Mental Models of the Earth, Sun, and Moon: Indian Children’s Cosmologies

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This study reports data on the acquisition of knowledge about astronomy in children from India. Based on prior research, we hypothesized that the cosmological models that children construct are influenced by both first-order and second-order constraints on knowledge acquisition. First-order constraints are the implicit assumptions that govern the construction of initial cosmological models. Examples of such constraints include the assumptions that the earth is flat and supported. Such first-order constraints are presumed to be universal. Second-order constraints arise from the specific properties ascribed to cosmological objects. For example, representations of the earth’s shape and location relative to the sun and moon constrain the kinds of mechanisms that are generated to account for the day–night cycle. We hypothesized that in cultures where both folk cosmologies and the scientific cosmological model are accessible to children, aspects of folk models are likely to be incorporated in children’s cosmologies if they provide a psychologically easier way of satisfying first-order constraints. This hypothesis is supported by our findings with regard to universality and culture specificity in children’s cosmologies. Indian children’s cosmologies honor a variety of universal first-order constraints. These include constraints on the shape of the earth (e.g., support and flatness) and on the relative locations and motions of objects in the cosmology (e.g., continuity). However, many Indian children borrow the idea that the earth is supported by an ocean or a body of water from folk cosmology. This solution to the support constraint on the shape of the earth is not found in American children’s initial cosmologies.

This article presents the results of a study examining the development of Indian children’s cosmologies. 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 naive beliefs in ways that take the new information into consideration. This general approach is supported by a variety of studies on naive beliefs about the physical world (McKloskey & Kargon, 1988; Wiser, 1988). Prior research on American children's knowledge of astronomy (Vosniadou & Brewer, 1992, 1994) is consistent with the general view of knowledge acquisition just outlined. Recently, Carey and Spelke (1994) suggested that cross-cultural comparisons of conceptual development can inform theories of domain-specific conceptual change by providing data on universal and culture specific aspects of children's knowledge representations. Such data can help clarify the nature of constraints that might govern conceptual development in various domains.

CHILDREN'S COSMOLOGIES

Certain aspects of children's knowledge of astronomy have been studied in both Western and non-Western settings (Nussbaum, 1979; Nussbaum & Novak, 1976; Sneider & Pulos, 1983). Prior research with American children (Vosniadou & Brewer, 1992, 1994) suggests that young children's mental models of the earth's shape and of the day-night cycle appear to honor a variety of first-order and second-order constraints. First-order constraints are implicit assumptions or "presuppositions" (Vosniadou & Brewer, 1994) about entities in the cosmology. Vosniadou & Brewer (1992, 1994) suggested that young children's initial models of the earth's shape appear to be constrained by two beliefs: (a) the earth is a flat plane (the "flatness" constraint) and (b) unsupported objects fall "down" on an up-down gradient (the "support" constraint). We assume that such constraints originate from the general principles of a naive physics of the kind described by Spelke (1990, 1991). For example, children who are told that the earth is round might initially construct a disc model (Vosniadou & Brewer, 1992) in which the earth is flat with round edges and is supported by ground "all the way down." Such a model would be consistent with both the flatness and support constraints. As children try to assimilate information from the scientific model provided by the adult culture, they initially construct synthetic models in which first-order constraints are modified. For example, the support constraint may be modified so that it no longer applies to the earth itself but is restricted to objects on earth (e.g., people). This allows for the construction of synthetic earth-shape models such as the hollow sphere, which represent the earth as a free-floating body in space.

Second-order constraints arise from the specific properties assigned to cosmological entities such as the earth, the sun, and the moon. Vosniadou
and Brewer (1994) suggested that mental models of the earth's shape impose second-order constraints on mental models of the day–night cycle. For example, children with initial earth-shape models, such as the disc model previously described, cannot explain the day–night cycle on the basis of the axis rotation of the earth because flipping the disc over would violate the support constraint and cause people to fall off the earth.

**THE CURRENT STUDY**

This study examines several aspects of Indian children's knowledge of astronomy such as their beliefs about (a) the shape of the earth; (b) the motions of the earth, sun, and moon; (c) the relative location of the earth, sun, and moon in space; and (d) the day–night cycle. Results of prior research by Vosniadou and Brewer (1992, 1994) on American children's mental models of the earth's shape and the day–night cycle (1994) are used for the purposes of cross-cultural comparison. Additionally, this study presents new data about children's overall cosmologies, allowing us to further examine issues concerning the internal consistency and explanatory power of children's models.

**Universality and Cultural Mediation**

Vosniadou and Brewer's (1992, 1994) analysis of constraints suggests that the same pattern of development in children's cosmologies should be observed in all cultures where the scientific model is the prevalent adult cultural model and the one presented in formal instruction. In the United States, the scientific model is the only prevalent cultural model, but the situation is more complicated in countries such as India and Greece, where indigenous cosmologies may compete with the scientific model. In these countries, the scientific model is the one presented to children in formal instruction and the one they eventually acquire. However, indigenous cosmologies embodied in mythology are more accessible to children in these cultures than equivalent pre-Copernican alternatives are in American culture. It is therefore possible, indeed likely, that such indigenous cosmologies also influence children's conceptual development. Prior work on children's earth-shape concepts illustrates this point. The American data (Vosniadou & Brewer, 1992, 1994) and Samoan data (Brewer, Herdrich, & Vosniadou, 1987) provide evidence that there are several distinct mental models of the earth that are compatible with both the flatness and support constraints (e.g., the American disc earth and the Samoan ring earth). However, the distribution of such models varies across cultures and can be influenced by a variety of culture specific beliefs. For example, the Samoan ring earth (in which the earth is shaped like an atoll) appears to be a unique, culture-specific variant of initial earth-shape models, which is influenced by prototypical organizations of Samoan social space (see Brewer et al., 1987). We expect that aspects of indigenous Indian cultural
models are most likely to be incorporated in children's cosmologies if they readily satisfy first-order constraints such as the flatness and support constraints. In other words, Indian children's initial cosmologies should honor certain universal first-order constraints, but the way in which these constraints are satisfied may be culturally mediated.

INDIGENOUS INDIAN COSMOLOGIES

An examination of historical sources reveals that from the earliest records in the Rig Veda in 2000 BC (Gombrich, 1975) through the middle ages, to the present time, there have always been several distinct indigenous cosmologies in India. However, because many of these cosmologies have important elements in common for our current purposes, we will merely present some of their salient features without attempting to give an exhaustive account of them.

One dominant theme in all the mythologies is the partition of the "egg-shaped" universe into sky, earth, and other worlds below and above the earth. The nether world and upper world do not correspond exactly to conceptions of hell and heaven in Western mythologies. They are merely peopled with other beings in the mythological scheme of living things.

Another dominant theme has to do with the shape of the earth. The earth is believed to be shaped like a disc or shallow bowl with a flat or dome-like sky cover on top. The earth itself floats on an ocean that separates it from the nether worlds. From the medieval period onward, indigenous cosmological accounts have the sun and the moon revolving around the disc-shaped earth to cause the phenomena of day and night (Gombrich, 1975).

