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Mental Models of the Day/Night Cycle

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This article presents the results of an experiment which investigated elementary school children's explanations of the day/night cycle. First, third, and fifth grade children were asked to explain certain phenomena, such as the disappearance of the sun during the night, the disappearance of stars during the day, the apparent movement of the moon, and the alteration of day and night. The results showed that the majority of the children in our sample used in a consistent fashion a small number of relatively well-defined mental models of the earth, the sun, and the moon to explain the day/night cycle. These mental models of the day/night cycle were empirically accurate, logically consistent and revealed some sensitivity on the part of the children to issues of simplicity of explanation. The younger children formed initial mental models which provided explanations of the day/night cycle based on everyday experience (e.g., the sun goes down behind mountains, clouds cover up the sun). The older children constructed synthetic mental models (e.g., the sun and the moon revolve around the stationary earth every 24 hours; the earth rotates in an up/down direction and the sun and moon are fixed on opposite sides) which represented attempts to synthesize the culturally accepted view with aspects of their initial models. A few of the older children appeared to have constructed a mental model of the day/night cycle similar to the scientific one. A theoretical framework is outlined which explains the formation of initial, synthetic, and scientific models of the day/night cycle in terms of the reinterpretation of a hierarchy of constraints, some of which are present early in the child's life, and others which emerge later out of the structure of the acquired knowledge.

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The research reported in this paper investigates elementary school children's mental representations of the day/night cycle and attempts to understand how these representations change during the knowledge acquisition process. The present work is a continuation of earlier investigations of the development of children's mental representations of the earth (Vosniadou & Brewer, 1992), in the context of a larger project directed at understanding the process of knowledge acquisition in the area of astronomy (Vosniadou & Brewer, 1987).

The Process of Acquiring Knowledge about the Physical World

During the last few years there has been a surge of research investigating how children acquire knowledge about the physical world, and more particularly how they come to understand the currently accepted scientific explanations of concepts such as matter, weight, density, heat, temperature, force, etc. This research has produced agreement on at least one fundamental issue: Children are not blank slates when they are first exposed to the culturally accepted, scientific views, but bring to the acquisition task some initial knowledge about the physical world which appears to be based on interpretations of everyday experience. There is, however, considerable disagreement about how to characterize these initial knowledge structures and about how to describe their development during the knowledge acquisition process.

Some researchers think that initial, intuitive, or naive knowledge consists of a large number of loosely organized phenomenological principles which represent minimal abstractions of common events (e.g., diSessa, 1993). Other researchers believe that children start with a few, probably innate, domain-specific principles, which are organized in theory-like structures and which constrain the knowledge acquisition process (Gelman, 1990; Spelke, 1990). Researchers also differ in whether they conceptualize the knowledge acquisition process in terms of the enrichment of initial structures (e.g., Spelke, 1991) or their replacement with new theories (e.g., Carey, 1991). Our studies of the development of the concept of the earth have led us to the development of a theoretical position (see Vosniadou, 1989, in press-a, in press-b; Vosniadou & Brewer, 1992), which will be further elaborated on in this article.

We assume that the process of acquiring knowledge about the physical world is constrained by a few domain-specific principles, such as those described by Gelman (1990) and Spelke (1991), which we call *presuppositions* (e.g., unsupported objects fall down). Presuppositions may be innate or empirically acquired constraints which are present from early infancy and which guide the way children interpret their observations and the information they receive from the culture to construct knowledge structures. We further believe that in order to give a full account of the knowledge acquisition process it is necessary to posit the existence of a set of second-order constraints, which we call *beliefs* and *mental models*. Beliefs and mental models are constraints which emerge out of the structure of previously acquired knowledge, and which in turn exert their influence on the acquisition of new knowledge.

In the context of this theoretical framework, we argue that conceptual change involves more than enrichment (e.g., Spelke, 1991), and cannot be fully described in terms of the direct replacement of one theory with another (e.g., Carey, 1991). Conceptual change is seen as the product of the gradual lifting of constraints, as presuppositions, beliefs, and mental models are added, eliminated, suspended, or revised during the knowledge acquisition process.

The construct of the mental model is used here to describe the kinds of mental representations we think individuals construct when they reason about the physical world (cf. Brewer, 1987). We use the term mental model to denote a particular kind of mental representation which has the following characteristics: (a) its structure is an analog to the states of the world that it represents (Johnson-Laird, 1980, p. 90); (b) it can be manipulated mentally, or "run in the mind's eye," to make predictions about the outcomes of causal states in the world (Collins, 1985, p. 80); and (c) it provides explanations of physical phenomena (Holland, Holyoak, Nisbett, & Thagard, 1986, p. 329). We further assume that mental models are dynamic structures which are usually created on the spot to meet the demands of specific problem-solving situations (Johnson-Laird, 1983; Vosniadou & Brewer, 1992, p. 543). This does not exclude the possibility that some models, or parts of them, which have been proven useful in the past, are stored as separate structures and retrieved from memory when needed. In addition to acting as constraints themselves, mental models can provide important information about the underlying knowledge structure (e.g., presuppositions and beliefs) from which they are generated.

Mental Models of the Earth

In Vosniadou and Brewer (1992), we investigated elementary school children's mental representations of the earth by asking a series of questions regarding the shape of the earth and about the regions on the earth where people live. We tried to understand the mental models underlying different patterns of responses to the same questions and to determine whether these models were used in a consistent fashion across a large number of problems.

The results of that study showed that most of the children we investigated were consistent in their use of a relatively small number of well-defined mental models of the earth. The youngest children tended to form an *initial* mental model of a flat earth, which could have the shape of a rectangle or a disc, and which was supported by ground. The flat earth mental model is consistent with everyday experience and is not influenced by the culturally accepted, scientific model of a spherical earth. The older children tended to form the culturally accepted model of a spherical earth, surrounded by space, with people living all around it (on the outside).

A number of intermediate or *synthetic* mental models of the earth were also identified, such as the model of a dual earth, the model of a hollow sphere, and the model of a flattened sphere. Children who form the synthetic model of a dual earth believe that there are two earths—a flat one, on which people live, and a round one which is up in the sky. Children who hold the hollow sphere model believe that people live on flat ground deep inside the spherical earth, and those that hold the model of a flattened sphere believe the earth is a sphere flat on the "top" and on the "bottom" where people live.

Our results showed that most of the first-grade children, about half of the third-grade children, and somewhat less than half of the fifth-grade children had formed a synthetic mental model of the earth. The predominance of synthetic models of the earth demonstrates how difficult it is for elementary school children to form the mental representation of a spherical earth with people living all around it, on the outside. This is the case despite the fact that the children in our culture are constantly exposed to the scientific information regarding the shape of the earth.

In order to explain the formation of these synthetic mental models we postulated that children start by conceptualizing the earth as a physical object, rather than as an astronomical object, and therefore assume that all the presuppositions which apply to physical objects in general apply to the earth as well (see Vosniadou, in press-b). Two of these presuppositions are particularly important because they have the potential for explaining the synthetic models that children form. They are the presuppositions that the ground is flat (as it appears to be) and that unsupported things fall.

Synthetic mental models of the earth can be explained by assuming that children either assimilate the culturally accepted view of a spherical earth to their initial model of a flat earth, or revise one of these presuppositions but not the other (Vosniadou & Brewer, 1992). For example, the synthetic model of the dual earth does not require changes in any of the presuppositions that give rise to the initial model of a flat earth. Children who form this mental model still believe that the ground is flat and that unsupported things fall. These children simply add to their existing beliefs the information that there is another earth which is spherical and which is up in the sky, like a planet.

The synthetic model of a hollow sphere, on the other hand, involves a modification in the child's presuppositions. The children who form this model have suspended the presupposition that the earth needs to be supported, although they still seem to believe that the people and objects located on the earth will fall if they are not supported. They also continue to believe that the ground is flat. In order to resolve the conflict between these presuppositions and the culturally accepted view, they create the mental model of a hollow sphere. By assuming that the earth is a hollow sphere and that people live on flat ground inside this sphere, these children succeed in reconciling their initial presuppositions with the scientific notion of a spherical earth.

From the above, we conclude that synthetic models are likely to be formed when the knowledge acquisition process requires a revision of presuppositions that are based on interpretations of everyday experience. In these cases, synthetic models function as intermediate steps in the change from an initial, intuitive model to the scientific culturally accepted one.

