a large extent, then, knowledge in this field must be transmitted through lessons and explanations from adults, and exposure to cultural resources such as pictures, books, stories and audio-visual media.

The process of acquisition of this knowledge is gradual. Young children frequently claim, for example, that it is possible to fall off the edge of the flat earth, and that the sky is 'on top' of the earth. Previous research has suggested that it is only by late childhood or adolescence that most individuals come to share the scientific view of a spherical, unsupported earth with objects falling towards its centre (e.g. Nussbaum & Novak, 1976; Sneider & Pulos, 1983; Vosniadou & Brewer, 1992). The development of this understanding can reveal much about how scientific concepts are adopted and how conceptual change is brought about.

One view is that, before individuals adopt the scientifically accepted concepts, they have intuitions, presuppositions or naïve theories that guide or constrain the acquisition of knowledge. If this is the case, it follows that the role of cultural transmission of scientific knowledge is relatively slight during the initial stages of acquisition. Instead, direct observations of the world are likely to be more significant until cultural information gradually begins to be synthesized into existing naïve theoretical constructs. The educational implication of this approach is that, since children's naïve preconceptions will tend to hinder their acquisition of scientific concepts, it may be necessary to help children to restructure their knowledge rather than simply to provide information for assimilation (Diakidoy & Kendeou, 2001).

This view is espoused by Vosniadou and her colleagues (e.g. Diakidoy, Vosniadou & Hawks, 1997; Samarapungavan, Vosniadou & Brewer, 1996; Vosniadou, 1994, 1996; Vosniadou & Brewer, 1992, 1994) in their work on children's understanding of the earth. They argue that young

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children's thinking is strongly influenced by observations of the local environment, for example, that landscapes are generally flat and objects need support. The young child is said to have a framework theory, or intuitive physics, that is based on these presuppositions.

According to this view, children have mental models of the earth. That is, even young children have 'theories' which are internally consistent representations. At first, they hold 'initial' models that are based on their framework theory and involve robust, 'entrenched' beliefs that the earth is flat and supported. As children are increasingly exposed to cultural information that is assimilated through the framework theory, these initial models gradually succumb to more sophisticated hybrid, or 'synthetic', mental models. For example, Vosniadou and her colleagues claim that some children reconcile the information that the earth is spherical with their entrenched beliefs that the world is flat by forming a 'dual earth' model. This consists of a round earth in the sky, and a flat earth on which people live. By late childhood, most children relinquish synthetic models and adopt the culturally received scientific one.

Based on the premise that all children, whatever their culture, share the same experiences of flatness and the need for support, Vosniadou and her colleagues have proposed that young children's framework physics is universal and, hence, that initial models all share the same deep structure. By interviewing children of various ages and cultures, and comparing their drawings, they claim to have shown that the developmental sequence of mental models, from intuitive through synthetic to scientific, is indeed universal. Though there were specific cultural influences, a number of similarities were found in the cosmologies of young children in various cultures, including Samoan (Brewer, Hendrich & Vosniadou, 1987), Greek (Vosniadou & Brewer, 1989), Native American (Diakidoy *et al.*, 1997) and Indian (Samarapungavan *et al.*, 1996).

An alternative view is that young children's concepts lack theoretical structure or coherence, and are not constrained by presuppositions or intuitions. Instead, until children have acquired a scientific model, they are 'theory neutral'. The development of understanding of the earth, for example, involves the gradual accumulation of fragments of cultural information that may be wholly inconsistent with one another. According to this view of development, children have no mental models prior to gaining understanding of the prevailing cultural theory. Children are, from an early age, the recipients and holders of cultural information that, at least until they understand the scientific theory, remains unsystematic and fragmented. As di Sessa (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 an investigation by Siegal, Butterworth and Newcombe (2003) evidence was obtained that tends to support the latter position. Using plastic models and a forced-choice procedure, they have shown that even 4- and 5-year-olds in Australia frequently demonstrate aspects of scientific understanding of non-intuitable cultural information. Moreover, they found little evidence for initial or synthetic mental models. They report that most children who did not yet have the scientific model showed considerable inconsistency and lack of coordination in their responses to questions. Moreover, Schoultz, Säljö and Wyndhamn (2001) found that, by providing children with a globe, even first grade Swedish children demonstrated sophisticated knowledge of the shape and properties of the earth. Again, no evidence of intuitive mental models or constraints was found. Such findings challenge the contention that even young children have systematic and internally consistent mental models of the earth.

Methodological issues

Why, then, do Vosniadou and her colleagues appear to have found a number of internally consistent models among their interviewees, while Siegal and Schoultz and their colleagues have not? One possibility is that the reason lies with the different methods used by researchers. Vosniadou and colleagues (e.g. Vosniadiou & Brewer, 1992, 1994; Diakidoy *et al.*, 1997) have employed children's drawings to inform the researchers' interpretations of what children think. Children's drawings of the earth are, indeed, strikingly different from adults', and a number of recurring, intriguing forms – such as the dual earth – demand explanation. But the explanation need not necessarily lie in mental models.

Siegal *et al.* (2003) have pointed out that the use of drawings might lead to misrepresentation of children's understanding. Since children are poor at drawing 3-dimensional objects and have difficulty combining perspectives (Blades & Spencer, 1994; Ingram & Butterworth, 1989; Karmiloff-Smith, 1992), they might elect, for example, to draw a flat or dual earth despite knowing it to be spherical and unitary. The internal consistency of a drawing could, then, be an artefact of the 2-dimensional medium rather than a representation of the child's mental reality.

Support for the contention that model selection and drawing may produce qualitatively different responses in this domain has been found in research designed to test the appropriateness of asking children to draw their views of the earth (Martin, Moore, Clifford & Nobes, 2003). Children drew pictures of the earth and, either two weeks before or two weeks later, selected and answered questions about plastic objects that represented the mental models of the earth that, according to Vosniadou and Brewer (1992), are the most prevalent. The children's drawings closely resembled those produced by Vosniadou and Brewer's respondents, yet for most children there was little or no relation between their drawings and their choice of models. Many whose drawings appeared to indicate initial or synthetic mental models chose a sphere and showed no evidence that the constraints postulated by Vosniadou and Brewer were operating on their model selection.

However, the medium (drawing vs. model) is unlikely to be the sole explanation. Samarapungavan *et al.* (1996) used clay modelling and model selection 'in response to problems with the classification of children's two-dimensional drawings of the earth's shape in the earlier Vosniadou and Brewer (1992) study' (p. 514). They report that children still showed evidence of holding mental models such as the sphere, hollow sphere and flat disc, although not of dual earth models.