INDIGENOUS COSMOLOGIES AND CHILD CONCEPTS

In the preceding presentation, we have tried to strip traditional cosmologies to their bare essentials, in terms of what they have to say about a naturalistic model of the universe. In the Indian context, these conceptions of the universe are intertwined with elements of theology and theistic cosmogony in a rich fabric of mythology. Our study made no attempt to directly test the knowledge that children had about indigenous cosmological theories. Our inferences about cultural mediation are based on the indirect evidence of the observed correspondences between the children's articulated views and the indigenous Indian cosmologies that were previously described. Our preliminary interviews with teachers did give us some information about the children's home backgrounds and the kinds of information they were likely to have been exposed to.

The parents of the children in the current study were highly educated and scientifically literate, urban middle-class professionals. However, it is com-
mon for well-educated adults in India to pass on religious mythologies to their children as a way of preserving their cultural traditions. The families of the children in the current study actively practiced Hindu religion. The children had access to folk mythologies from the readings of Hindu religious texts at home and in the schools that were private religious schools. The children were also likely to have had exposure to folk cosmological models from television series, movies, and mythological comic strips, which were very popular in India during the time of our study. For example, the two most widely watched television series at the time of our study were rather literal interpretations of two Hindu epics, the Ramayana and the Mahabharata.

As noted earlier, the more naturalistic aspects of traditional Indian cosmologies are intertwined with clearly mythological elements. We believe that children are most likely to assimilate those aspects of the indigenous cosmologies that do not conflict with their empirical knowledge and that are fairly close to their everyday experiences. For example, we do not believe that children are likely to incorporate certain elements of traditional cosmologies, such as the idea that the ocean below the earth was layered into seas of water, milk, and nectar. Such elements fly in the face of children's everyday observations as well as their more general beliefs about the material composition of the natural world.

**METHOD**

**Participants**

The participants were 38 children who attended two private elementary schools in which English was the medium of instruction. There were 19 children in the first grade, ranging in age from 5;8 to 6;4 years (mean age = 6;2 years) and 19 children in the third grade, ranging in age from 7;6 to 8;5 years (mean age = 7;11 years).

**Setting**

This study was conducted in the city of Hyderabad. The city is the state capital of Andhra Pradesh (a southern state) and a center of commerce and industry. Geographically, it is an inland city located on the Deccan Plateau in peninsular India. Culturally, Hyderabad is typical of any modern Indian city, a blend of industrial Western and traditional Indian cultures.

**Astronomy Curriculum in Schools**

In the schools that the children attended, the astronomy curriculum was comparable to that taught to American elementary school children. The first-grade children had been taught one unit on the shape of the earth. The third graders were taught units on the shape and motion of the earth and on the day-night cycle in the second grade. In the third grade, students had
been taught a unit on the solar system (in which they studied the locations
and motions of the planets relative to the sun) several months prior to the
beginning of our study. Although there were no globes permanently placed
in the children's classrooms, the teachers told us that they had used globes,
which they had obtained from central resource rooms in their schools, when
they taught units on the earth's shape and the day–night cycle.

Materials
The instrument used to assess children's cosmologies was a structured astra-
nomical questionnaire. The questionnaire used in the Indian study was a
modified version of a longer questionnaire1 developed for the University of
Illinois Astronomy Project (Vosniadou & Brewer, 1992, 1994). In this article,
we focus on four aspects of children's knowledge of astronomy. We present
data on Indian children's conceptions of (a) the earth's shape; (b) the
movements of the earth, the sun, and the moon; (c) the day–night cycle; and
(d) children's overall cosmologies.

Each target concept was tested with several questions. Some questions re-
quired only verbal responses, whereas others required the children to explain
their verbal responses with clay models that they made or with Styrofoam
models that they selected (see Figure 1). The set of Styrofoam models con-
tained a decoy shape (a cone) to test our assumption that the children's
choice of models did reflect their beliefs about the shape of the earth.

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1Unlike the Vosniadou and Brewer (1992, 1994) studies, the India study employed physical
models of the earth, sun, and moon for some questions. The use of these models was developed
by Vosniadou and Brewer for a second set of studies with American children (Vosniadou &
Brewer, in preparation).
Scoring
The general scoring procedure employed was developed by Vosniadou and Brewer (1992, 1994). The child's response to each question was first scored independently, and we then determined if a given child's pattern of scores for a target concept (such as the earth's shape) would fit a theoretically predicted pattern for one of a class of preestablished mental models. If a child's response pattern failed to meet the classification criteria for any preexisting model, we then reread the protocol to determine if the child might have a new unique model that we had not anticipated. If so, we established a new mental model category and specified the response criteria for classification in that category. If we were unable to understand the child's response pattern in terms of a consistent mental model, the child was scored as being unclassifiable or "mixed" with regard to the target concept. Two independent judges scored all the protocols, and the degree of agreement between judges was high (94%). After scoring the protocols independently, the two judges resolved all the remaining disagreements through discussion.

Procedure
Each of the children was tested once individually. An average interview lasted about 45 min. Most of the children chose to answer questions in English, which was the medium of instruction at their school. However, the children were also given the option of answering in Hindi (the national language) or Telegu (the regional language). Each child's responses were written down by the interviewer and also recorded on tape for later transcription. Follow-up questions were asked if the child's response on any given question was ambiguous or inconsistent.

RESULTS
In this section, we present data on Indian children's conceptions of the earth's shape; the motions of the earth, the moon, and the sun; and the day-night cycle. We then discuss how these concepts are integrated in children's overall cosmologies.

The Shape of the Earth
Ten questions were used to examine children's beliefs about the shape of the earth. The children were placed into various mental-model categories based on their responses to these questions. Tables 1a and 1b show the types of responses that were given by children placed in each of eight mental-model categories to each question concerning the earth's shape. Following Vosniadou and Brewer (1992), acceptable deviations in a mental model
category were those responses that were semantically ambiguous but could be interpreted in a manner that was consistent with the model in question. Responses that were not theoretically predicted for a particular mental model but that were subsequently judged to be acceptable deviations are shown in italics in Tables 1a and 1b (there were only two responses of this type). Additionally, there were some response types that were considered neutral because they did not differentiate between different mental model categories. For example, many of the verbal response on Question 2 (Where do people live on earth?), though unambiguous in and of themselves (e.g., “on land,” “in houses”), were not specific with regard to which part of the earth’s surface people could live on.

Of the 38 children tested, 36 were assigned to one of the eight mental model categories in Tables 1a and 1b. Two children gave responses that deviated significantly from the theoretically predicted pattern of responses for each of the mental model categories in Tables 1a and 1b. Their responses across the various earth shape questions appeared to be mutually inconsistent. They were classified as having mixed or underdetermined models.