The Present Study

The purpose of the present investigation was to see if the theoretical framework developed to account for the development of the concept of the earth could explain the changes in elementary school children's mental models of the day/night cycle. In addition, we were interested in finding out if we could identify a small number of mental models of the day/night cycle which children used in a consistent manner, and to see whether these models could be characterized as synthetic in ways similar to those discovered in the case of the shape of the earth. The present study opens up a set of new issues because mental models of the day/night cycle involve not a single concept, but a number of interacting concepts (earth, sun, moon, and stars), and these models require the explanation of the complex interaction of a number of different phenomena.

In the pages that follow we present a brief account of the explanations of the day/night cycle found in the history of astronomy. We continue with a review of the empirical literature on children's explanations of the alternation of day and night. Then we turn to our own study.

Explanations of the Day/Night Cycle in the History of Astronomy

The earliest theories of the day/night cycle in different cultures focus on the movement of the sun as the main cause of the day/night cycle, but differ as to whether they conceptualize the sun as going below the earth at night or not. One early Chinese cosmology postulated that the earth was flat and square and that the sun moved to other distant parts of the earth (Needham, 1975). The early Greek philosopher, Anaximenes, believed that the earth was flat like a table. One early Greek commentator notes that Anaximenes "says that the heavenly bodies do not move under the earth, as others suppose, but round it, as a cap turns round our head. The sun is hidden from sight, not because it goes under the earth, but because it is concealed by the higher parts of the earth" (Heath, 1932, p. 10). An early Indian cosmology also postulated that the sun did not go below the earth, but instead turned a dark side to earth and then retraced its path back to the east where it would rise (Gombrich, 1975). The early Greek philosopher, Xenophanes, believed the earth was flat and extended down indefinitely. He stated that the sun was made of fire. When the sun set, the fire was extinguished and at each dawn a new sun was ignited (Heath, 1932).

Another common explanation of the day/night cycle was that the setting sun goes under the earth and back to the place where it rises. The Sumerians believed the earth was a flat disc and that when the sun set in the west it went under the earth to rise in the east (Lambert, 1975). The early Egyptians believed the earth was the shape of a river valley and that when the sun set it went beneath the earth to come back up on the other side (Plumby, 1975). A contemporary group of Quechua speakers in Peru have a somewhat similar view. They believe the earth to be a roughly east/west oriented river valley. They believe the sun sets at the west end, and during the night travels under the river to come up at the east end (Urton, 1981).

As Greek astronomy matured, the standard view (e.g., that of Aristotle and Ptolemy) was that the earth was a sphere which was in the center of the universe. The sun and moon were attached to larger spheres which rotated around the motionless earth. The revolutionary movement of the sun around the earth gave rise to the day/night cycle (Heath, 1932). Clearly in the early stages of understanding the day/night cycle, philosopher-scientists developed a wide range of very different models to account for observed data. In the next section we will examine children's explanations of the same phenomena.

Prior Research on Students' Explanations of the Day/Night Cycle

Most studies of knowledge acquisition in astronomy have focused on an examination of students' ideas about the shape of the earth and about gravity (e.g., Nussbaum, 1979; Nussbaum & Novak, 1976; Sneider & Pulos, 1983). However, two relatively recent studies explored students' explanations of the alternation of day and night. One study, conducted by Sadler (1987), investigated the ideas of 25 ninth-grade students about the day/night cycle, the seasons, and the phases of the moon. This study revealed the following five distinct explanations of the reasons for the alternation of day and night: (1) the earth spins, (2) the sun moves around the earth, (3) the moon blocks out the sun, (4) the sun goes out at night, and (5) the atmosphere blocks the sun at night. Sadler reports that over half of the students who participated in this study were completing a one-year course in Earth sciences but that these students did not provide correct answers more often than the others, although they did tend to use scientific terms like "orbit" and "tilt" more often than the students who did not take the course.

A more detailed study of students' ideas about astronomical phenomena, including the alternation of day and night cycle, was conducted by Baxter (1989). In this study, the responses of 20 students ranging in age from 9 to 16 years of age were obtained in individual interviews. These responses revealed the following six explanations of the day/night cycle: (1) the sun goes behind hills, (2) clouds cover the sun, (3) the moon covers the sun, (4) the sun goes around the earth once a day, (5) the earth goes around the sun once a day, and (6) the earth spins on its axis once a day. Research with additional subjects showed a preference on the part of the younger students for the explanation in which the earth goes around the sun once a day and its gradual replacement with the explanation in which the earth spins. Despite this change, many of the students age 15–16 years still believed that the reason for the day/night cycle is that the earth goes around the sun or the sun goes around the earth or that the moon covers the sun.

While the studies described above identify students' explanations of the day/night cycle, they are limited in their scope. The explanations are not described in great detail, and the researchers do not provide explicit information about the criteria used to derive students' explanations and about the consistency with which these explanations were used. Neither do they attempt to provide an account of how these explanations were formed, or how they change with development. We will try to answer some of these questions in this paper. In the next section we will elaborate and expand the theoretical framework we have developed to explain the Baxter (1989) and Sadler (1987) findings and to make further predictions.

Constructing a Mental Model of the Day/Night Cycle

We assume that the construction of a mental model of the day/night cycle depends on individuals' representations of a number of interacting concepts (such as the concepts of the earth, the sun, and the moon), and that it is constrained by two kinds of presuppositions: *ontological presuppositions*, such as the presuppositions that physical objects are solid, stable, fall down when not supported, etc.; and *epistemological presuppositions*, which are presuppositions about the general character of explanations of physical phenomena, such as a preference for physical/causal explanations. These presuppositions influence the way individuals interpret their observations and the information they receive from the culture to generate specific beliefs about the nature of the physical world and constrain the way these beliefs are mapped into mental models. An outline of this process is given in Figure 1. Beliefs and mental models themselves can function as second-order, domain-specific constraints which further influence the acquisition process.

In the next section we describe the hypothesized knowledge acquisition process which underlies children's initial explanations of the day/night cycle and discuss the ways in which people's models of the earth and the sun further constrain their mental models of the day/night phenomenon.

Hypothesized Knowledge Acquisition Process

Presuppositions

We assume that elementary school children in our culture operate under the constraints of certain epistemological presuppositions. For example, they have some criteria which are used to decide what constitutes a phenomenon,