A second possible reason for the differences between researchers' findings concerns how mental models are identified. Vosniadou and her colleagues' approach has been to conduct an inductive search by asking a series of questions about the shape of the earth, transcribing the responses, and then trying 'to see if we could find evidence in the data for the consistent use of a small number of well defined mental models of the earth' (Vosniadou & Brewer, 1992, p. 547). To work out the criteria by which to assign children to mental models, Vosniadou and Brewer (1992) first made 'A careful examination of our data, together with the findings of prior research in this area' (pp. 548–549). They then referred back to their data because 'it became apparent that a number of modifications of the pattern of responses were needed . . . Analysis of the data also suggested a re-examination of the patterns of expected responses for both the dual earth model and the hollow sphere model' (p. 554). Mental models are, then, largely derived from the very data they are used to classify.

There is a danger with this circular approach that consistency will be 'discovered' because evidence of inconsistency is ignored. To illustrate this point, Vosniadou and Brewer (1992) asked children where people live, and to draw the sky. It would be predicted that children with consistent scientific mental models would say that people and the sky are all around the earth. Yet Vosniadou and Brewer classified children as having scientific mental models regardless of whether they drew people around or inside the earth, and the sky as a line around or above it. Furthermore, Vosniadou and Brewer (1992) found it necessary to allow one 'acceptable deviation' to be discounted per child. An acceptable deviation was defined as a statement being 'in principle inconsistent with the mental model in question' (p. 554). For example, children were classified as having spherical mental models despite saying that we look up to see the earth. Vosniadou and Brewer (1992) were able to disregard problematic responses and tolerate deviations because, on finding these apparent inconsistencies, they modified the mental models to allow for them. In these ways, inconsistent responses were rendered consistent. While Vosniadou and Brewer (1992) provide possible justifications for their modifications (e.g. 'drawings depicting the sky with a horizontal line located above the top of the circle . . . could represent conventional ways of drawing the sky' (pp. 555–556)), the alternative explanation – that these are true inconsistencies resulting from children's fragmented knowledge of the earth – can by no means be discounted.

Another reason to suspect that Vosniadou and Brewer's (1992) method of analysis tends to increase apparent consistency is that there was considerable overlap between some of their questions. For example, they asked both 'show me where the people live', and 'show me where Champaign [the children's home town] is'. These questions are likely to have consistent answers because children will tend to position a town where they have previously said that people live. Similarly, children were asked both 'is there an edge to the earth?' and 'can you fall off the edge?': a child who has said there is no edge is very unlikely to say that you can fall off it.

Finally, a degree of consistency is to be expected because children who are correct on one question (perhaps because they are older, better informed or more intelligent) are likely to be correct on others, and vice versa. These points might explain Vosniadou and Brewer's (1992) finding that, when they compared random allocations of individual responses with actual combinations of responses, the distributions were statistically different.

To date, then, Vosniadou and Brewer's (1992, 1994) approach has characterized mental models inductively on the basis of collected data. A required second stage involves deductive methods, where the definitions and criteria by which mental models are classified are determined before testing, and are validated empirically. This is one of the aims of the current paper.

Cultural sources of knowledge

The influence of culture is evident in Vosniadou and colleagues' findings. While they claim that the *structure* of initial models is universally restrained by flatness and the need for support, they report considerable cultural differences in the *content* of children's models. For example, it appears that some Indian children believe that the earth is a dish that floats on water (Samarapungavan *et al.*, 1996); Samoan children describe a 'Ring' universe, reflecting an important symbol in that culture (Vosniadou, 1994); and Native American children use psychological causality to explain the movement of the sun and moon in the day-night cycle (Diakidoy *et al.*, 1997). These beliefs reflect each culture's mythology, suggesting that information is transmitted through, for example, conversations, stories and pictures.

Siegal *et al.* (2003) compared the responses of Australian children with those of children in England. They found that, although there was no significant difference in their spatial reasoning, young Australian children understood the shape of the earth earlier than did their English counterparts. These researchers suggest a number of possible reasons for the different rates of knowledge acquisition by their Australian and British respondents. Australia is a large landmass saliently located in the Southern Hemisphere whose inhabitants often have close cultural links with people living in the Northern Hemisphere. It therefore seems likely that Australian children might be exposed to discussions and stories about other countries that would provide information about, for example, the sphericity of earth. Other possible reasons include differences between school systems or the mass media in the two countries.

This paper focuses on the opportunity afforded by London's large Asian school population to look at a number of these issues. Asian children growing up in London have strong links with another continent because almost all have parents or grandparents who were born in Asia and have close family there. Moreover, they are culturally and linguistically different from the majority culture, and therefore likely to have increased awareness of their families' origins. These factors might be expected to increase exposure to geographical information and, relative to their classmates who lack such international contacts, enhance children's understanding of, for example, the shape of the world.

The cultural diversity of East London offers a natural experiment in the role of culture in cognitive development. The present study compared for the first time the knowledge of the earth of children of different cultures – Gujarati and white[1] – growing up in the same area, and attending the same schools and classes. In this way, the possible impact of differential schooling, that may account for previous findings of cross-cultural differences, was controlled.

Unlike most of their white classmates, Gujarati children in London have close family ties with another continent. Many have spoken by telephone to, or even visited, their Indian relatives. The view that these family connections are key influences in children's understanding of the earth would be supported if Gujarati children were found to have superior levels of understanding of the earth compared to white children.

A potentially confounding factor in cultural comparisons is that of language. Especially during the early years, Gujarati children attending schools in London tend to have rather poorer spoken English than their white classmates as a result of their usually speaking Gujarati at home. Thus their performance in interviews might be affected because their poorer English hinders their acquisition of information, comprehension of interviewers' questions, or expression of views.

In this study children of three age groups were tested in order to compare the mental model account of knowledge acquisition (Vosniadou & Brewer, 1992, 1994) with that of fragmentation accounts (e.g. di Sessa, 1988). Classmates with very different cultural and linguistic backgrounds – Gujarati and white British – were included to investigate whether, with language controlled for, any differences between children's understanding of the earth might arise from factors such as family connections and cultural mythologies.

We hypothesized that children's responses would reveal evidence for fragmented knowledge rather than mental models, as indexed by inconsistency rather than consistency. The prediction for the relative performance of white and Gujarati children was left open as Gujarati children could be expected to have had greater exposure to information about the earth's properties than their white classmates, but might be hampered by their poorer English language skills.

Method

Sample

Participants were 167 children (82 Gujarati and 85 white) attending eight infant and primary schools in East London. The children were divided into three age groups: 4–5-year-olds (M = 5.19 years, SD = 0.41); 6–7-year-olds (M = 7.03 years, SD = 0.48); and 8-year-olds (M = 8.28 years, SD = 0.26). In each group, there were approximately equal numbers of children of each gender and ethnicity.

The Gujarati children were all born in the UK and were bilingual. The majority of their families emigrated

[1] Gujarat is a state in western India. 'White' refers here to people of European origin.

from Gujarat, a state in western India, during the 1960s and 1970s. Typically, these children spoke Gujarati at home (because some older members of the family lacked English), but English at school. The schools were all multicultural English-medium state schools.