The idea that the earth floats on a body of water is associated with several earth shape models found among Indian children, but is almost never present among American children (Vosniadou & Brewer, 1992). The pervasive belief that the earth is supported by a body of water appears to be culturally specific to Indian children and probably has its roots in the indigenous cosmologies of India. Therefore, we treat these Indian variants of the basic earth shape models previously found by Vosniadou and Brewer (1992) as unique and separate mental model categories. We discuss this aspect of Indian children’s models more fully after we have presented the data for all the earth models.

**Sphere in Space Models.** Eleven children were classified as having spherical earth models. Children with the sphere in space model thought that the earth is an unsupported sphere floating in space. Some of these children said that people live only on top of the sphere, but others said that people live all over the surface of the sphere.

**Sphere on Water Models.** Four children thought that the earth is a sphere floating on an ocean of water. These children deviated from the theoretically predicted pattern of responses for spheres only on Q9a through c and Q10 by indicating their belief that the earth was supported by a body of water. These children indicated that people lived only on the top of the earth. The following protocol illustrates the responses of children with sphere on water models.
Table 1a. Frequency of Responses to Earth Shape Questions for Spherical Models

<table>
<thead>
<tr>
<th>Earth Shape Questions</th>
<th>Sphere in space (n=11)</th>
<th>Sphere on water (n=4)</th>
<th>Spheroid in space (n=3)</th>
<th>Hollow sphere in space (n=4)</th>
<th>Hollow sphere on water (n=1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1 What is the shape of the earth?</td>
<td>a) Round: 3; b) Ball: 4; c) Sphere: 4</td>
<td>a) Round: 2; b) Ball: 1; c) Sphere: 1</td>
<td>a) Round: 2; b) Ball: 1; c) Sphere: 1</td>
<td>a) Round: 1; b) Ball: 1; c) Sphere: 2</td>
<td>a) Round: 1</td>
</tr>
<tr>
<td>Q2 Where do people live on earth?</td>
<td>a) All over: 4; b) On top: 3; d) Houses: 2; e) Countries: 2</td>
<td>a) All over: 1; b) On land: 1; c) On land: 1; d) Countries: 2</td>
<td>c) On land: 1; d) Countries: 2</td>
<td>c) On land: 3; f) Inside, on the land: 1</td>
<td>f) Inside, on the land: 1</td>
</tr>
<tr>
<td>Q3 Can you make the earth for me with this clay?</td>
<td>a) 11</td>
<td>a) 4</td>
<td>a) 3</td>
<td>a) 2 b) 2</td>
<td>b) 1</td>
</tr>
<tr>
<td>Q4 (Show earth shape models) Which one of these looks most like the earth?</td>
<td>a) 11</td>
<td>a) 4</td>
<td>a) 3</td>
<td>a) 2 b) 2</td>
<td>b) 1</td>
</tr>
<tr>
<td>Earth Shape Questions</td>
<td>Disc in space (n=5)</td>
<td>Disc on water (n=4)</td>
<td>Rectangular earth on water (n=4)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Q1 What is the shape of the earth?</td>
<td>a) Round: 4; d) Circle: 1</td>
<td>a) Round: 2; d) Circle: 1; i) Don't know: 1</td>
<td>e) Like candle: 1; f) Flat/straight: 2; g) Rectangle: 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q2 Where do people live on earth?</td>
<td>a) All over: 2; b) On top: 1; c) On land: 1; d) Houses: 1</td>
<td>b) On top: 4</td>
<td>c) On land: 1; d) Houses: 2; g) In different places: 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q3 Can you make the earth for me with this clay?</td>
<td>c) Disc: 5</td>
<td>c) Disc: 4</td>
<td>d) Square: 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q4 (Show earth shape models) Which one of these looks most like the earth?</td>
<td>c) Disc: 5</td>
<td>c) Disc: 4</td>
<td>d) Square: 4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Indian Children's Cosmologies

Sphere on water: Rohit (third grade)
Experimenter: What is here (points to space below sphere) below the earth?
Rohit: There is an ocean.
Experimenter: Can you explain that a little more? Where is the ocean? Is it here (points to region of the South Pole) on the bottom of the earth or is it here (points to space below sphere) below the earth?
Rohit: Under the ball. The ball is floating on the ocean.

Spheroid in Space Models. The spheroid models in this study bear some resemblance to the "flattened sphere" models found by Vosniadou and Brewer (1992) in American children because both types of models involve the assumption that the sphere is imperfect or that it has flat surfaces on it. Children with flattened sphere models in the Vosniadou and Brewer (1992) study believed that the sphere is flattened out on the top and on the bottom where people live. They also believed that the earth has no end or edge. The children with spheroid models in the study presented here responded as if they believed that the earth is really a spheroid (or perhaps a geodesic sphere) with flat planes all over, rather than just on the top and bottom as was the case with the flattened sphere models. The children with spheroid models said that people could live on the top and sides of the sphere but not on the bottom. Unlike the flattened sphere models in the Vosniadou and Brewer (1992) study, children with spheroid models said that the earth does have ends or edges.

Three Indian children were classified as having spheroid models. These children deviated significantly from the response pattern for sphere models on certain specific questions. On Q5, unlike children with sphere models, those with spheroid models explained the flat-round conflict by saying that the earth had flat parts all over it that one could not see from far away or from space. These children could be distinguished from children in the sphere category who merely reiterated that the earth "looked" flat where we lived though we could see that it was really round from space. Two of the children with spheroid models said that the earth had an end or edge (Q7) and that this end or edge was the South Pole (Q8a–b). Follow-up questions at the end of the interview revealed that both children thought that the "South Pole" was a physical object rather like a knob or stick on the bottom of the earth. They also said that one could see the South Pole from space and touch it if one flew to the bottom of the earth in a spaceship. One child said that it was possible to reach the end of the sphere by going up into space (Q7). Further questioning revealed that this child regarded the earth as a spheroid body with a finite surface area and referred to the area of space...
adjacent to and surrounding the sphere as the area where the earth “ended” and space began.

**Hollow Sphere in Space Models.** Children who were placed in this category all believed that the earth is spherical in shape, but hollow, and that people live inside this hollow earth. In most cases, the lower hemisphere consists of land and is hollow, allowing people to live inside it. The upper hemisphere is the sky that forms a dome-like cover over the lower hemisphere. Some children referred only to the lower hemisphere in which people live as constituting the earth. The sky is not considered a part of the earth in these cases, although it occupies the same position relative to the lower hemisphere as in the model just described. One child in this study believed that the entire sphere is made of land, but is hollow inside, “like an eggshell.”

There were four children with a hollow sphere in space model. Q5 (the flat–round conflict question) and Q6 were crucial in differentiating the hollow sphere model from the sphere model. Children with hollow sphere models resolved the flat–round conflict on Q5 by saying that the earth is flat inside but looks round from outside or from space. On Q6, children with hollow sphere models all indicated that people live inside a hollow hemisphere or sphere.

**Hollow Sphere on Water.** As was the case with the sphere models, we distinguished between children who thought that the hollow sphere floats in space and those who thought that it floats on an ocean of water (see Table 1a). One child believed that the hollow sphere was supported by water.