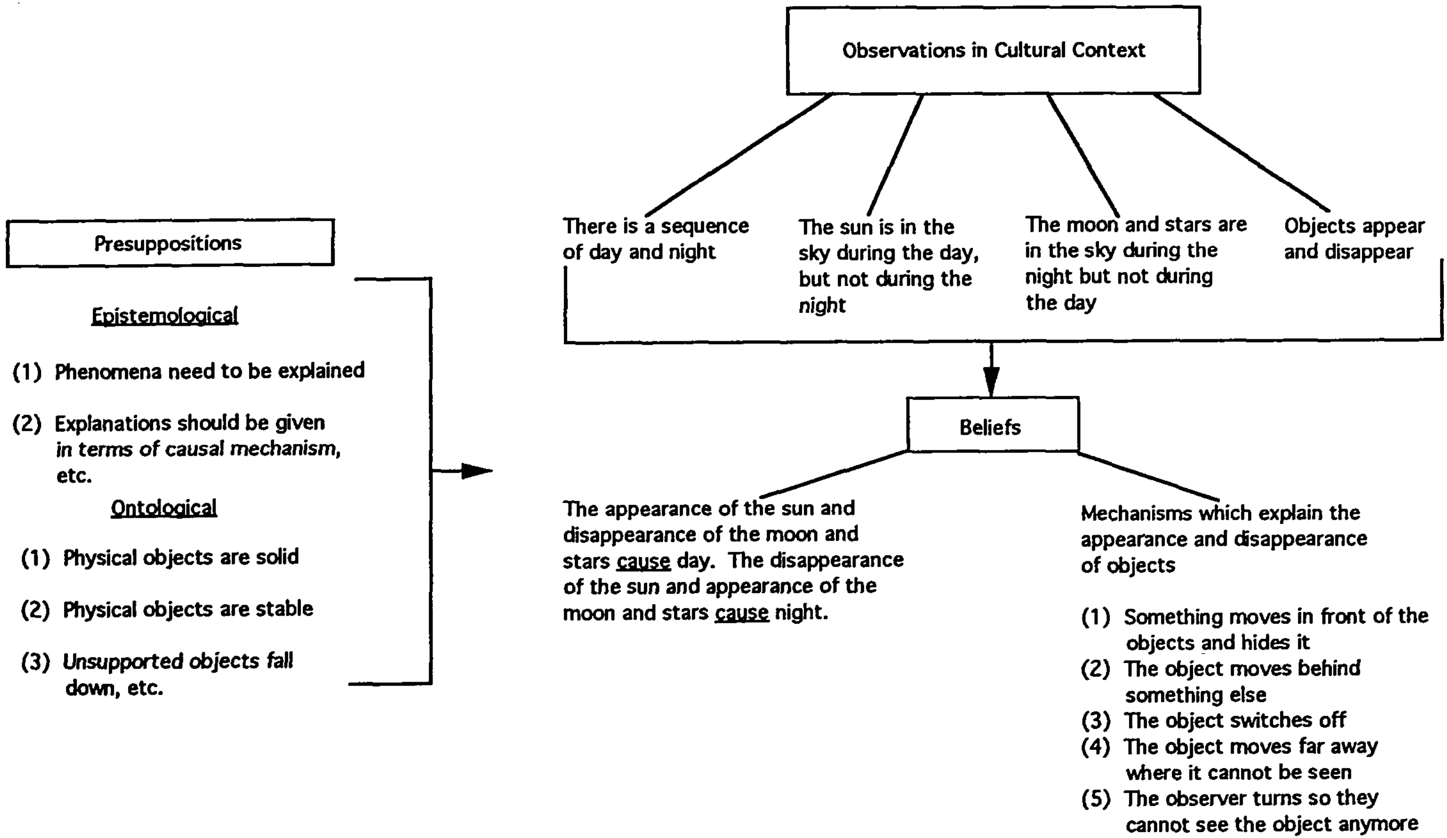


Figure 1. Hypothesized knowledge acquisition process underlying elementary school children's beliefs regarding the alternation of day and night

they know that phenomena require an explanation, and are predisposed to prefer causal explanations of physical phenomena. We further assume that children are constrained by a set of ontological presuppositions regarding the nature of physical objects (e.g, that physical objects are solid, stable, require support, etc.). These presuppositions form the background within which children interpret their observations and constrain the inferential process that uses these observations to generate specific beliefs about the nature of the physical world.

We do not know if these presuppositions are universal or are restricted to children raised in the culture in which the children in our sample were raised. We have some cross-cultural data (Brewer, Herdrich, & Vosniadou, 1987; Samarapungavan & Vosniadou, 1988; Vosniadou & Brewer, 1990) suggesting that the ontological presuppositions we have identified are found across different cultures, but the resolution of this important issue remains a question for future research (see also Vosniadou, in press-b).

Observations and Related Beliefs

The core observation related to the day/night cycle is that the sun is out in the sky during the day, but not during the night. A related observation is that the moon and stars are in the sky during the night, but not during the day. (Most young children are not aware that the moon is sometimes present in the day sky.) From these observations, and given the presuppositions already discussed, many children derive the beliefs that day is caused by the appearance of the sun and the disappearance of the moon and stars; and that night is caused by the disappearance of the sun and the appearance of the moon and stars.

The appearance and disappearance of things is a very common and salient phenomenon in the everyday experience of the child. Observations of infants show preoccupation with making things appear or disappear (e.g., Piaget, 1963), and studies of language acquisition show that words and utterances expressing the disappearance and reappearance of objects or persons are among the very first to appear in the lexicon of the young child (Bloom, 1970; Brown, 1973). By the end of the preschool years children seem to have available to them a number of possible mechanisms that explain the disappearance and reappearance of objects, such as: something moves in front of the object and hides it, the object moves far away where it cannot be seen, etc.

Despite the availability of a range of mechanisms we predict that the particular mechanisms which are selected to explain the day/night cycle are the mechanisms that meet the constraints imposed by children's mental models of the earth and the sun, the moon and the stars. Some of these constraints are given in Figure 2.

Constraints on Explanatory Mechanisms

Explanations of the day/night cycle may vary depending on how an individual conceptualizes the earth, the sun, the moon, and the stars. Since mental

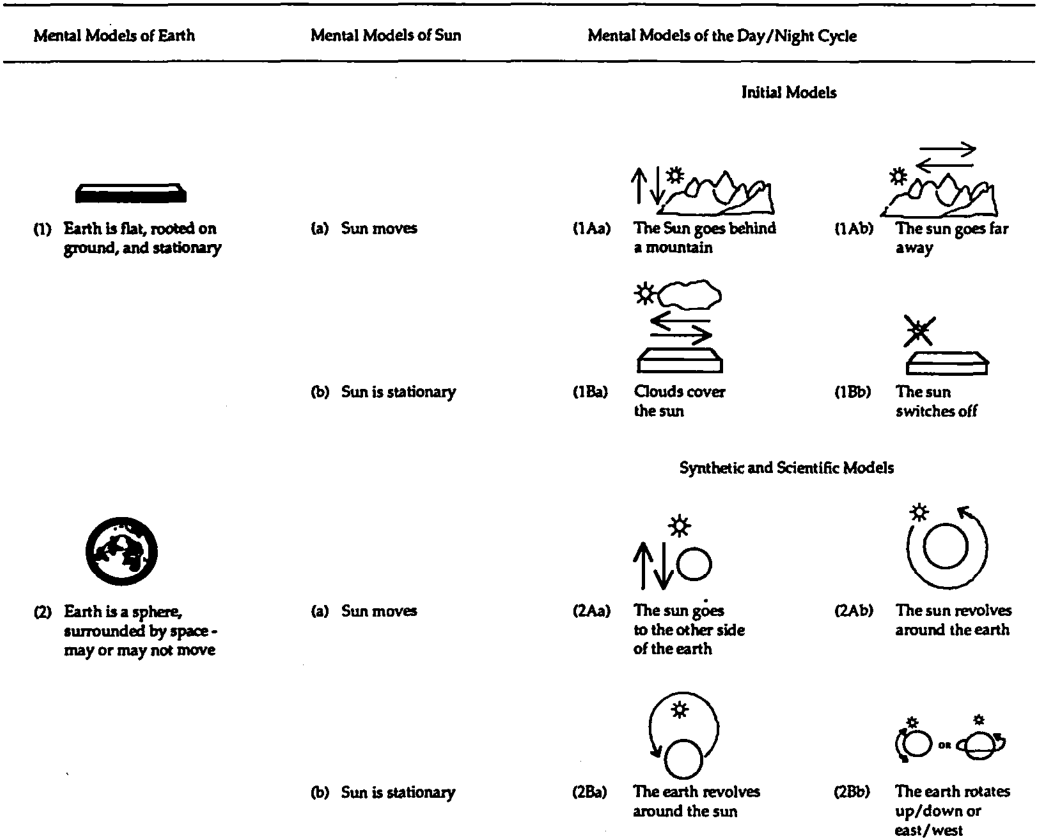


Figure 2. Constraints on the selection mechanisms that explain the day/night cycle.

models of these celestial bodies are constrained by ontological presuppositions of the sort discussed by Vosniadou & Brewer (1992), these presuppositions also act as indirect constraints on mental models of the day/night cycle. In this section we will examine how children's mental models of the earth and the sun constrain their mental models of the day/night cycle. The question about how the mental models of the moon and the stars influence the mental models of the day/night cycle will be addressed in the next sections.

Initial Models

Based on our studies of individuals' representations of the earth, we assume that children start by forming a mental model of a flat and stationary earth, supported by something, usually dirt and rocks. Given the mental model of a flat, supported, stationary earth, the disappearance of the sun can be explained by different mechanisms depending on whether the sun is conceptualized to be stationary or moving. If children think that the sun moves they can hypothesize that at night it goes behind mountains (Figure 2, 1Aa) or that it goes far away (Figure 2, 1Ab). If the sun is conceptualized as stationary, children can hypothesize that something else (e.g., clouds, moon, darkness, etc.) comes and covers it up (Figure 2, 1Ba), or that it switches off (Figure 2, 1Bb).

These mental models of the day/night cycle are called initial models because they rely exclusively on interpretations of experience which can be derived from everyday observations. The synthetic models discussed below show the influence of the culturally accepted, scientific information about the earth, sun, and the day/night cycle.