Apparatus

Three green plastic models, each about 15 cm in diameter, were presented to the children. Each represented one of the most common mental models proposed by Vosniadou and Brewer (1992): the sphere, flat-topped sphere and disc corresponding to scientific, hollow earth and flat earth mental models, respectively. The dual earth mental model could be represented by use of both the sphere and disc. A hollow, transparent globe, consisting of separable halves and measuring 17.5 cm in diameter, could be used to represent the sky, either as a sphere or hemisphere.

Measures

Children's responses to the following four questions are presented here. These questions are based on those used by Vosniadou and Brewer (1992) about the properties of the earth, and concern the key concepts of shape, gravity and support. Each question was phrased to force a choice between a counterintuitive, correct response, or an intuitive, incorrect response.

1. 'Look at these models. Here is a round ball, here is a part of a ball with a flat top, here is a flat surface. Can you point to the model that shows how you think the world really is?'
2. 'If you walked for many days in a straight line, would you fall off the edge of the world?'[2]
3. 'Can people live up there, down there (all over the world)?'
4. 'Some children think the sky is all around; other children think the sky is only on top. Show me, using the model of the world you have chosen, where the sky really is.'

A Gujarati interviewer was involved in piloting the interview instrument, both in English and Gujarati, to ensure that the instructions and questions were comprehensible to Gujarati children in either language.

The long form of the British Picture Vocabulary Scale (BPVS) was used to assess children's verbal vocabulary comprehension age for standard English (Dunn & Dunn, 1982).

[2] Siegal *et al.* (2003) found that exchanging the potentially ambiguous word 'earth' with 'world' made no difference to children's responses.

Procedure

The children were interviewed individually at school for 20–25 minutes. They were introduced to the interview by being told that we were interested in what children of their age thought about the world; that the interview was not a test; that no one apart from the researchers – including their teachers – would know what they said; and that they could say that they didn't know, not answer, or terminate the interview, if they wanted.

The participants were first assessed using the BPVS and then given a 15-item interview of fixed order that began with the questions about the shape and properties of the earth that are reported here. The interview went on to consider the day/night cycle and perspective taking (see Siegal *et al.*, 2003, for a description and discussion of this instrument).

If, in the interviewer's opinion, a child did not understand the question, the interviewer would repeat and, if necessary, reformulate it.[3] Children were not asked to explain or justify their responses (an approach that we have since explored in Martin, Clifford, Moore & Nobes, 2001).

Props were hidden from the children until they were required. The participants were then shown all three models and asked the first question. Children could use more than one model if they desired. The other models were then moved out of sight, and, for the remainder of the interview, each child was asked the questions with reference to his or her chosen model(s). The interviewers did not point to, or touch, any part of the models except to hold them up for the child.

The Gujarati children were interviewed by the Gujarati researcher. While they were invited to be interviewed in Gujarati, all but one chose to use English. Initial coding took place during the interview, and all interviews were audio recorded to allow later inter-rater reliability checks. The three fieldworkers had some knowledge of previous work in this area, but were not aware of the specific research hypotheses.

Results

The responses of the three age groups of Gujarati and white children to four questions about the shape of the

[3] Vosniadou and her colleagues have used repeated and similar questions in their interviews. This approach was avoided here because, as Siegal (1999) and Siegal, Waters and Dinwiddy (1988) have argued, if a question is asked more than once there is a danger that children will assume that their first answer must have been incorrect. Children will then strive to provide alternative answers in the hope that they will hit upon the 'right' one, or in an attempt to provide an account that, although misconceived, is coherent.

Table 1 *Percentage of responses to the four questions by children's ethnicity and age group (years)*

Response	Gujarati (n = 82)				White (n = 85)				All (N = 167)			
	4–5	6–7	8	All	4–5	6–7	8	All	4–5	6–7	8	All
Model chosen												
Sphere	66.7	86.2	96.6	84.1	59.3	96.6	100	85.9	62.7	91.4	98.3	85.0
Flat-topped sphere	25.0	0	3.4	8.5	11.1	0	0	3.5	17.6	0	1.7	6.0
Disc	8.3	13.8	0	7.3	29.6	3.4	0	10.6	19.6	8.6	0	9.0
You can't fall off the edge	65.2	48.3	57.1	56.3	70.4	75.9	82.8	76.5	68.0	62.1	70.2	66.7
People can live all over	54.2	69.0	82.8	69.5	51.9	69.0	96.6	72.9	52.9	69.0	89.7	71.3
The sky is all around	25.0	55.2	62.1	48.8	37.0	65.4	69.0	57.3	31.4	60.0	65.5	53.0

earth are presented here. In the first stage of the analysis, responses to each question were examined to determine any links between performance and age, ethnicity and language, and the relative influence of these factors on children's responses. In the second stage of analysis, associations between responses to questions were investigated to assess whether they were best predicted by a mental models or fragmentation account of knowledge.

The relative influences of age, ethnicity and language skills

Table 1 shows the proportion of correct responses by the Gujarati and white children. In response to question 1, most children chose the spherical model of the earth: even at age 4–5 years, a significant majority of children chose this model ($\chi^2(1) = 6.63$, $p = 0.01$). The proportion who did so increased with age: the 6–7-year-olds ($\chi^2(1) = 12.95$, $p < 0.001$) and 8-year-olds ($\chi^2(1) = 22.87$, $p < 0.001$) were significantly more likely to choose the sphere than the 4–5-year-olds. There was no significant difference between Gujarati and white children overall ($\chi^2(1) = 0.10$) or at any of the specific age levels.

Within all age groups significant majorities of white children said in response to question 2 that you can't fall off the earth ($\chi^2(1) = 8.96$, $p < 0.01$; $\chi^2(1) = 15.50$, $p < 0.001$; $\chi^2(1) = 24.89$, $p < 0.001$). The improvement with age was not significant ($\chi^2(2) = 1.20$, $p = 0.55$). Gujarati children did not perform significantly better than chance on this question, except at age 4–5 years ($\chi^2(1) = 4.26$, $p < 0.04$). The white children performed significantly better than the Gujaratis at age 6–7 ($\chi^2(1) = 4.69$, $p = 0.03$), at age 8 ($\chi^2(1) = 4.47$, $p = 0.03$) and overall ($\chi^2(1) = 7.58$, $p = 0.006$).

Responses to the third question, whether people can live all over the world, showed a strong developmental progression. The performance of both ethnicities at age 4–5 years was at chance level, but by age 6–7 highly significant proportions of both white ($\chi^2(1) = 8.34$, $p < 0.005$) and Gujarati ($\chi^2(1) = 8.34$, $p < 0.005$) children were correct. At age 8, all but one white child and five Gujarati children answered correctly. There were no significant differences between ethnicities overall ($\chi^2(1) = 0.29$, $p = 0.59$), or at any age.