**Disc in Space Models.** Five children thought that the earth was round, but flat like a thick disc and that people live on top of the disc. Four of these children thought that the disc floats in space (see Table 1b). In contrast, the only American child with a disc model (Vosniadou & Brewer, 1992) thought that the disc is rooted in the ground. One Indian child with a disc model did say “underground” in response to Q10 (What is below the earth?), but refused to elaborate on this response. Therefore, it was not possible to determine if the child thought that the disc is comprised of ground “all the way down,” as was the case for the disc model found by Vosniadou and Brewer (1992) or whether he was merely referring to the region of space below the earth as the “underground.”

**Disc on Water Models.** Four children met the criteria for disc models previously discussed, deviating only in their belief that the disc was floating on a body of water. The criteria for distinguishing these children from the
disc in space models were the same as those used to distinguish the other types of earth on water models just described.

**Rectangular Earth on Water Models.** Four children thought that the earth is flat, shaped like a square or a rectangle, and that it floats on water. Rectangular earth on water models are very similar to the disc on water models previously described except that children with rectangular models maintained that the earth is flat, straight, or rectangular (Q1, Q3, Q4). There was only one deviation from this pattern (see Table 1b); this child said on Q1 that the earth was shaped like a candle, referring to an Indian oil lamp that is a flat, shallow tray containing oil and a wick. The pattern of responses on other questions was the same as for the disc on water models. One of the children with the rectangular earth model also gave a mythological response; she said that below the flat earth there are layers of "Pataal" (the mythological term for the netherworld) and water.

**Developmental Progression in Earth Shape Models.** The data show that there is a developmental progression in children's mental models of the earth (see Table 2). Following Vosniadou and Brewer (1992), earth shape models were classified as initial (rectangular and disc earth), synthetic (sphere on water, spheroid in space, and hollow sphere in space and on water), and scientific (sphere in space). The proportion of first and third graders assigned to the initial, synthetic, and scientific model categories was significantly different, $\chi^2 (2, N = 38) = 14.512, p < .01$. In the third grade, 42% of the children had scientific models, 47% of them had synthetic models, and only 11% had initial models. In contrast, 68% of the first graders had initial or mixed models, but only 16% of them had synthetic models, and 16% had scientific models.

<table>
<thead>
<tr>
<th>Earth Models</th>
<th>Grade 1</th>
<th>Grade 3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Sphere in space</td>
<td>3</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td>2. Sphere on water</td>
<td>0</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>3. Spheroid in space</td>
<td>0</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>4. Hollow sphere in space</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>5. Hollow sphere on water</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>6. Disc in space</td>
<td>4</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>7. Disc on water</td>
<td>4</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>8. Rectangular earth on water</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>9. Mixed or underdetermined</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>19</td>
<td>19</td>
<td>38</td>
</tr>
</tbody>
</table>
The Movements of the Earth, Moon, and Sun

**Factual Questions.** Children were asked two kinds of questions about the movements of the earth, moon, and sun. The first kind were factual questions: The children were asked whether each of these celestial bodies moves. If children said that a given body such as the earth moves, they were asked to show how this body moves with the help of a physical model.

**Generative Questions.** The second kind of questions were generative questions, which called for predictions about what would happen if a given object (e.g., the earth) stopped moving. In categorizing children's beliefs about the motions of the earth, sun, and moon, we only used their answers on the factual questions. This procedure was used because children's predictions about what would happen if a particular object stopped moving depended on their knowledge of the shapes, relative locations, and relative motions of the earth, moon, and sun. Children's responses to the factual motion questions are presented in Table 3. Physical models of the moon and the sun selected by the children (in a procedure similar to that described for earth models) were used to examine their ideas about the motion of the moon and sun, as well as about the day–night cycle.

Children were assigned to the various motion models in Table 3 based on the particular combination of motions that they ascribed to the earth, the moon, and the sun. In determining the motion models, we decided to treat models that combined the axis rotation of the moon or sun with a single type of motion through space (up–down or revolution) as being internally consistent. However, we treated models that ascribed multiple types of motion through space to the same body (e.g., up–down motion and revolution) as being mixed.

Motion Models 1 and 2 approximate the scientific model of motion; Model 1 is a somewhat more sophisticated model in which the moon rotates on its axis as well as revolving around the earth. Seven children had these types of models. Six children had synthetic heliocentric motion models (Models 3–5) in which the earth rotates on its axis and revolves around the sun. Each of these synthetic models deviates in significant ways from the scientific model of the solar system. For example, in Model 4, the moon is thought to be stationary like the sun. Five children had motion models (Models 6, 7, and 13) in which the earth, the moon, and the sun occupy fixed locations in space (they are either stationary or rotating on their axes). Nineteen children had geocentric motion models (Models 8–12) in which the earth occupies a fixed location in space (it is stationary or rotating on its axis) and the moon and the sun revolve around the earth or move up and down. One child had a very nonparsimonious model (Model 14) in which the earth rotated on its axis and revolved around the sun, the moon traveled
Table 3. The Motion of the Earth, Moon, and Sun: Frequency of Motion Models by Grade

<table>
<thead>
<tr>
<th>Earth Motion</th>
<th>Moon Motion</th>
<th>Sun Motion</th>
<th>Grade 1</th>
<th>Grade 3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Rotates, revolves around sun</td>
<td>Rotates, revolves around earth</td>
<td>None</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2. Rotates, revolves around sun</td>
<td>Revolves around earth</td>
<td>None</td>
<td>1</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>3. Rotates, revolves around sun</td>
<td>Moves parallel to earth around sun</td>
<td>None</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4. Rotates, revolves around sun</td>
<td>None</td>
<td>None</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>5. Rotates, revolves around sun and moon</td>
<td>None</td>
<td>None</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>6. Rotates</td>
<td>Rotates</td>
<td>Rotates</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>7. Rotates</td>
<td>None</td>
<td>None</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>8. Rotates</td>
<td>Revolves around earth</td>
<td>Revolves around earth</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>9. None</td>
<td>Revolves around earth</td>
<td>Revolves around earth</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>10. Rotates</td>
<td>Rotates, up and down</td>
<td>Rotates, up and down</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>11. Rotates</td>
<td>Up and down</td>
<td>Up and down</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>12. None</td>
<td>Up and down</td>
<td>Up and down</td>
<td>9</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>13. None</td>
<td>None</td>
<td>None</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>14. Rotates, revolves around sun</td>
<td>Moves with earth around sun, up and down</td>
<td>Rotates, up and down</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Total 19 19 38

with the earth around the sun and moved up and down, and the sun moved up and down.

*Developmental Progression in Motion Models.* First graders were more likely than third graders to ascribe motions to either the earth, the moon, or the sun that were inconsistent with the scientific model (see Models 3-14 in Table 3). For example, 58% of first graders said that the earth does not move (Models 9, 12, and 13), whereas only 26% of third graders did so. Similarly, 68% of first graders said that the sun revolves around the earth or moves up and down (Models 8, 12 and 14), whereas only 37% of third graders did so.