Synthetic and Scientific Models

The mental model of a flat, stationary earth rooted in the ground seems to place strong constraints on a child's understanding of the scientific explanation of the day/night cycle. For example, it is difficult to conceptualize a flat earth that is rooted in the ground as spinning or revolving around the sun. As children come to form a mental model of a spherical earth surrounded by space, an additional class of day/night mental models become available to them. Even when the spherical earth is thought to be stationary and the sun as moving, children can think of the sun as going down to the other side of the earth, or as revolving around the spherical earth (Figure 2, 2Aa, 2Ab). On the other hand, children who have been exposed to the scientific information that the day/night cycle is due to the rotational movement of the earth can conceptualize the spherical earth as either revolving around a stationary sun (Figure 2Ba), or as rotating around its axis (Figure 2Bb), or both.

Criteria for the Evaluation of Explanations: Accuracy, Consistency, and Simplicity

Kuhn (1977) discusses five criteria (or values) which scientists use to evaluate the adequacy of a theory. Three of these, *accuracy, consistency,* and *simplicity*, seem to us to be good criteria by which to judge children's explanations of the day/night cycle.

A theory should be accurate within its domain in the sense that the consequences deducible from the theory should agree with the results of existing observations and experiments. In our case this means that children's explanations of the day/night cycle should be consistent with the empirical observations which are related to the phenomenon of the alternation of day and night (see Figure 1). On the basis of the existing research findings (Baxter, 1989; Sadler, 1987), we would expect that children's explanations will indeed demonstrate such empirical accuracy.

Kuhn's (1977) second criterion is the criterion of logical consistency. A theory should be internally consistent with itself as well as with other accepted theories about related phenomena. Notice that researchers who claim that children's explanations of phenomena are fragmented or loosely organized are asserting that children do not adopt a principle of logical consistency in theorizing about the physical world (see, e.g., diSessa, 1988, 1993; Reif & Allen, 1992; Solomon, 1983).

In our discussion of the constraints that the mental models of the earth and the sun impose on the mental models of the day/night cycle, we have assumed that children *will* show logical consistency. We assume, in other words, that children with the mental model of a stationary sun will not choose to explain the alternation of day and night on the basis of the sun's movement, as in (Figure 2) models 1Aa and 1Ab or models 2Aa and 2Ab. Similarly, we expect children with mental models of a flat and stationary earth will not provide explanations according to which the earth rotates around its axis or revolves around the sun. Children who say that the sun or the earth is stationary in response to questions regarding the movement of the sun and the earth and then go on to explain the day/night cycle in terms of the movement of the sun or the movement of the earth, are logically inconsistent.

It is logically possible, however, to think that the sun moves but not to use the movement of the sun as the mechanism to explain the day/night cycle. This would mean that the mental models 1Ba or 1Bb in Figure 2 would still be logically consistent models for a child who had the model of a moving sun. The interdependencies between children's mental models of the sun, moon, stars and earth are rather complex and are described in detail later in this article, when we discuss the criteria used for the derivation of children's mental models of the day/night cycle. What should be stressed here is that our hypothesis that children will show logical consistency makes strong predictions about the relationships between individuals' mental models of the earth and the sun and their mental models of the day/night cycle, which allow us to test this hypothesis.

A third criterion by which to judge a theory is, according to Kuhn (1977), the criterion of simplicity—"a theory should be simple, bringing order to phenomena that in its absence would be individually isolated and, as a set confused" (Kuhn, 1977, p. 322). We think that it is possible to decide whether children are sensitive to the criterion of simplicity in their explanations of the day/night cycle by looking at the similarity of the mechanisms used to explain the disappearance of the sun during the night and the moon during the day.

If children think that the moon and stars are causally implicated in the day/night cycle then their mental models should include an explanation for the appearance of the moon and the stars during the night and their disappearance during the day. If, in addition to empirical accuracy, children strive for logical consistency, then they should use mechanisms to explain the appearance and the disappearance of the moon and stars which obey the same constraints as those that govern the appearance and disappearance of the sun.

Logical consistency does not require, however, that the *same* mechanism is used to explain the appearance and disappearance of *all* celestial objects. Children who think that the sun goes behind the clouds at night, but that the moon and stars switch on and off are as internally consistent as children who use the same mechanism to account for the disappearance of the sun, moon, and stars. Using the *same* mechanism to explain the disappearance of the sun, the moon and stars during the alternation from day to night, shows sensitivity not only to logical consistency but also to simplicity of explanation.

To conclude, we hypothesize that elementary school children will be able to provide accurate and logically consistent mechanistic explanations of the day/night cycle. We predict that the younger children's explanations will be in terms of the occlusion of the sun by clouds, the sun switching off, the sun moving behind something, or the sun moving far away, depending on whether the sun is conceptualized as stationary or moving. We further predict that the older children will generate synthetic and scientific models—according to which the earth revolves around the sun, the sun revolves around the earth, or the earth rotates around its axis. In addition, our theoretical framework predicts certain interrelationships between children's mental models of the earth, the sun, the moon and the stars and their mental models of the day/night cycle which can provide important information about children's sensitivity to issues of simplicity of explanation.

Methodological Issues

The methodology used in this study is similar to the methodology described in Vosniadou and Brewer (1992). It consisted of asking children questions, some of which required a verbal response, and others which required making a drawing. Some of the questions used could be answered on the basis of information derived either from experience or from instruction (e.g., Where is the sun during the day? Does the earth move?). Other questions required explanations of phenomena which cannot be directly observed, and about which children do not usually receive direct instruction (e.g., Where is the sun at night? Where are the stars during the day?). These latter types of questions have the potential of revealing the kinds of mental models individuals use generatively to answer novel questions and to solve unfamiliar problems.

Different sets of questions were asked about the sun, the moon, and the stars, and children's responses to these questions were used as the basis for deriving information about their mental models of these celestial objects. The children were also asked to explain the phenomenon of the day/night cycle in a separate set of questions. Children's overall mental models of the day/night cycle were derived at the end by comparing each child's mental models of the sun, the moon, and the stars with his or her explanations of the alternation of day and night. Only the children who exhibited logical consistency in their models and explanations were considered to have an internally consistent overall mental model of the day/night cycle. The others were placed in a mixed category.

METHOD

Subjects

The subjects for this study were 60 children: 20 first graders, ranging in age from 6 years and 4 months to 7 years and 5 months (*mean* age, 6 years and 9 months); 20 third graders ranging in age from 9 years and 3 months to 10 years and 3 months (*mean* age 9 years and 9 months); and 20 fifth graders ranging in age from 10 years and 3 months to 11 years to 9 months (*mean* age 11 years). The children attended an elementary school in Urbana, Illinois and came from predominantly middle-class backgrounds. Approximately half of the children were girls and half were boys. These subjects were the same subjects as those in Vosniadou and Brewer (1992).

Materials

The materials consisted of a 48-item questionnaire. The questionnaire was developed through extensive pilot work and was designed to provide information about children's knowledge of certain critical concepts in astronomy, including their ideas about the earth's shape and gravity. Only the 13 questions investigating children's ideas about the disappearance of the sun at night, the movement of the moon, the explanation of the day/night cycle, and the disappearance of the stars during the day will be discussed in this paper. These questions were selected for their potential to differentiate

TABLE 1
Questions Used to Investigate Children's Mental Models of the Day/Night Cycle

The Disappearance of the Sun at Night	
Q22:	Where is the sun at night?
Q23:	How does this happen?
Q24a:	Does the earth move?
Q24b:	Does the sun move?
Explanations of the Day/Night Cycle	
[The experimenter drew a circle to depict the earth and placed a figure on the upper left side of the circle.]	
Q25:	Now make it so it is day for that person. Good! Now make it so it is night for that person.
Q26a:	Tell me once more how this happens.
The Movement of the Moon	
Q30:	Does the moon move?
Q31:	Does the moon move along with you when you go for a walk?
Q32:	Does the moon move when you are asleep in your bed?
Q33:	Why does the moon move?
The Disappearance of the Stars During the Day	
Q36a:	Where are the stars at night?
Q36b:	Where are they during the day?
Q37:	Do the stars move?

among the different mental models of the day/night cycle previously discussed. The 13 questions are given in Table 1.

Questions 22 and 23 (Where is the sun at night, How does this happen?) provide information about children's explanation of the disappearance of the sun at night. Questions 24a and 24b (Does the earth move? and Does the sun move?) revealed children's knowledge regarding the movement of the earth and the sun. This information was necessary to allow us to test our prediction that children's beliefs about the movement of the earth and the sun would constrain their choice of mechanism to explain the disappearance of the sun at night.