Similar improvements with age occurred with responses to the fourth question. A majority of younger children said the sky was only on top (Gujaratis: $\chi^2(1) = 3.63$, $p = 0.06$; whites: $\chi^2(1) = 12.0$, $p < 0.001$). By age 6–7, the proportion of Gujaratis who gave correct answers had increased to chance, and whites to significant levels ($\chi^2(1) = 4.92$, $p = 0.03$), and by age 8 most children of each ethnicity were correct (Gujaratis: $\chi^2(1) = 3.38$, $p = 0.07$; whites: $\chi^2(1) = 8.34$, $p < 0.01$). Any differences between ethnicities at any age group, or across all three age groups, did not approach significance (overall $\chi^2(1) = 1.20$, $p = 0.27$).

Table 2 *Mean (SD) number of questions answered correctly (maximum = 4), by age group (years) and ethnicity*

Age group	Gujarati	White	Both
4–5	2.09 (0.97)	2.19 (0.74)	2.14 (0.85)
6–7	2.59 (0.87)	3.00 (0.93)	2.79 (0.91)
8	2.97 (1.05)	3.48 (0.69)	3.22 (0.92)
All	2.57 (1.02)	2.91 (0.95)	2.74 (0.99)

Table 2 shows the mean number of correct responses to the four questions made by children of the three age groups and two ethnicities. A 2 (ethnic groups) × 3 (ages) analysis of variance revealed that the white children gave significantly more correct responses than the Gujarati children ($F(1, 161) = 6.34$, $p = 0.01$). However, this difference was due almost entirely to the Gujaratis' relatively poor performance on the second question (fall off the edge of the world). When the mean number of correct responses to the other three questions were compared, there was no significant difference between the ethnicities (mean scores out of possible 3 correct: Gujarati = 2.02, white = 2.14, $F(1, 163) = 0.85$, $p = 0.36$).

There was a significant difference across the age groups in the mean number of target questions answered correctly ($F(2, 161) = 20.84$, $p < 0.001$). Tukey tests (with

Table 3 *Logistic regression models (using backwards LR) for each question with age, ethnicity and language comprehension*

Question	Age	Ethnicity	Vocabulary	χ^2	p	Goodness of fit*
Model selection: sphere vs. other	✔	✘	✔	39.83	< 0.0001	106.6
Fall off the world	✔	✘	✔	16.90	< 0.0005	162.3
Live all over the world	✔	✘	✘	20.90	< 0.0001	163.6
Sky all around	✔	✘	✘	14.89	< 0.0005	164.6

Note: ✔ A tick indicates that the variable is included in the regression model
* –2 log likelihood

a 0.05 significance level) showed that 8-year-olds gave significantly more correct answers than the 6–7-year-olds, who in turn responded correctly significantly more than 4–5-year-olds. There was no significant interaction between age and ethnicity.

A second ANOVA was carried out on the children's BVPS scores. As would be expected, there was a significant improvement in children's vocabulary comprehension with age ($F(2, 161) = 65.07$, $p < 0.001$), and the white children performed significantly better than their Gujarati classmates ($F(1, 161) = 71.56$, $p < 0.001$). There was, however, a significant interaction between ethnicity and age group ($F(2, 161) = 4.70$, $p = 0.01$). While the white children scored higher on the BPVS than the Gujarati children in each age group, post-hoc Tukey tests ($p < 0.05$) revealed these differences to be significant only at the 6–7 and 8-year levels. Within ethnicities, each older age group scored higher than younger age groups, differences that were significant, however, only between white 6–7 and 8-year-olds.

To assess whether language differences between ethnicities explained the difference in their performance, logistic regressions (backwards LR) were run in which age, ethnicity and language were the independent variables and performance on each of the four questions was the dependent variable for each separate regression (Table 3).

These analyses indicated that, for all four questions, age was a significant factor in predicting performance. Also, vocabulary predicted responses for the first two questions (model selection and falling off the earth). Since vocabulary and age share a large amount of variance it is to be expected that in some instances one variable, but not the other, would fit into the model. For no question reported here did ethnicity seem to contribute to responses, over and above age and vocabulary. In all cases, however, the goodness of fit was modest (as indicated by the high values of the log likelihood coefficient).

The relative influence of language on children's total number of correct answers to the four questions was also investigated by using vocabulary as a covariate in an ANCOVA. Following this analysis, there was no significant difference between the scores of the Gujarati and white children ($F(1, 160) = 0.05$). The differences between the three age groups were reduced to a nonsignificant trend ($F(2, 160) = 2.42$, $p = 0.09$). There was no significant interaction between age and ethnicity ($F(2, 160) = 0.36$).

Mental models or unconnected fragments of knowledge?

If children have mental models of the earth, their knowledge within this domain should exhibit a degree of systematicity and consistency. There should, therefore, be strong associations between the answers given by children. For example, children with scientific mental models would be expected not only to choose the sphere but also to say that people can live all over the world. On the other hand, children with initial or synthetic mental models would be expected to choose a different model and to say that people can only live on top. There would, then, be an association between answers to these two questions, the nature of the association being predicated upon the respondents' underlying mental models.

In contrast, a fragmentation account leads to the prediction that no strong associations between children's responses would occur. For example, children who chose the sphere would be no more likely to say that people can live all over than would children who chose another model.

In the second stage of analysis, these two contrasting accounts were tested by assessing the degree of association between children's answers. It was necessary to compare children within age and cultural groups since it is likely that associations could occur because of these factors, rather than as a result of any mental models they might have. For example, younger children might be expected to be incorrect, and older children correct, on most questions. This would result in associations between answers, due to age. In Table 4 associations between all pairs of answers by children of different ages and ethnicities are presented.

In order to test whether the associations between responses reported in Table 4 were due to age, ethnicity or language factors, the logistic regressions reported

Table 4 *Associations between responses to pairs of questions, by age group and ethnicity*

Response pair	Gujarati	White	Both			
	All		4–5	6–7	8	All
Sphere chosen – can't fall off	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Sphere chosen – live all over	n.s.	**	n.s.	n.s.	**	**
Sphere chosen – sky all around	n.s.	n.s.	+	n.s.	n.s.	n.s.
Can't fall off – live all over	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Can't fall off – sky all around	*	n.s.	n.s.	n.s.	**	**
Live all over – sky all around	n.s.	n.s.	**	n.s.	+	n.s.

+ $p < 0.1$; * $p < 0.05$; ** $p < 0.01$

above were run again. This time responses that were associated with each target response were added in to each model as independent variables to see whether they would add significantly to the goodness of fit of each of the models reported. In no case did the associated variables add to the goodness of fit of the models, suggesting that age and vocabulary factors were mediating any response relationships between these variables.