*Responses to Generative Motion Questions.* On the generative motion questions, children who had said that the earth, the moon, or the sun
move were asked what would happen if these objects were to stop moving. All but one child answered the generative motion questions in terms of their consequences for the day–night cycle. In responding to the generative motion questions, 15 children with heliocentric motion models (Motion Models 1–5 and 7) indicated their belief that the movement of the earth caused the day–night cycle. These children, interviewed during the daytime, said that there would be no night if the earth stopped moving at the time of the interview. All of these children said that the sun was stationary. Although eight of these children said that the moon moved, their answers on the generative motion questions indicated that the moon’s motion had no causal role in the day–night cycle.

In contrast, the 13 children with geocentric motion models (see Models 8–12 in Table 3) responded to the generative motion questions as though they believed that the movements of the sun and moon caused the day–night cycle. These children had a “hydraulic theory” in which the sun cannot move unless the moon is moving in the opposite direction and vice versa. They said that there would be no night if the sun stopped moving and no day if the moon stopped moving.

Several children had nonheliocentric motion models in which the earth was thought to rotate on its axis (see Models 6–8, 10, 11, and 14 in Table 3). However, these children tended to respond to generative motion questions by saying that nothing of consequence would happen if the earth stopped moving. These children had nonspherical earth-shape models, such as the disc on water model, and the earth’s axis rotation has no power to explain the day–night cycle for such models.

The Day–Night Cycle

The children were asked to explain the day–night cycle on Q14. The question was worded as follows: “Imagine that there is a little boy here on earth (experimenter places stick pin on top of child’s selected earth model). With your models of the earth, sun, and moon, show me how it changes from day to night for this little boy. First make it day for the little boy. Where is the moon during the day? Good, now make it night for the little boy. Where is the sun at night? (If still not clear asks) Can you explain to me once more, how it changes from day to night?” Table 4 shows the categories of explanation provided by the children for the day–night cycle.

Day and Night Caused by Earth Motion.

Axis rotation. In all, 13 children explained the occurrence of day and night in terms of the earth’s axis rotation. Day–Night Model 1 comes closest to the scientific model of the day–night cycle. Six children had this model. A variety of synthetic models of the day–night cycle (Models 2–4) also explain the transition from day to night and vice versa in terms of the axis rotation.
### Table 4. Frequency of Mental Models of the Day–Night Cycle by Grade

<table>
<thead>
<tr>
<th>Day–Night Model</th>
<th>Grade 1</th>
<th>Grade 3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Day and night caused by earth’s axis rotation from east to west. During the day the moon still revolves around the earth but cannot see it because of the sun's light.</td>
<td>1</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>2. Day and night caused by the earth’s axis rotation from east to west. The sun is stationary, and the moon is stationary or moving with the earth on the other side of the earth from the sun.</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3. Day and night caused by the earth’s axis rotation from east to west. The sun and moon are stationary to the east and west of the earth, respectively. Because the earth also revolves around the sun, its location relative to the stationary moon changes each day, causing the phases of the moon.</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>4. Day and night caused by the earth’s axis rotation from top to bottom. The sun and the moon are stationary above and below the earth, respectively.</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>5. The earth revolves in an elliptical orbit that circumscribes the stationary sun and moon. When the earth is nearer the sun in its orbit, it is day, and when it is further from the sun and nearer the moon, it is night.</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>6. The sun and moon revolve around the stationary earth. During the day the sun is above the earth, and the moon revolves down to the other side of the earth. During the night the reverse happens.</td>
<td>0</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>7. The sun and moon move up and down from outer space (the area above the sky) into the sky. During the day the sun is in the sky and the moon moves back into outer space. During the night the reverse happens.</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>8. The sun and moon move up and down parallel to each other on opposite sides of the earth. During the day the sun is up and the moon is down below the earth. During the night the reverse happens.</td>
<td>4</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>9. The sun and moon move up and down parallel to each other on opposite sides of the earth. During the day the sun is in the sky and the moon is down in the ocean below the earth. During the night the reverse happens.</td>
<td>4</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>10. The stationary sun and moon, located to the east and west of the earth, respectively, are occluded by clouds.</td>
<td>4</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>11. Mixed 1: Day and night is caused by the earth’s axis rotation from east to west and by the up and down motion of the sun and moon.</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>12. Mixed 2: Child explains day and night as in Model 1 previously mentioned but cannot explain how people inside the hollow, egg-shell-like earth see the sun and moon.</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>19</td>
<td>19</td>
<td>38</td>
</tr>
</tbody>
</table>
of the earth. These models differ from Day–Night Model 1 in that the moon is assumed to be located on the opposite side of the earth from the sun relative to the axis of the earth's rotation. Seven children had these types of synthetic models, and all but one of them represented the moon and the sun as being stationary and located on opposite sides of the earth. One child who had said that the moon traveled parallel to the earth around the sun (Motion Model 3, Table 3), also said that the moon was on the opposite side of the earth from the sun relative to its axis of rotation.

**Revolution.** One child (Day–Night Model 5) said that the day–night cycle is caused by the revolution of the earth along an elliptical orbit that circumscribes the stationary sun and moon.

**Day and Night Caused by Motion of the Sun and Moon.**

**Revolution.** Three children (Day–Night Model 6) said that the day–night cycle is caused by the revolution of the sun and moon around a stationary earth along the same orbit.

**Up-down motion.** Fifteen children used the linear up-down motion of the sun and moon to explain the day–night cycle. Of these 15 children, 4 children (see Model 7 in Table 4) with hollow sphere earth models made a distinction between the sky (which was the dome shaped hemisphere that covered the lower hemisphere made of land) and “outer space” or “space” (which represented the area beyond the sky dome). They said that the sun and moon moved down from outer space into the sky and back up again during the day–night cycle. Five children said that the sun and moon move up and down in the space that surrounds the earth (see Model 8 in Table 4), and six children said that the sun and moon sink into and rise from the ocean that supports the earth (see Model 9 in Table 4).

**Day and Night Caused by Occlusion of the Sun and Moon.** Four children explained the day–night cycle in terms of the occlusion by clouds of a stationary sun and moon located above the earth (Model 10).

**Developmental Progression of Day–Night Models.** The results show a developmental progression in models of the day–night cycle. Following Vosniadou and Brewer (1994), models of the day–night cycle were classified as initial (Models 9–10), synthetic (Models 2–8), and scientific (Model 1). There was a significant difference, \( X^2 (2, N = 38) = 5.867, p < .05 \), in the proportion of initial, synthetic, and scientific models between first and third graders. Only one first grader (5%) had a scientific model, whereas 42% of first graders had initial day–night models, and 47% had synthetic day–night models. In contrast, only 11% of Indian third graders had initial day–night models, whereas 58% of them had synthetic models, and 26% had scientific models.
Synthetic and scientific models of the day-night cycle are contingent on the abandonment of the support constraint on models of the earth’s shape (Vosniadou & Brewer, 1994). It is only when the earth is represented as a free-floating body surrounded by space that day-night explanations based on the movements of the sun and moon in the space that surrounds the earth, or based on the movement of the earth itself, can be constructed.