The next set of questions (Q25, Q26a) required an explanation of the alternation of day and night. We expected that these explanations would be based on the belief that the day/night cycle is caused by the appearance and disappearance of the sun. If the children saw the appearance and disappearance of the moon and the stars as causally related to the day/night cycle, they should provide an explanation of the disappearance and appearance of the moon and the stars as well.

The questions about the movement of the moon (Q30, Q31, Q32, Q33) and about the disappearance of the stars during the day (Q36a, Q36b, Q37) were designed to provide further information about the relationship that children saw between the sun, the moon and the stars. This information was intended to enable us to understand children's mental models of the day/night cycle and to judge whether these models were empirically and logically consistent and showed sensitivity to issues of simplicity of explanation.

Procedure

The children were seen individually in an interview which lasted between 30 and 45 minutes. The experimenter made detailed notes of children's responses. The interview was also recorded using a tape-recorder. The scoring was done later on the basis of both the transcribed data and the experimenter's notes.

Scoring

The data were scored by two independent judges who examined the four sets of questions (the disappearance of the sun at night, the alternation of day and night, the movement of the moon, and the disappearance of the stars during the day) separately, assigning children to various categories of explanations. All disagreements were discussed until consensus was achieved. Our previous work (Vosniadou & Brewer, 1992, pp. 545–547, 554–555) has shown high reliability for classifying children's responses to these types of questions. In assigning children to mental models we followed a procedure similar to that described in Vosniadou and Brewer (1992). First, we identified, on the basis of our data and previous research in this area, a set a possible explanations for the disappearance of the sun or the stars, of the movement of the moon, etc. Then, we generated the pattern of responses to our questions which would be expected assuming that the children used each explanation consistently to answer all relevant questions. We then checked the expected pattern of responses against the pattern of obtained responses to the relevant questions, and assigned children to various categories of explanations. If the children were *not* logically consistent, they were placed in the mixed category.

After we classified each child's responses to the four sets of questions, we examined the four sets of responses combined and assigned children to an overall mental model of the day/night cycle. At the end, we checked to see whether the derived mental models of the day/night cycle were consistent with children's mental models of the earth which had been derived in our earlier paper. The derivation of the mental models of the day/night cycle was done independently from and without knowledge of children's mental models of the earth.

The detailed criteria used for assigning children to a category of explanation for the four sets of questions are described in Table 2 and are discussed in the next section.

RESULTS

In this section we present the criteria used to assign the children to the various categories of explanations of the disappearance of the sun at night, the alternation of the day and night, the movement of the moon, and the disappearance of the stars during the day. Then we present the criteria for assigning children to overall mental models of the day/night cycle and discuss the consistency between mental models of the day/night cycle and mental models of the earth.

Logical consistency in children's responses to the various questions was a necessary requirement for being assigned to an explanation type. The response patterns judged as logically consistent for each set of questions are described below.

The Disappearance of the Sun at Night

Four questions were asked to determine children's explanations of the disappearance of the sun at night. These questions can be found in the top row of Table 2. Children's answers to these questions were classified into 11 explanation types which are shown in the first column of Table 2. The first explanation type attributes the day/night cycle to the *occlusion of the sun* by clouds or darkness. Explanations 2 to 6 focus on the *movement of the sun* as the primary reason for its disappearance, while explanations 7 and 8 use the *movement of the earth* as the primary reason for the disappearance of the sun at night. The body of the table contains, for each question, the types of responses that were classified as instances of each explanation type.

Responses to Question 24b, "Does the sun move?", were critical in differentiating the children who attributed the disappearance of the sun to the *movement of the sun* from those who attributed it to the *movement of the earth.* Children assigned to explanation types 2 to 6 were expected to say that the sun moves up/down or east/west. Children assigned to explanation types 7 and 8 were expected to say that the sun is stationary or to mention movements that could not be used to explain the day/night cycle (e.g., that the sun rotates around its axis or moves due to the expansion of the universe).

Responses to Question 24a, "Does the earth move?" were critical for assigning children to explanations 7 and 8. For explanation 7 the children were expected to say that the earth turns, spins, goes around in circles, or moves and for explanation 8 that the earth goes around the sun. Affirmative responses to question 24a "Does the earth move?" were not considered inconsistent with explanations 1 to 6 because it is possible to have a model of the earth moving which does not explain the disappearance of the sun at night. Ideally we expected that the children who attributed the disappearance of the sun at night to the sun's movement would say that the earth is stationary. However, many children who are exposed to the information that the earth moves do not understand exactly how the earth moves or do not realize that this movement has any explanatory power with respect to the alternation of day and night. It is possible to construct various mental models where the movement of the earth is not logically inconsistent with the explanation of the disappearance of the sun based on the sun's movement (e.g., the earth moves/shakes as in an earthquake, or that the earth moves rotationally but very slowly—once during a year, and so on).

TABLE 2
Explanation Types for the Disappearance of the Sun at Night Questions and Their Frequency as a Function of Grade[a]

Type of Explanation	Where is the sun at night? Q22	How does this happen? Q23	Does the earth move? Q24a	Does the sun move? Q24b
1. The sun is occluded by clouds or darkness[b] (2, 2, 1=5)	Behinds clouds In darkness In the sky	Clouds or darkness cover the sun up	No or Yes	Yes or No
2. The sun moves in and out of space (1, 1, 0=2)	In space	The sun goes way out into space	No or Yes	Yes, it goes into space
3. The sun goes down on/in the ground (6, 1, 1=8)	The sun moves down on/in the ground; moves down behind hills, mountains, in the water	The sun moves down	No or Yes	Yes, it moves up/down
4. The sun goes down to other side of the earth (2, 0, 1=3)	Below the earth; under the earth; down to the other side of the earth	The sun moves down to the other side of the earth	No or Yes	Yes, it moves up/down
5. The sun goes down, unspecified (2, 0, 0=2)	Down	The sun goes down; it goes to another country	No or Yes	Yes, it moves up/down

(continued)

TABLE 2 (Continued)

6. The sun revolves around the earth (0, 1, 0=1)	At the other side of the earth	The sun goes around the earth	No or Yes	Yes, it goes around the earth
7. The earth turns and the sun is fixed (3, 7, 12=22)	Stays where it is or on the other side of the earth	Earth turns, turns around, spins, rotates, goes around in circles, or moves	Yes; earth turns, spins, goes around in circles or moves	No or if Yes only axis rotation or movement due to expansion of universe
8. The earth revolves around the sun (0,1, 2=3)	Stays where it is or on the other side of the earth	The earth goes around the sun	Yes it goes around the sun	As above
9. God made day and night (0, 1, 0=1)	Anything	God made it that way	No	No
10. Mixed (1, 2, 3=6)	Anything	Logically inconsistent responses	Inconsistent responses	Inconsistent responses
11. Undetermined (3, 4, 0=7)	Anything	No response, do not know, irrelevant or ambiguous response	No or Yes	Yes or No

[a] $n=60$

[b] The numbers in parentheses give the frequency of explanation type for each grade. The first number is the frequency for Grade 1, the second for Grade 3, and the third for Grade 5. The last number gives the frequency across grades.

Information about how children's responses to Questions 22 and 23 were used to assign them to the specific explanation types is presented in Table 2, which also shows the frequency of these explanations as a function of grade. Table 3 gives a protocol example from each explanation type. A more detailed discussion of certain aspects of the classifications is given below.

The critical information for placing a child in explanation type 4 (*sun goes down to the other side of the earth*) was the use of phrases such as *below, under,* or *down* to the other side of the earth to Question 22, "Where is the sun at night? These phrases were used to distinguish explanation type 4 from explanation type 3 (*the sun goes down on/in the ground*). Two children did not give enough information in their responses to Questions 22 and 23 to determine whether they believed the sun stays on the ground or whether it goes down, to the other side of the earth. For example, Jeff (protocol number 5, Table 3) said that the sun goes down "to a city or something." This city could be on the same side or on the "other" side of the earth. These two children were placed in explanation type 5 (*the sun goes down, unspecified*).