The predictions of the two contrasting accounts (mental models vs. fragmentation) were also tested by considering each child's combination of responses to all four questions. Three responses were possible to the first question (choose a model): sphere, flat-top or disc. These responses were coded 1, 2 and 3, respectively. For each of the other three questions (Would you fall off?; Can you live all over?; Where is the sky?) two responses were possible – correct, coded 1, or incorrect, coded 2. For each child, then, there were 24 ($3 \times 2 \times 2 \times 2$) possible ways of responding to the four questions. Each way of responding is termed a *Response Combination* (RC). In the Appendix each RC is defined and allocated a number. For example, a child who chose the sphere and said that you cannot fall off, cannot live all over, and the sky is only on top would have an RC of 1,1,2,2, which is RC number 4 (RC4).

Each child's RC was determined and, for each group of children (according to ethnicity, age, or both) the *observed distribution* of children's RCs to the four questions was mapped.

If mental models are present they should be apparent in the observed distribution of RCs. That is, mental models would be indicated by particular RCs being given by children significantly more frequently than would be expected by chance. For example, children with flat earth mental models would be expected to choose a disc and say that you can fall off the earth, cannot live all over and the sky is only on top. They would therefore have RC24.

According to Vosniadou and her colleagues, there are approximately six common mental models to which more than 80% of children's responses can be assigned (e.g. Vosniadou & Brewer, 1992; Diakidoy *et al.*, 1997). The remaining children are described as being in transition, and their models are said to be 'mixed' or 'undetermined'. If this were the case, over 80% of children would be expected to give one of about six RCs, each corresponding to one of the common mental models, and fewer than 20% of children would give other RCs, each of which would correspond to mixed models.

By contrast, if children's knowledge were structured in such a way that there is no connection, or coherence, between fragments of knowledge, a very different distribution of RCs should occur. The probability of a child giving a certain answer to one of the questions would not be associated with how they responded to other questions.[4] Like tosses of a coin, each response would be independent. The chances of a particular RC occurring would equal the product of the probabilities of each answer being given. For example, if within a group of children the proportion of correct responses, and therefore the chances of being correct, on each of the four questions were 0.8, 0.5, 0.6 and 0.4 respectively, then the proportion of children expected to answer all four correctly, and therefore to have RC1, would be $0.8 \times 0.5 \times 0.6 \times 0.4 = 0.096$. The distribution of RCs that would be expected if responses were not associated can be generated by calculating the probability of each RC in this way. This *fragmented distribution* is the distribution that would be expected to occur if children's knowledge were fragmented because their responses would therefore lack any coherence.

The two contrasting accounts, mental models and fragmentation, lead to different predictions concerning the distribution of observed RCs. If Vosniadou and her colleagues are correct, only a small number of RCs would be given by children, each corresponding to a mental model. If the fragmentation account is correct, the observed distributions should not differ significantly from the fragmented distributions.

[4] Except insofar as questions are of similar difficulty: a child who answered one question correctly is likely to answer another equally hard question correctly, and vice versa.

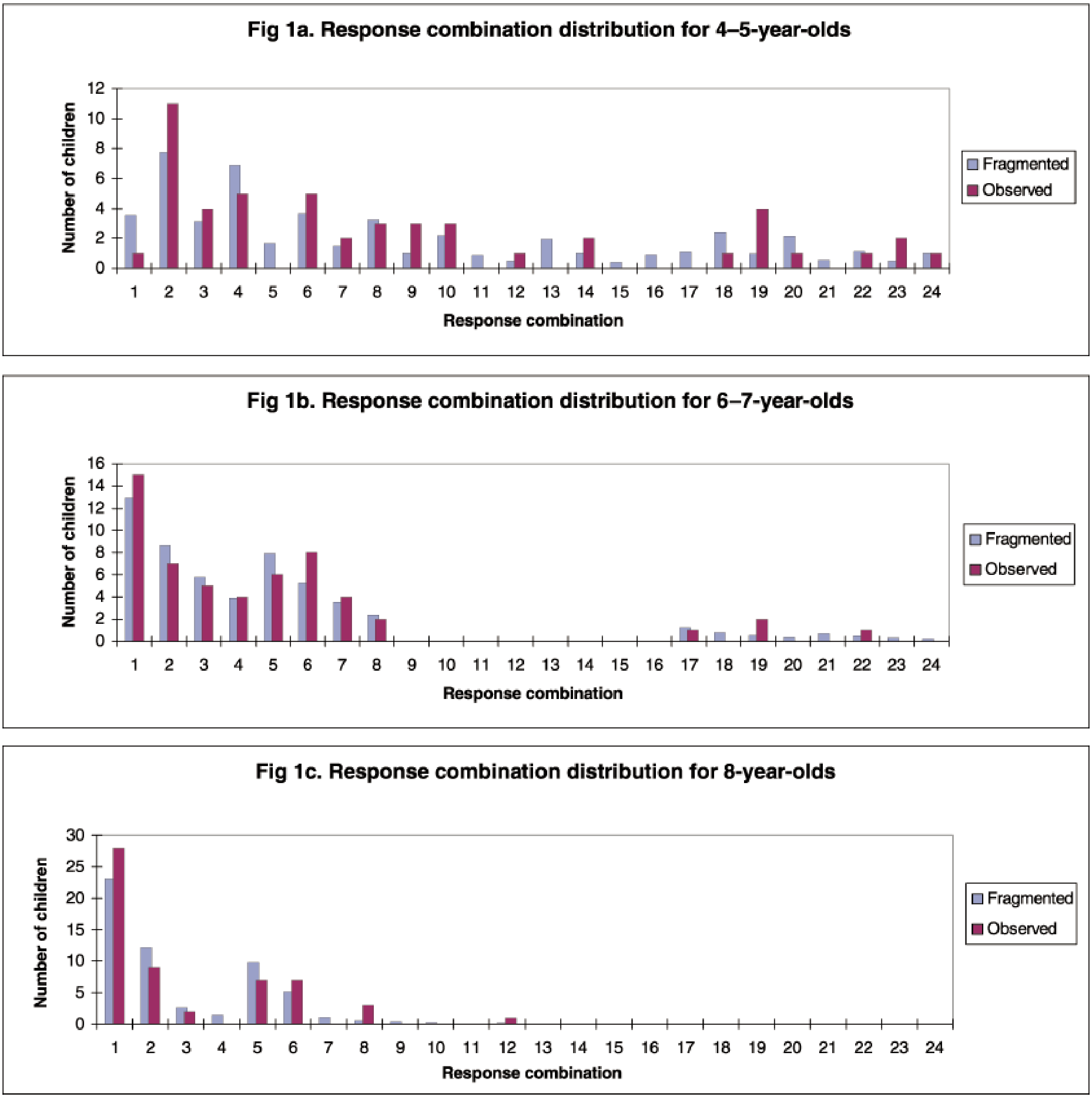
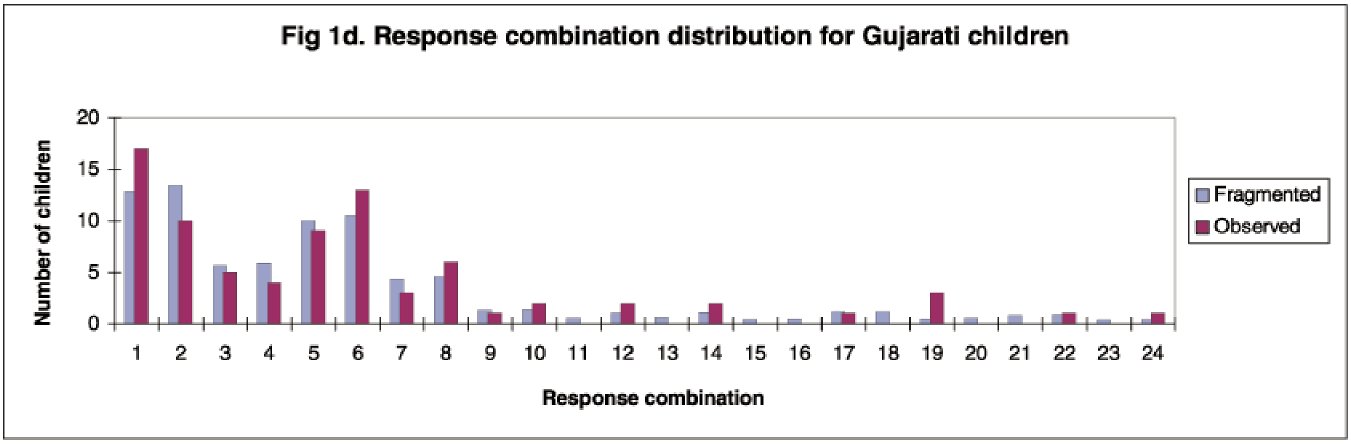
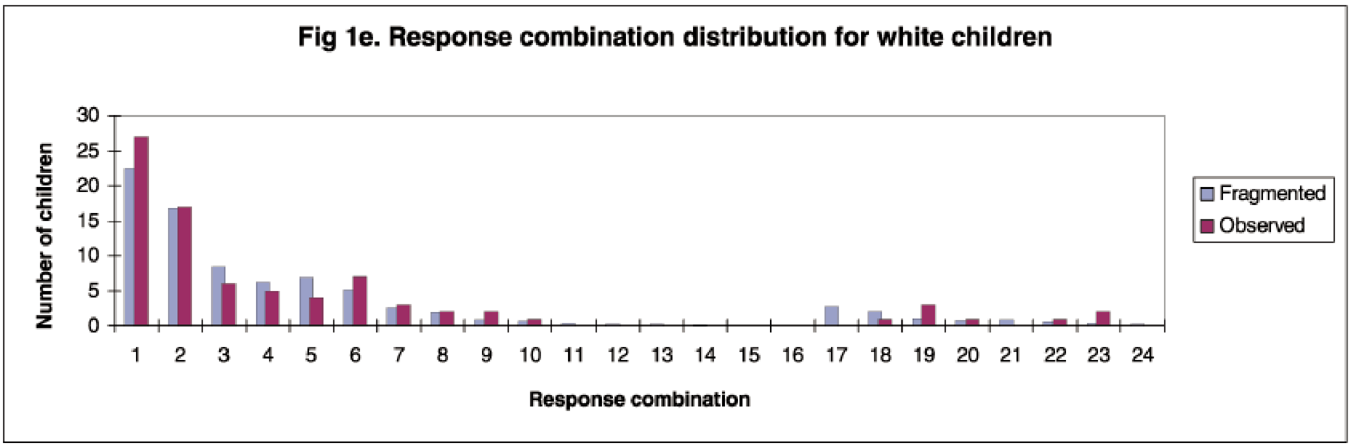