Indian Children’s Cosmologies
We categorize children’s cosmologies on the basis of the relative locations and motions ascribed to the earth, the moon, and the sun. We use information from the children’s models of motion, their explanations for the day–night cycle, and their identification of objects in a picture of the solar system. Children were shown a black and white picture of the solar system (Q15a–e) and were asked to identify what it was. They then had to locate the sun, earth, and moon in the picture. Finally, they were shown a planet other than the earth in the picture (Saturn) and asked to identify what it was. This information was combined with information on children’s models of motion and the day–night cycle to determine the children’s overall cosmologies. Children who were scored as having mixed mental models of the earth’s shape, of motion, or of the day–night cycle were classified as having inconsistent cosmologies. Additionally, children whose mental models for the earth’s shape, of motion, or the day–night cycle were internally consistent but mutually contradictory were classified as having inconsistent cosmologies. Only four children had inconsistent cosmologies.

Heliocentric Cosmologies. All of the children who were classified as having heliocentric cosmologies located the sun in the center of the picture of the solar system (Q15a–e) and identified one of the planets orbiting the sun as the earth. Their models of motion all involved the assumption that the earth revolves around the sun. The children with heliocentric cosmologies said that the day–night cycle resulted from the motion of the earth. On the generative motion questions, all of the heliocentric children stated that if the earth stopped moving at the time of the interview, it would always be day. Overall, only 12 children (32%) had some kind of heliocentric cosmology. An examination of the earth shape concepts of children with heliocentric cosmologies suggests that a representation of the earth as a spherical or spheroid body is necessary (thought not sufficient) for the construction of a heliocentric cosmology. The different types of heliocentric cosmologies are discussed next.

Heliocentric Type 1. This cosmology corresponds most closely to the current scientific model (see Figure 2). Six children (16%) were placed in this category. Five of the children with Heliocentric Type 1 cosmologies had sphere in space models, and one had a spheroid in space model.
All six children said that the earth rotates on its axis and revolves around the sun, that the moon revolves around the earth, and that the sun is stationary. One of these children also said that the moon rotates on its axis. All these children said that the axis rotation of the earth causes the day–night cycle. They correctly identified the earth, the sun, and the moon in the picture of the solar system. They also identified Saturn either by name or as "a planet."
**Heliocentric Type 2.** This cosmology differs from the Heliocentric Type 1 cosmology primarily with regard to the location and motion of the moon (see Figure 2). Only one child (who had a sphere on water earth model) had this type of cosmology. This child said that the moon travels with the earth around the sun in an orbit that circumscribes the earth's orbit around the sun. He used the (east–west) axis rotation of the earth to explain the day–night cycle. This child correctly identified the sun in the picture of the solar system but he said that Mercury was the earth and identified Venus as the moon. Saturn was identified as “a planet.”

**Heliocentric Type 3.** This cosmology also differs from the Type 1 cosmology only with regard to the location and motion of the moon. The four children in this category said that the moon does not move and is located on the side of the earth opposite to the sun (see Figure 2).

All of these children, who had either sphere or spheroid in space models, used the axis rotation of the earth to explain the day–night cycle. Children in this category correctly identified both the earth and the sun in the picture of the solar system but said there was no moon in the picture. All of them identified Saturn either by name or as “a planet.”

**Heliocentric Type 4.** This cosmology is a synthetic cosmology in which the earth rotates on its axis and revolves in an elliptical orbit that circumscribes the stationary sun and moon (see Figure 2). This cosmology differs from the preceding ones in that the day–night cycle occurs as a result of the revolution of the earth. Only one child (who had a sphere on water earth model) had this type of cosmology. This child correctly identified the sun in the picture of the solar system, but identified Mercury as the moon and said that Venus was the earth. He also identified Saturn as “a planet.”

**Geocentric Cosmologies.** Twenty-two children (58%) had some sort of geocentric cosmology. Children with all kinds of earth-shape models constructed geocentric cosmologies. These children showed little consistency in their responses to questions about the picture of the solar system (Q15a–e). The only thing they had in common was that none of them identified the sun as being in the center the solar system. Although some geocentric children identified the sun in the picture of the solar system as “the earth,” others said that there was no earth in the picture. Many geocentric children said that the picture represented “the night sky.” A few children said that they did not know what the picture was.

**Geocentric Type 1.** This cosmology is a synthetic cosmology in which the stationary sun and moon are located on opposite sides of the earth, and the earth rotates on its axis to cause the day–night cycle (see Figure 3). Two children were assigned to this category. One of these children believed that the earth is a sphere in space, and the other believed that it is a sphere on water. They both located the earth in the center of the solar system and said
that there was no sun in the picture (Q15a–e). Both children said that Mercury was the moon. One of these children also identified Saturn as a planet, but the other child could not identify it.

**Geocentric Type 2.** This cosmology assumes that the sun and moon revolve around a stationary earth. The revolution of the sun and moon is also used to explain the day–night cycle (see Figure 3). Two children were assigned to this cosmology. The responses of these children to Q15a through e were similar to those of the Geocentric Type 1 children.

**Geocentric Type 3.** This cosmology is very common among children in India. Fifteen of the 38 children were categorized as using this cosmological
model. Essentially, these children believe that the earth is stationary and that the sun and moon move up and down relative to the earth (see Figure 3). They also use the up-down motion of the sun and moon to explain the day–night cycle. Children with a variety of earth-shape models, ranging from the sphere to the rectangular earth, constructed this type of cosmology. The cosmology has support in children’s everyday experience as several of them said they have seen the sun “sink” into the horizon. It is also reinforced in everyday language by sentences such as, “the sun rises in the morning,” which are as common in the children’s native tongues as they are in the English language. On Q15a through e, these children incorrectly identified most bodies, and the only consistent feature of their responses was that they said that the sun was not in the picture.

Geocentric Type 4. This is a very immature cosmological model in which the earth is located below the sun and the moon, but all three objects are stationary. The day–night cycle is caused by the occlusion of the moon and sun by clouds (see Figure 3). Three first graders (two with rectangular and one with a disc earth model) had this type of cosmology. All three children said (Q15a–e) that they did not recognize the picture of the solar system.

Developmental Progression in Children’s Cosmologies. The results indicate that there is a developmental progression in children’s models. Third graders were more likely to have scientific (Heliocentric Type 1) and synthetic (Heliocentric Types 2–4 and Geocentric Types 1–2) cosmologies, whereas first graders were more likely to have initial cosmologies (Geocentric Types 3–4). Although 26% of third graders had a scientific cosmology, only 5% of the first graders did. On the other hand, 74% of the first graders had initial cosmologies, whereas only 21% of the third graders did.