In explanation type 6 (*the sun revolves around the earth*), the earth is considered fixed and the sun revolves around it. The one child who was placed in this category thought that the sun and the moon "trade places" as they revolve around the earth every 24 hours. This child stated that the sun is "on the other side of the earth" to Question 22, "Where is the sun at night?", because "the sun goes around the earth" (Question 23). See protocol number 6, Table 3 for more details. Note the interesting contrast of explanation type 6 with explanation type 8 (*the earth revolves around the sun*) in which the sun is considered fixed and the earth revolves around it.

There were some children who could not be classified into one of the nine explanation types. A pattern of responses was scored as explanation type 10 (*mixed*) when more than one mechanism was used to explain the disappearance of the sun at night, thus resulting in an internally inconsistent model. For example, Sandra (protocol number 10, Table 3) starts by explaining the disappearance of the sun in terms of the up/down movement of the sun, continues with an occlusion explanation, and when asked whether the earth moves changes to an earth axis rotation explanation. A number of children were classified as explanation type 11 (*undetermined*). The children placed in this category either said that they did not know how to explain the phenomenon in question or gave an explanation which we could not understand. An example of one of the undetermined responses is given in Table 3 (protocol number 11). Many of the mixed and undetermined responses revealed children's attempts to keep elements of their initial explanations (usually in terms of an occlusion or sun moving up/down mechanism) as they replaced them with the culturally accepted explanation of a rotating earth.

Examination of Table 2 shows that, as was expected, most of the first-grade children provided explanations in terms of the initial mental model of

TABLE 3
Protocol Examples of Explanations of the Disappearance of the Sun at Night

1. The sun is occluded by clouds or darkness	2. The sun moves in and out of space	3. The sun goes down on/in the ground	4. The sun goes down to the other side of the earth.
Tamara (No. 3, Grade 5) E: Where is the sun at night? C: It's hiding. E: It's hiding? Where's it hiding? C: I don't know...cause it won't shine. E: How does this happen? C: The clouds block it. E: Does the earth move? C: It goes around. It goes east, west, north. E: Does the sun move? C: Yes.	Kristie (No. 52, Grade 1) E: Where is the sun at night? C: Gone in space. E: How does this happen? C: When it get dark it goes way into space. E: Does the earth move? C: Yes, the earth just floats. E: Does the sun move? C: Yes	Betsy (No. 53, Grade 1) E: Where is the sun at night? C: Down. E: Down where? C: Below the hills E: How does this happen? C: I don't know. E: Does the earth move? C: No. E: Does the sun move? C: It goes up and down.	Brian (No. 43, Grade 1) E: Where is the sun at night? C: Under the earth. E: How does this happen? C: Because the moon comes out and the sun comes down. E: Does the earth move? C: No. E: Does the sun move? C: Yes, it goes down.

5. The sun goes down, unspecified.	6. The sun revolves around the earth.	7. The earth turns and the sun is fixed.
Jeff (No. 45, Grade 1) E: Where is the sun at night? C: Down there. E: Where's there? C: It goes down. E: Down where? C: It goes to a city or something. E: Does the earth move? C: No. E: Does the sun move? C: Yes.	Karen (No. 37, Grade 3) E: Where is the sun at night? C: Well, it goes under the earth to China. See, while we have day, China has night and while China has night, we have day. E: How does this happen? C: Well, the moon and the sun trade places every...I guess it's... E: Do you mean 24 hours? C: OK, every half of 24 hours they will change, they trade. Like they ...in the a.m. the sun is here...for 12 hours and the moon is in China for 12 hours. And when China has sun for 12 hours, we have the moon for 12 hours. E: Well, does the sun move then? C: Oh yes, it moves every hour. Well, every year, yaa. It moves very slow. Every year it moves a little bit, but it moves slowly and uhmm, every year it's gone around once. E: It's gone around what? C: The sun has gone around the earth once...every year. Well, not once...it goes around every year, the sun does. But the earth moves around in a circle every year. E: Does it move around anything? C: To me, everything moves around the earth, and it doesn't move around anything.	Cindy (No. 29, Grade 3) E: Where is the sun at night? C: On the other side of the earth. Because when night comes over here the sun goes onto the other side of the earth and it's day on there. E: How does this happen? C: The earth turns around. E: Does the earth move? C: Yeah. E: Does the sun move? C: No.

(continued)

TABLE 3 (Continued)

8. The earth revolves around the sun.

Isaac (No. 39, Grade 3)

E: Where is the sun during night?
C: On the other side of the earth.
E: How does this happen?
C: The earth moves around and it has a line and the sun keeps going around that, around the earth. . . I mean around the sun.
E: Now wait, I just got a little confused. How does the earth move again?
C: It moves around the sun. . .
E: does the sun move?
C: No.
E: Now, what's that thing about the line?
C: Well, the line is like a path that it just keeps going around, it doesn't go back and forth.

9. God made day and night.

Jamie (No. 21, Grade 3)

E: Where is the sun at night?
C: It's in another land, or maybe another planet.
E: How does this happen?
C: It's the way the earth is made.
E: Can you explain this move?
C: It's just the way God created it.
E: Does the earth move?
C: No.
E: Does the sun move?
C: No.

10. Mixed

Sandra (No, 27, Grade 3)

E: Where is the sun during the night?
C: It went down to the moon.
E: How does this happen?
C: Because at 5 o'clock the sun sets and it rises in the morning and sets at night. It goes down when it has to.
E: Why does it have to?
C: Because it sun, it's night and day and it's supposed to be night around 5 or 6 o'clock and day around 1 or 2 or 3 o'clock.
E: So is the sun moving?
C: Yes.
E: Can you tell me how it moves?
C: I don't think it really moves, but I think the clouds just cover it all up.
E: Does the earth move?
C: No. . .the earth do move I mean.
E: How does the earth move?
C: Because it rotates around, and that's how the sun goes down, because the earth is turning to one half and the other half be day and it wait for 24 hours and it turn to the other half. And this half be night and this half be day.

11. Undetermined

Charles (No. 36, Grade 3)

E: Where is the sun at night?
C: Behind the moon.
E: How does this happen?
C: The earth is rotating. The earth is going around in circles on its axis. And it's making the sun move toward the moon. It looks like it because the earth is rotating.
E: Does the earth move?
C: Yes.
E. Does the sun move?
C: Some, maybe, yes.

a sun moving down on the ground, whereas most of the older children provided explanations in terms of the rotational movement of the earth.

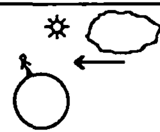
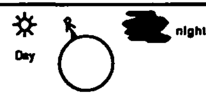
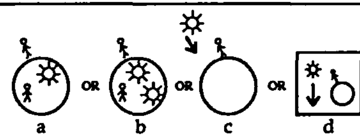
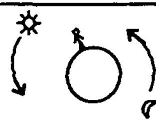
The Alternation of Day and Night

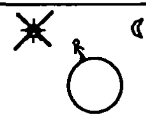
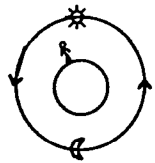
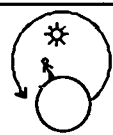
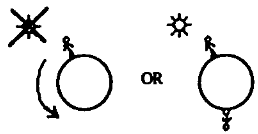
Children's explanations of the alternation of day and night were determined on the basis of their responses to Questions 25 and 26a, which are shown in Figure 3. For Questions 25, the experimenter drew a circle to depict the earth and placed a figure on the upper left side of the circle. She then said, "Make it so it is day for this person" and then "Make it so it is night for this person." In Question 26a a verbal explanation of the day/night cycle was requested ("Tell me once more how this happens.") When assigning children to categories of explanations we looked at the consistency between their drawings and their verbal explanations. Children were placed in an explanation category when the drawing and their verbal explanation indicated that the same mechanism was used to explain the day/night cycle. Neutral drawings (e.g., the child simply crosses out the sun, as shown in Figure 3, Explanation Type 6) were accepted if the verbal explanation was unambiguous. Similarly, neutral verbal explanations were acceptable if the drawing was unambiguous. If the drawing and the verbal explanation were both ambiguous, the child's response was placed in an undetermined category. If they were inconsistent with each other (in that they implied the use of different mechanisms), the child was scored as mixed.

When the decision was made to use the drawing of a circle to depict the earth with a figure placed on the upper left side to depict the people who live on the earth we had not yet understood children's mental models of the earth. This drawing turned out to be somewhat problematic because some of the children who participated in this study did not think of the earth as a sphere, or did not believe that it is possible for people to live on the surface of this sphere. Some children in our sample believed that the earth is flat like a rectangle or like a disc, or a hollow sphere with people living on flat ground deep inside it (see Vosniadou & Brewer, 1992).