Figure 1 *Response combination distributions of age and ethnic groups. (NB. Each child's combination of responses to the four questions is his or her 'response combination'. The 'fragmented' distribution is the distribution of these response combinations by a group of children that would be expected if these responses lacked any coherence.)*

Each group of interviewees' fragmented and observed distributions are likely to be different from those of other groups since their probabilities of responses differ: for example, higher proportions of 8-year-olds than of 4–5-year-olds will answer each question correctly. For this reason, separate pairs of observed and fragmented distributions are presented for each group. The observed and fragmented distributions of RCs for each age group are compared in Figures 1a–c, for each ethnic group in Figures 1d–e, and for all children in Figure 1f.

It is clear that, for each group, there is close resemblance between the fragmented and observed distributions.





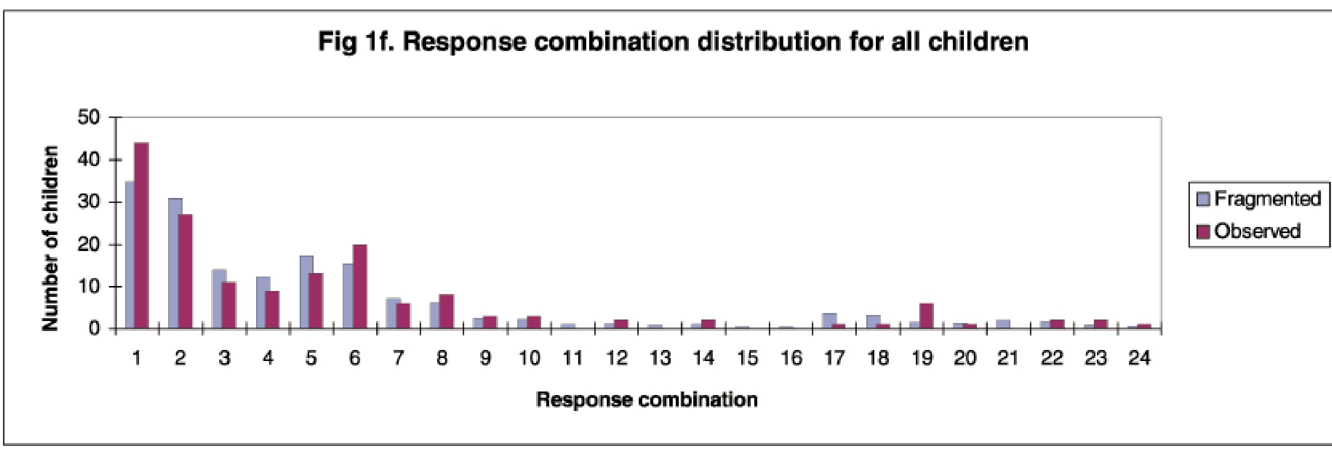


Figure 1 *Continued.*

Correlations between the two distributions, which range from moderately strong to very strong (and all highly significant), are given in Table 5 (last column). These findings indicate little or no consistency occurring in the children's responses to the four questions. Correlations were lowest for the younger children, suggesting the possibility of some modest coherence within these children's responses.