### Table 5. Frequency of Children’s Cosmologies by Grade

<table>
<thead>
<tr>
<th>Cosmology</th>
<th>Grade 1</th>
<th>Grade 3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heliocentric Type 1</td>
<td>1</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Heliocentric Type 2</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Heliocentric Type 3</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Heliocentric Type 4</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Geocentric Type 1</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Geocentric Type 2</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Geocentric Type 3</td>
<td>11</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>Geocentric Type 4</td>
<td>3</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Mixed</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>19</td>
<td>19</td>
<td>38</td>
</tr>
</tbody>
</table>
DISCUSSION

Comparing Earth Shape and Day–Night Models of Indian and American Children

Earth Shape Models. Vosniadou and Brewer (1992) found six distinct types of earth-shape models among American children; the sphere, the flattened sphere (a variant of imperfect sphere models like the Indian spheroid), the hollow sphere, the dual earth, the disc earth, and the rectangular earth. Of these, the only type of earth shape model not found in the Indian study was the dual earth model. This model involves the belief that there are two earths, a flat one on which people live and a round one up in space. Variants of all the other earth shape models found among American children were also found among Indian children. There is however, a difference between the Indian and American children in the frequency distributions of the various earth shape models.

The proportion of children classified as having mixed earth-shape models differs for Indian (5%) and American (23%) children. However, this may be in large part due to the difference in methodology between the two studies. The methodology of the study presented here (in which children construct and select three-dimensional physical models of the earth) was developed 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. Apparently, the use of the models reduces the ambiguity of some children’s responses and allows a clearer demonstration of their models.

One major difference between the Indian and American children is that a number of Indian children (34%) represent the earth as floating on water. Among Indian children, the belief that the earth floats on a body of water occurs in conjunction with a variety of earth shape models such as the sphere, the hollow sphere, the disc, and the rectangular earth. In contrast, this conception was not found among American elementary school children (Vosniadou & Brewer, 1992).

Although the proportion of sphere in space models was virtually identical (approximately 28%) among Indian and American children, the modal alternative to this model was different in each culture. Among American children, the modal alternative was the dual earth model (20%), but among Indian children, the modal alternative was the disc model (24%). Only one American child had a disc model. As noted in the introduction, both the idea that the earth is shaped like a disc and the idea that the earth is floating on a body of water are common themes in indigenous Indian cosmologies. Interestingly, the prevalence of purely mythological responses was very low among Indian children as it had been among American elementary school children. Only one Indian child gave a clearly mythology-based response in
the course of the interview. Thus, although the Indian children did appear to be influenced by the naturalistic aspects of the indigenous cosmologies, they could clearly distinguish between mechanistic and mythological explanations.

As was the case with American children, Indian children show a developmental progression from initial earth-shape models among younger children to synthetic and scientific earth-shape models among older ones (see the Results section).

**The Day–Night Cycle.** In general, explanations of the day–night cycle across the two cultures were based on one of five types of mechanisms: (a) occlusion of the sun and moon, (b) geocentric linear motion of the sun and moon (up and down or east and west), (c) geocentric orbital motion of the sun and moon (they go around the earth), (d) orbital motion of the earth around the sun and moon (the earth goes around the sun and the moon), or (e) axis rotation of the earth. Mental models of the day–night cycle based on each of these types of mechanisms were found among both Indian and American children. However, among the Indian children, the belief that the earth is floating on a body of water also influences variants of day–night cycle models. For example, American children with initial day–night models based on the up–down motion of the sun and moon say that the sun and moon go down “to the earth” or “behind the hills.” In contrast, Indian children who use the same general mechanism to explain the day–night cycle say that the sun and moon go down into the ocean underneath the earth (see Model 9 in Table 4). Another difference is that 30% of American children are classified as having mixed or inconsistent models of the day–night cycle, but only 5% of Indian children are categorized as having mixed models. However, as was the case with earth-shape models, we believe that these differences stem from the somewhat different methodology employed in the two studies.

The developmental progression of day–night models is similar across the two cultures with older children more likely to have synthetic and scientific models and younger children more likely to have initial models.

**Methodological Issues With Regard to Cultural Comparison**

Because of time constraints, a direct examination of children’s knowledge of the folk cosmologies or the kind of cultural information they are exposed to at home was beyond the scope of this study. As noted in the introduction, we make our inferences about cultural mediation from the observed correspondence of children’s cosmologies with indigenous ones. Data on children’s access to folk models (through parent interviews and by testing children’s knowledge of folk cosmologies) would be a valuable complement to this research. However, the presence of culturally unique initial cosmolo-
gies that are very similar to indigenous folk cosmological models in Indian children is, in our view, best explained by the cultural mediation hypothesis. The Indian children's access to folk cosmologies through television and print media and the fact that their local geography did not provide any direct empirical support for such cosmologies supports our inferences about cultural mediation. We now discuss the role of constraints on the construction and restructuring of cosmological models.

The Role of Constraints in the Development of Astronomy Knowledge

The notion of constraints has been central to many recent accounts of children's conceptual development (Carey & Spelke, 1994; Gelman, 1990; Keil, 1990). For the purposes of the present article, we assume the position sketched out by Vosniadou and Brewer (1994), that there appear to be at least two orders of constraints that influence the conceptual development of children's cosmologies. Certain first-order constraints stem from implicit assumptions about the nature of physical objects, which may be innate or acquired, but that are present in early infancy. Such first-order constraints limit the kinds of mental models that can be constructed with regard to various cosmological entities. Other examples of first-order constraints may be certain ontological and epistemological assumptions about entities in the cosmology (Vosniadou & Brewer, 1994). However, as noted earlier, once constructed, representations of specific cosmological bodies such as the earth become sources of second-order constraints on conceptual change.

First-Order Constraints on Cosmologies.

Ontological and epistemological assumptions. A comparison of children's cosmologies across cultures shows that there do appear to be universal principles that constrain the way in which children construe astronomical objects and events. For example, both American and Indian children treat astronomical objects as inanimate physical entities and explain astronomical phenomena in terms of a mechanistic causal framework. Indian children, who have access to folk cosmological models as well as the scientific model that is taught in school, selectively incorporate those aspects of folk cosmologies that are compatible with a physical mechanistic cosmological model. Our results also indicate that across cultures, children appear to assume that certain phenomena such as the day-night cycle should be explained by their cosmological models.

Assumptions about physical objects. As previously discussed, our results indicate that across cultures, children's initial cosmological models honor a variety of first-order constraints that appear to originate in a naive physics (Carey & Spelke, 1994; Needham & Baillargeon, 1993; Spelke, 1991). Examples of such constraints include the flatness and support constraints on
mental models of the earth's shape and constraints on motion (Carey & Spelke, 1994), such as the principle of continuity (every object must follow a single connected path, and the paths of two objects may not intersect at a given point in space and time). Children's initial cosmologies may also be constrained by beliefs about the location (central) and size (largest) of the earth relative to other cosmological entities. Indian children's initial (Geocentric Types 3-4) cosmologies are consistent with these constraints. Data on American children's cosmological models (Vosniadou & Brewer, 1996, which is currently being analyzed, will provide more information on the universality of constraints on the earth's relative location and size.