As will become clear in the protocol examples presented in Table 4 and the drawings presented in Figure 3 and Figure 4, some of the children explicitly rejected our drawing and put their figure inside the circle, on a flat line inside the circle, or on a flat line underneath the circle. Others did not say anything but ignored the drawing and made their own. In some cases, however, the drawing and the placement of the figure may have resulted in pictorial representations of the day/night cycle which were inconsistent with the verbal explanations or which did not reflect them accurately. We tried to take the child's point of view into consideration as much as possible when interpreting the drawings, but in a few cases we may have placed children in the mixed category when they did not actually belong there. We could have decided not to use the drawing data, but had we done so, much interesting and valuable information would have been lost in order to eliminate a relatively small number of problematic cases.

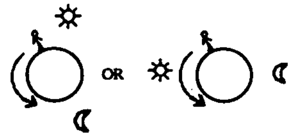
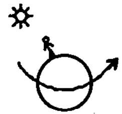
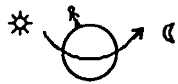
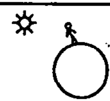
Figure 3. Explanations of the day/night cycle. and their frequencies as a function of grade.

Type of Explanation	Given the drawing below the experimenter says: Now make it so it is day for that person Good! Now make it so it is night for that person.  Q25	Show me. Tell me once more how this happens. Q26a
1 The sun is occluded by clouds or darkness (1, 1, 1 = 3)[a,b]		Clouds or darkness or night cover up the sun
2 Day is replaced by night (1, 0, 0 = 1)		Day moves to another place and darkness replaces it
3 The sun moves into space (1, 1, 0 = 2)		The sun goes into space and then comes back down
4 The sun goes down on/in the ground (*and the moon goes up*) (4, 0, 0 = 4)		The sun goes down on/in the ground (over the hill, in the water) and the moon comes up
5 The sun goes down to the other side of the earth (and the moon comes up) (3, 0, 0 = 3)		The sun goes down under the earth or to the other side of the earth (and the moon goes up)

Type of Explanation	Now make it so it is day for that person Good! Now make it so it is night for that person. Q25	Show me. Tell me once more how this happens. Q26a
6 The sun goes down - unspecified with respect to earth side (3, 0, 0 = 3)		The sun goes down It goes to another city
7 The sun and moon revolve around the earth (0, 2, 0 = 2)		The sun and moon move around the earth every day
8 The earth revolves around the sun (1, 2, 1 = 4)		The earth goes (turns) around the sun
9 The earth turns up/down and the sun is fixed (moon unspecified) (1, 1, 5 = 7)		The earth turns around (*spins or rotates*) The sun stays in one place

(*continued*)

Figure 3 (Continued)

Type of Explanation	Now make it so it is day for that person Good! Now make it so it is night for that person. Q25	Show me. Tell me once more how this happens. Q26a
10 The earth turns up/down and the sun and moon are fixed at opposite sides (0, 3, 5 = 8)		When it is daytime the earth turns (spins or rotates) around the sun. When it is nighttime, it turns to where the moon is
11 The earth turns sideways moon unspecified (0, 0, 1 = 1)		The earth turns away from the sun
12 The earth turns sideways and the sun and moon are fixed at opposite sides (0, 2, 0 = 2)		When the earth goes around its orbit, this side becomes day and this side becomes night
13 The earth turns in unspecified direction moon unspecified (2, 2, 2 = 6)		The earth turns around (spins or rotates)
14. Mixed (2, 5, 4 = 11)	Logically inconsistent response	Logically inconsistent response
15. Undetermined (1, 1, 1 = 3)	No response, irrelevant or ambiguous response	No response, irrelevant or ambiguous response

[a] $\underline{n} = 60$

[b] The numbers in parentheses give the frequency of explanation type for each grade. The first number is the frequency for grade 1, the second for grade 3, and the third for grade 5. The last number gives the frequency across grades.

Finally, it should also be mentioned that children's responses were placed in the mixed category if *at any other place in the interview* they provided an explanation of the day/night cycle which was different from the one they gave in response to Questions 25 and 26a. Such opportunities existed at different parts in the interview, for example, when children were asked about the apparent movement of the moon, or the disappearance of the stars during the day. The strict criteria for internal consistency we employed may explain the relative large number of mixed cases for this set of questions (11/60).

The exact criteria for assigning children to each explanation type are given in Figure 3 and will be further discussed. Figure 3 also shows the frequency of children's explanations as a function of grade. Protocol examples for each explanation type can be found in Table 4 (pp. 150–151). The drawings of the children whose protocols were used in Table 4 are shown in Figure 4 (p. 152).

In explanation type 1 the sun is occluded by clouds, while in explanation type 2, day goes away and night takes its place. Explanation type 2 does not use occlusion as the mechanism for the disappearance of the sun but rather the *movement of the sun* (as well as everything else that constitutes day) to another place.

In order to be placed in explanation type 4 (*the sun goes down on/in the ground*) a child had to provide some evidence, either in a drawing or in a verbal statement or in both, that the sun goes down *on* or *in* the ground (not down to the other side of the earth). Statements such as "on" or "in the ground" "behind hills," "in the water," etc. were used by the children together with drawings which depict the sun going down but not to the other side of the earth.

Children's depictions of the sun going down on the ground varied considerably. As shown in Figure 3, some children placed the sun inside the circle depicting the earth (Figure 3, explanation type 4, drawings a and b). There were a variety of other options. In drawing *b* the child drew another sun to indicate the downward movement. In drawing *c* the child showed with an arrow how the sun goes down to the ground. In drawing *d* we have a child with a two-earth model who showed the sun going down towards the flat ground which is supposed to be below the spherical earth. These drawings show that the way children conceptualize the movement of the sun varies greatly depending on their mental model of the earth, but the exact relationship between mental models of the earth and mental models of the day/night cycle will be discussed later in this article. Finally, it is important to note that all but one of the children placed in this category implicated the moon in the day/night cycle by saying that when the sun goes down, the moon goes up.

The crucial difference between explanation type 5 (*the sun goes down to the other side of the earth*) and explanation type 4 is that the children provided evidence either in their drawing or in their verbal statements or in

TABLE 4
Protocol Examples for Explanations of the Day/Night Cycle

1. The sun is occluded by clouds or darkness.	2. Day is replaced by night.	3. The sun moves out into space.	4. The sun goes down on/in the ground (and the moon comes up).	5. The sun goes down to the other side of the earth (and the moon goes up).
Tamara (No. 9, Grade 5)	Autumn (No. 51, Grade 1)	Allison (No. 52, Grade 1)	Harmony (No. 41, Grade 1)	Timothy (No. 47, Grade 1)
E: Now can you make it so it is day for that person? C: He's outside the earth. E: Where should he be? C: In here (see Figure 4, drawing 1). E: ...OK now, make it daytime for him. C: The sun is out here, but it looks like it's in the earth, when it shines... E: OK. What happens at night? C: The clouds covered it up. E: Tell me once more how it happens. C: Cause at 12 o'clock it's dark.	E: Now make it day for that person. C: Sun and clouds in the sky. Rainbow, raindrops (see drawing 2 in Figure 4). E: Now make it so it is night for that person. C: Everything goes away. E: Can you make it night? C: How? E: Go ahead and draw it in. How would it be? C: The stuff would go away E: Do you know were it would go? C: Into another place. E: Do you know how that happens? C: Yes. Um the night takes over the sun.	E: Now make it so it is day for that person. C: (child makes drawing 3 shown in Figure 4) Right here? E: Whatever you think. Now make it night. C: It goes in space. E: Show me. Tell me how it happens. C: The sun comes back down. It goes into space and when it gets dark the moon comes back out.	E: Can you make it day for this person? C: (see drawing 4 in Figure 4) E: Now make it night for that person. C: To make it night, erase the sun and replace it with the moon. E: Can you tell me once more how it happens? C: The sun goes down and the moon comes up, and then the moon goes down and the sun comes up. E: Where is the moon when the sun is up? C: The moon is where the sun rests.	The child makes the drawings shown in Figure 4. E: Tell me once more how it happens. C: When the moon comes up and the sun goes down. E: Where was the moon before? C: Under the earth. E: What time was it when it goes under the earth? C: Day.