To assess whether there were any discrepancies between the observed frequencies of RCs and the frequencies predicted from the fragmentation account, all 24 observed and fragmented RC pairs were compared in each of the 12 age and/or ethnicity groupings of the children. None differed significantly. When all 167 children were considered, the number who gave RC19 ($n = 6$) was found to be marginally significantly greater than that

Table 5 *Correlation coefficients (Pearson's r) between observed and fragmented RC distributions for each set of 3 or 4 questions*

Age	Ethnicity	*N*	Questions 1, 2 & 3		Questions 1, 2 & 4		Questions 1, 3 & 4		Questions 2, 3 & 4		All 4 questions	
			r	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*
4–5 years	Gujarati	24	0.95	< 0.001	0.87	< 0.001	0.90	< 0.001	0.74	0.04	0.77	< 0.001
	White	27	0.83	< 0.001	0.82	< 0.001	0.69	0.01	0.73	0.04	0.67	< 0.001
	Both	51	0.91	< 0.001	0.93	< 0.001	0.82	< 0.001	0.80	0.02	0.79	< 0.001
6–7 years	Gujarati	29	0.98	< 0.001	0.96	< 0.001	0.98	< 0.001	0.74	0.03	0.91	< 0.001
	White	29	1.0	< 0.001	0.99	< 0.001	1.0	< 0.001	0.98	< 0.001	0.99	< 0.001
	Both	58	1.0	< 0.001	0.98	< 0.001	1.0	< 0.001	0.89	0.003	0.96	< 0.001
8 years	Gujarati	29	0.99	< 0.001	0.92	< 0.001	0.98	< 0.001	0.88	< 0.001	0.92	< 0.001
	White	29	1.0	< 0.001	0.99	< 0.001	1.0	< 0.001	0.99	< 0.001	0.99	< 0.001
	Both	58	1.0	< 0.001	0.96	< 0.001	1.0	< 0.001	0.96	< 0.001	0.97	< 0.001
All	Gujarati	82	0.99	< 0.001	0.94	< 0.001	0.99	< 0.001	0.84	0.009	0.94	< 0.001
	White	85	0.98	< 0.001	0.99	< 0.001	0.99	< 0.001	0.97	< 0.001	0.97	< 0.001
	Both	167	0.99	< 0.001	0.97	< 0.001	0.99	< 0.001	0.93	0.001	0.96	< 0.001

predicted on the fragmented distribution ($n = 1.48$). This combination involved children choosing the disc, saying you could fall off it, not live all over, and the sky is all around.

The small numbers of children in some age/ethnicity groups (minimum = 24), and the relatively large number of possible RCs (24) are likely to have led to some attenuated correlations. On the other hand, these numbers may also have masked significant differences between fragmented and observed distributions. However, the extent of any such differences is unlikely to approach those predicted from the mental model theory.

Some RCs occurred more commonly than others. A total of 138 of the 162 children (85.19%) each gave one of the eight most commonly occurring RCs, a proportion that reduced to 124 of 162 (76.54%) when the six most common were considered. These proportions are almost identical to those predicted from the fragmented distribution (85.00% and 76.88%, respectively).

Of the 24 RCs, four correspond to mental models described by Vosniadou and Brewer (1992, pp. 555–571). RC1 corresponds to their 'spherical earth' model, RC3 to the 'flattened sphere', RC12 to the 'hollow sphere', and RC24 to the 'disc/rectangular earth'. In addition, children could use both the sphere and the disc to represent the dual earth. The remaining RCs correspond to Vosniadou and Brewer's mixed models. Of the 162 children, 58 (35.8%) gave RCs that corresponded to the mental models described by Vosniadou and Brewer (1992). The observed number of children with RCs that corresponded to mental models did not differ significantly from that predicted from the fragmented distribution (35.8% vs. 31.2%, $\chi^2(1) = 0.68$). In contrast, Vosniadou and Brewer report that 49 of the 60 (81.7%) children whom they interviewed gave one of these responses, a difference that is highly significant (81.7% vs. 31.2%, $\chi^2(1) = 36.9$, $p < 0.001$).

Most of the observed RCs that were consistent with mental models (44/58 = 75.8%) were RC1, in which children were correct on all four questions. This proportion is slightly (but non-significantly) greater than that predicted from the fragmented distribution (75.8% vs. 68.7%, $\chi^2(1) = 0.71$).

There was no evidence for the flat earth model, since only one of the children gave RC24. Neither was there support for the dual earth model, since no child chose to use both the sphere and the disc.

It is possible that the inconsistency between children's responses occurs because one or more of our questions was misunderstood by children. For example, some children might have said that it is impossible to fall off the earth not because they knew it had no edge, but because they thought the edge was too far to walk to, or because there were mountains or oceans in the way. The consequence would be to create the impression of inconsistency. In order to test this possibility, fragmented and observed distributions were computed four more times, each with one of the four questions omitted. If a question were poor and so introduced inconsistency, we would expect its omission from the analysis to increase consistency, and therefore for the fragmented and observed distributions to diverge. As the central columns in Table 5 show, no strong divergence was found: in each case, correlations between the two distributions remained at least moderately strong and significant. Again, the lowest correlations occurred with the youngest group of children.

Discussion

The rate of acquisition of knowledge in this domain is by no means uniform. For example, although almost all 6–7-year-olds knew that the earth is spherical, a large proportion of 8-year-olds did not know that the sky is all around the earth. Similarly, Gujarati children in East London seemed to make no improvement between 4 and 8 years of age on the question about falling off the edge of the earth, whereas their white classmates did. While age is important, then, so too are other factors.

It was suggested that, owing to their presumed greater exposure to information about people on another continent, Gujarati children might perform better than their white classmates. This was not found to be the case. No differences were found between the groups' responses, except that Gujaratis were significantly more likely to say that it is possible to fall off the edge of the world. This difference was accounted for by the Gujaratis' relatively poor English language skills. Therefore, no evidence was found for the children's performance on these questions being influenced by culture *per se*. Instead, the only difference between the cultural groups' responses seems to have resulted from differences in verbal abilities. Good language comprehension is liable to enhance children's acquisition and communication of information in domains such as cosmology that are heavily constrained by the transmission of cultural knowledge. The finding that differences in comprehension were most closely associated with responses about falling off the earth suggests that children found this question most linguistically challenging.

According to Vosniadou and Brewer (1992, 1994), children have a framework theory based on intuitions of flatness and support that guide their responses to questions such as those asked in the present study. No evidence of such a theory or intuitions was found in the present study. Even 4–5-year-olds – at an earlier age than those generally tested by Vosniadou and her colleagues – tended to give the correct, counterintuitive answers by choosing the sphere to represent the earth rather than alternative flat models, and saying that you can't fall off the earth. It appears that children's responses were either based on culturally transmitted scientific knowledge or were guesses because the children simply didn't know.