**Second-Order Constraints on Cosmologies.** The results of the study presented here support Vosniadou and Brewer's (1994) position with regard to the existence of second-order constraints on knowledge restructuring. For example, Vosniadou and Brewer (1994) hypothesized that only children with spherical earth models or approximations of such models (e.g., spheroids) would explain the day-night cycle in terms of the axis rotation of the earth. Our results confirm this prediction. Although several Indian children with disc or hollow earth models said that the earth rotated on its axis (see Motion Models 6, 8, 10, 11, and 14), none of these children used the axis rotation mechanism to explain the day-night cycle. Clearly, given their earth-shape models, axis rotation could not explain the occurrence of the day-night cycle.

Another example of second-order constraints comes from culturally unique aspects of Indian children's cosmologies. For example, several Indian children with geocentric cosmologies explained the day-night cycle by saying that the sun and moon sank into and rose from the ocean that supported the earth. This variant of a linear day-night model was never present among American children because they did not represent the earth as floating on a body of water. Instead, American children with initial earth-shape models (who believe that the earth is supported by ground) say that the sun and moon sink to and rise from the ground or the hills.

**Constraints and Cultural Mediation.** The results of our study show that although certain assumptions about astronomical objects impose universal constraints on children's initial cosmologies, the specification of these constraints in children's representations is culturally mediated. Thus, although all initial representations of the earth honor the support constraint, the specific kind of matter that provides support for the earth (e.g., ground or water) may be culturally influenced. The high frequency of disc earth models (which are very rare among American children) among Indian children also reflects the influence of indigenous models. It is likely that when Indian children are first told that the earth is "round" they tend to
favor the interpretation that the earth is round like a disc (a folk model) because this interpretation allows the incorporation of the round earth information in a way that satisfies the flatness constraint. Overall, these results support our initial predictions about cultural mediation. In cultures where indigenous cosmologies and the scientific model are both accessible to children, children selectively incorporate those elements of indigenous cosmologies, which can more readily satisfy first-order constraints, than the scientific model.

The Development of Astronomy Knowledge
The results of this study are consistent with Vosniadou and Brewer's (1994) position that children's conceptual development in astronomy is driven by attempts to assimilate information from the cosmological model(s) of the adult culture. In this assimilatory process, children are forced to first modify and eventually abandon the core constraints that govern their initial cosmological models. The assimilatory process is reflected in synthetic models that children construct out of attempts to reconcile their initial models with new information from the adult world. In the course of attempting to restructure their cosmologies, children—like scientists—may use physical analogies (Nersessian, 1992) to guide model reconstruction. For example, one Indian boy made an explicit analogy to an "egg shell" in explaining his hollow earth model. This child later gave a scientific explanation of the day–night cycle. A follow-up question, about how people inside the egg-shell earth could see the sun and moon, triggered a series of attempts by the child to resolve the apparent anomaly. First, the child asked whether the sun and moon were "inside" or "outside" the earth. Then, before the experimenter could answer, the child said, "No, can't be inside! Because both (i.e., sun and moon) would be with us as we turned." Clearly, the child seemed to be mentally testing a simulation of his reconfigured cosmology.

Implications for Conceptual Change
Several researchers have attributed the difficulty that children experience in acquiring scientific concepts primarily to their limited metacognitive competence (e.g., diSessa, 1988; D. Kuhn, 1989). In particular, it has been suggested that children are not sensitive to the need for empirical and logical consistency in their representations of the world. The findings of the study presented here do not support this position. The children's cosmologies are empirically accurate in the sense that they can account for many of the phenomena or empirical observations known to children such as the day–night cycle. Children could also generate predictions for novel circumstances on the basis of their cosmologies as reflected in their answers to the generative questions about planetary motion.

An interesting aspect of the Indian children's cosmologies is that they
show a considerable degree of internal consistency that is not immediately obvious if one looks at individual aspects of the cosmology such as planetary motion and the explanation of the day–night cycle independently of each other. For example, 58% of the children said that the earth rotated on its axis, but only 34% of the children used the axis rotation of the earth to explain the transition from day to night. However, as noted earlier in the discussion of responses to generative motion questions, when children’s beliefs about the shape of the earth and its location relative to the sun and moon were taken into account, it became obvious that the axis rotation of the earth had no power to explain the day–night cycle for many of these children. This is important because in much of the existing research, students are judged to be inconsistent if they appear to use a specific scientific concept correctly in some instances but not in others. However, as several researchers (Vosniadou & Brewer, 1994; Wiser, 1988) have noted, in reality the students might be responding on the basis of an internally consistent representation that resembles the scientific model in some aspects and differs from it in others.

Overall, our findings support the theoretical position of researchers like Carey (1991) and Chi, Slotta, and de Leeuw (1994), who suggested that for children as well for scientists, conceptual change entails a change in the core principles that govern reasoning about entities in a domain. For example, the transition from geocentric cosmological models to the scientific one involves the revision of core constraints on mental models of the earth such as the flatness and support constraints. The lifting of these constraints allows for the reassignment of motions to cosmological objects and consequently provides for new explanations of phenomena such as the day–night cycle. By this account, children find it hard to acquire scientific theories because these theories are inconsistent with the initial theories that children spontaneously construct. In other words, children have difficulties with theory restructuring for the same reasons that scientists have had difficulties with theory restructuring in the history of science (T.S. Kuhn, 1962; Thagard, 1992). Additionally, for children, the problem of theory restructuring is often compounded because they may initially not realize that adults have a model that is inconsistent with their own. Because teachers are usually unaware of children’s initial models, they make no attempt to address the assumptions on which these models are based in science instruction. Consequently, children only gradually come to realize that the adult model is based on domain-specific assumptions or constraints that are different from their own.

**CONCLUSIONS**

This study examined the development of Indian children’s knowledge of astronomy. Our findings are consistent with Vosniadou and Brewer’s (1992,
1994) account of knowledge acquisition in astronomy. Younger children tend to construct initial cosmological models that are very different from the scientific one. As they are exposed to information about the scientific model from the adult culture and try to assimilate this information, the children begin to restructure their initial models in ways that give rise to a variety of synthetic cosmologies. These synthetic cosmologies are in turn restructured as children eventually acquire the scientific cosmological model.

The initial construction of children's cosmological models is constrained by core principles originating from a naive physics as well as by certain ontological and epistemological assumptions about cosmological entities. The results of this study support our hypothesis that positing first-order and second-order constraints on children's cosmologies can help explain both universal and culture specific aspects of such cosmologies. For example, Indian children's initial and synthetic cosmologies often incorporate those aspects of folk cosmologies that are consistent with certain constraints such as the flatness and support constraints on models of the earth's shape. In the course of conceptual development, the children eventually revise these initial constraints and are able to acquire the scientific cosmological model that is presented to them in the course of schooling.

REFERENCES


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