The findings of this study support the contention that the young child's underlying knowledge structures of properties of the earth are fragmented (e.g. di Sessa, 1988), as opposed to being organized into coherent models (e.g. Vosniadou & Brewer, 1992, 1994). Language skills and age accounted for the few associations that occurred between answers to pairs of questions. The distributions of combinations of responses to all four questions, and to each possible set of three questions, closely resembled the distributions that were predicted from the fragmentation account, and were very different from those that would occur if children had mental models. Especially for the two older age groups, correlations between the fragmented and observed distributions were strong (typically $r > 0.9$) and highly significant. The number of children who gave RCs that were consistent with the mental models described by Vosniadou and Brewer (1992, 1994) was very similar to that predicted by the fragmentation account, and considerably fewer than was predicted by the mental model account. The fragmentation account of children's knowledge, then, explained almost all the variance in the children's responses. If children have mental models, their influence on responses to our questions was negligible.

Vosniadou and her colleagues' approach involves searching for mental models derived from their participants' responses, and then classifying the same responses according to these mental models. With this post-hoc, circular process there is a danger of 'finding' consistency – and therefore evidence of mental models – when in reality there is none. To illustrate this point, if the same approach were taken with the present data by defining mental models according to the six most commonly occurring RCs, it could be claimed that over three-quarters (77%) of children had consistent mental models. This proportion would rise to 85% if we chose to look for eight mental models, and even higher if 'acceptable deviations' were introduced. These proportions are very similar to those reported by Vosniadou and her colleagues (e.g. Diakidoy *et al.*, 1997; Vosniadou & Brewer, 1992), according to whom six earth shape models accounted for over 80% of the participants' responses. Yet our analyses show that these proportions are almost identical to those that would be expected by chance alone, i.e. if there were no consistency between children's responses, as shown by the fragmented distribution.

The distinction between knowledge (the awareness of certain facts) and understanding (the application of these facts in novel situations) is captured by Vosniadou and Brewer's (1992) use of factual and generative questions.[5] They propose that factual questions elicit knowledge because they test children's exposure to scientific facts but not their ability to use these facts. Generative questions, on the other hand, ask children to explain phenomena, predict events or reason about material which they cannot directly observe or have not been told about. Generative questions test understanding and hence provide information about possible underlying conceptual structures.

Of our four questions, questions one and three could be argued to be factual questions, as they concern

[5] The distinctions between 'knowledge', 'understanding' and 'guessing' have been explored in a follow-up study in which children were asked to explain and justify their responses to the questions (Martin, Clifford *et al.*, 2001).

information that is likely to have been communicated by, for example, formal schooling. Questions two and four, however, are generative questions. It might be argued that the inconsistencies reported here result from the lack of association between knowledge and understanding rather than from the absence of mental models. However, the mental model account would still predict consistency between responses to the two generative questions. We looked for such consistency but found none.

Another possible explanation of our findings of inconsistency is that our interviewees guessed their answers because of the forced-choice nature of our questions. This would lead to random response combinations, and hence to any underlying coherence being concealed. Were this the case, children would be expected to perform worse (i.e. give more incorrect answers) in our interviews than in Vosniadou and her colleagues'. But we found the opposite: even our 4–5-year-old interviewees showed knowledge and understanding of aspects of the earth that were apparent only in the responses of their older participants. Also, systematic omission of each of the four questions from the analysis resulted in little or no reduction in correlations between fragmented and observed RC distributions. This indicates that none of the four questions increased inconsistency.

The picture of knowledge acquisition that emerges from these findings is of a process of gradual accumulation, piece by piece, of loosely related fragments of cultural information. These are disorganized until the coherent scientific notion of the earth is gained. It remains for future research to establish whether this is also the case for knowledge acquisition in other domains.

The finding that language ability is an important factor in children's understanding of some aspects of the earth suggests that the transmission of this cultural information is likely to be principally linguistic. It may be the case that, although globes, photographs and other visual resources are important sources of information, understanding within this and other domains of scientific understanding is acquired primarily through conversations with adults, spoken classes given by teachers and children's own reading (Siegal, 1997, 2002).

In summary, the data presented here indicate that children's knowledge of the earth is fragmented. Fragments of knowledge appear to be acquired independently from one another, at different rates according to their content and to the linguistic ability of the child. It is likely that cultural transmission of some or all fragments is primarily linguistic, perhaps through conversations, schools and the media. There was no evidence that children's responses to questions are guided by intuitions of flatness or support. These findings are inconsistent with Vosniadou and Brewer's (1992, 1994) claim that young children's knowledge is organized into distinct mental models.

Appendix: definitions of the 24 possible response combinations

Combination number	Combination	Model choice			Fall off?		Live all over?		Sky	
		Sphere	Flat top	Disc	No	Yes	Yes	No	Around	On top
		1	2	3	1	2	1	2	1	2
1	1,1,1,1	Y	N	N	Y	N	Y	N	Y	N
2	1,1,1,2	Y	N	N	Y	N	Y	N	N	Y
3	1,1,2,1	Y	N	N	Y	N	N	Y	Y	N
4	1,1,2,2	Y	N	N	Y	N	N	Y	N	Y
5	1,2,1,1	Y	N	N	N	Y	Y	N	Y	N
6	1,2,1,2	Y	N	N	N	Y	Y	N	N	Y
7	1,2,2,1	Y	N	N	N	Y	N	Y	Y	N
8	1,2,2,2	Y	N	N	N	Y	N	Y	N	Y
9	2,1,1,1	N	Y	N	Y	N	Y	N	Y	N
10	2,1,1,2	N	Y	N	Y	N	Y	N	N	Y
11	2,1,2,1	N	Y	N	Y	N	N	Y	Y	N
12	2,1,2,2	N	Y	N	Y	N	N	Y	N	Y
13	2,2,1,1	N	Y	N	N	Y	Y	N	Y	N
14	2,2,1,2	N	Y	N	N	Y	Y	N	N	Y
15	2,2,2,1	N	Y	N	N	Y	N	Y	Y	N
16	2,2,2,2	N	Y	N	N	Y	N	Y	N	Y
17	3,1,1,1	N	N	Y	Y	N	Y	N	Y	N
18	3,1,1,2	N	N	Y	Y	N	Y	N	N	Y
19	3,1,2,1	N	N	Y	Y	N	N	Y	Y	N
20	3,1,2,2	N	N	Y	Y	N	N	Y	N	Y
21	3,2,1,1	N	N	Y	N	Y	Y	N	Y	N
22	3,2,1,2	N	N	Y	N	Y	Y	N	N	Y
23	3,2,2,1	N	N	Y	N	Y	N	Y	Y	N
24	3,2,2,2	N	N	Y	N	Y	N	Y	N	Y

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