(continued)

TABLE 4 (Continued)

6. The sun goes down, unspecified as to which side of the earth (and the moon goes up).	7. The sun and the moon revolve around the earth.	8. The earth revolves around the sun.	9. The earth rotates up/down and the sun is fixed (moon unspecified).	10. The earth rotates up/down and the sun and moon are fixed at opposite sides.
Quinten (No. 44, Grade 1) E: Now make it day. Now make it night. C: (see drawing 6 in Figure 4) E: Tell me once more how this happens. C: Because he's on top of the earth and the sun's going to be coming out of the whole space. The sun's supposed to be in the middle of the whole part. . . and it comes out. Then he'll be standing on the earth so he'll get to see the sun. And when the moon comes, he can see the moon too. E: Does the sun move? C: Only up and down. E: Does the moon move up and down too? C: Yes	Karen (No. 37, Grade 3) The child makes drawing 7 shown Figure 4. E: Now make it so it is night. C: We have to cross out the sun and put it over here. E: Tell me once more how it happens. C: Well, the sun vibrates around the earth every 12 hours. And then the moon goes the other direction and vibrates around the earth every 12 hours. So both us and China have the moon and the sun.	Mike (No. 11, Grade 5) E: Make it so it's day time for this person C: (see drawing 8, Figure 4) E: Make it so it's night. C: Moon (child draws moon) C: Tell me once more how it happens. C: The earth turns around the sun, and the sun gives heat.	Chad (No. 19, Grade 5) Child makes drawing 9 shown in Figure 4. E: Tell me how it happens. C: The sun stays in one place and the earth turns. E: How? C: It turns around.	Robert (No. 5, Grade 5) E: Now make it so it is day for that person. C: (child makes drawing 10 shown in Figure 4) E: Now can you make it nighttime? C: Can I draw him somewhere else? (draws figure at the bottom of the earth) E: Sure. C: (Child draws arrows to show how earth spins) E: Tell me how it happens. C: When it was daytime, the earth spinned around to the sun. When it was nighttime, the earth turned around to where the moon is.

11. The earth rotates left/right and the sun is fixed (moon unspecified).	12. The earth rotates left/right and the sun and moon are fixed at opposite sides.	13. The earth rotates in unspecified direction, moon unspecified.
Eddie (No. 20, Grade 5) C: (Child makes drawing 11 shown in Figure 4) E: Tell me how it happens. C: Cause when the earth turns away from the sun, it gets dark.	Venika (No. 33, Grade 3) C: (Child makes drawing 12, Figure 4) E: Can you tell me how this happens? C: When the earth turns around its orbit, this side comes day and the other side comes night.	Joshua (No. 1, Grade 5) C: (Child produces drawing 13, Figure 4) E: How does this happen? C: Cause the world rotates.

Figure 4. Drawings of children whose protocols are given as examples of explanations of the day/night cycle.

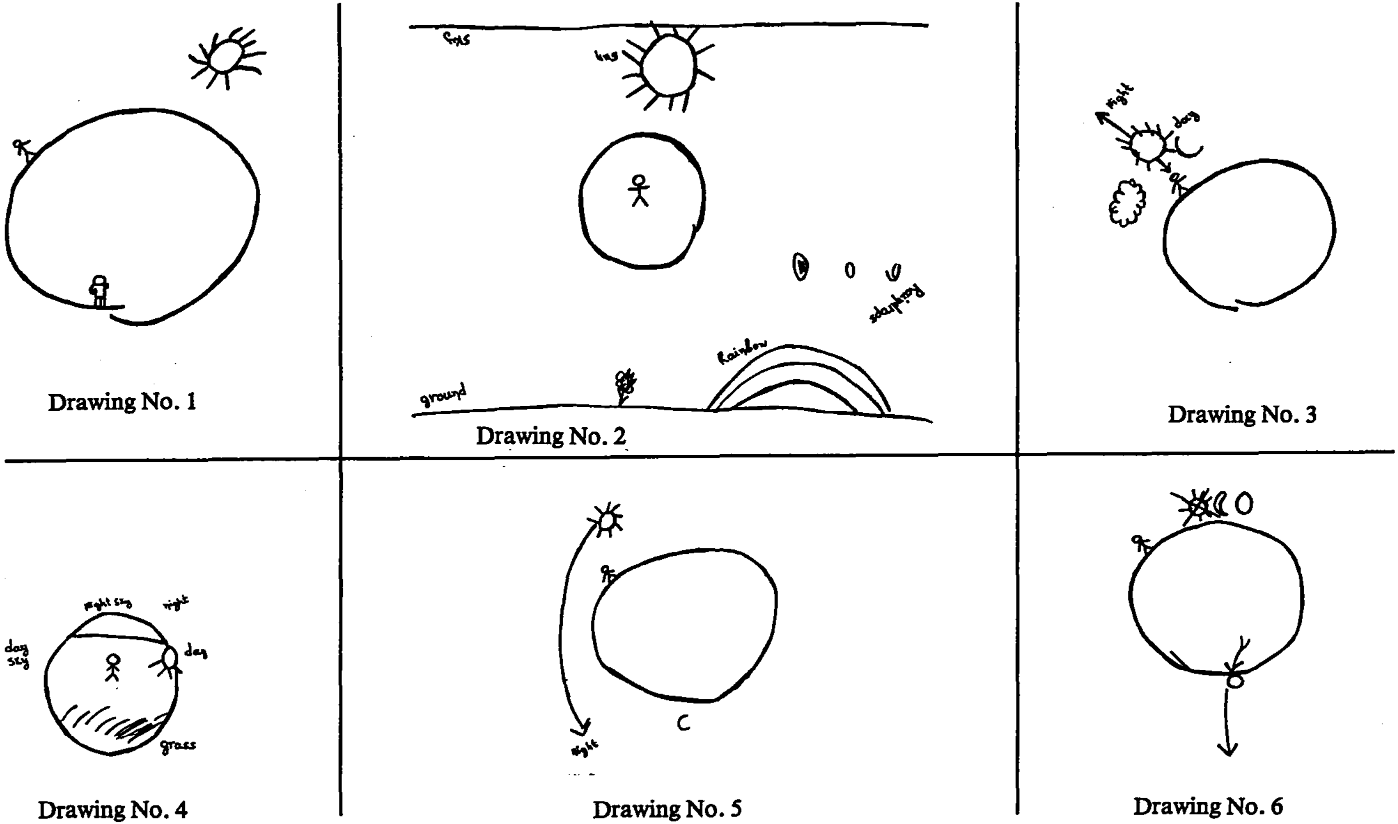
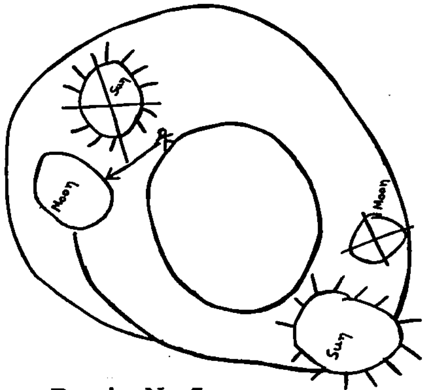
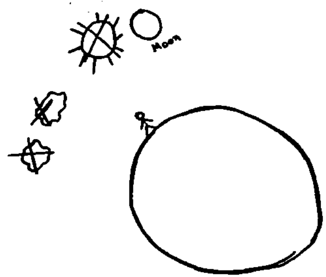


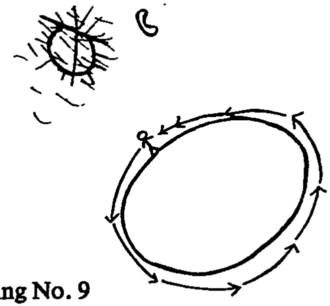
Figure 4 (Continued)



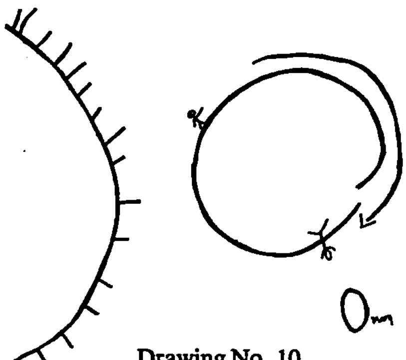
Drawing No. 7



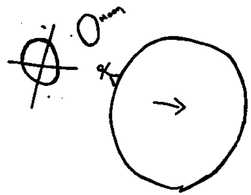
Drawing No. 8



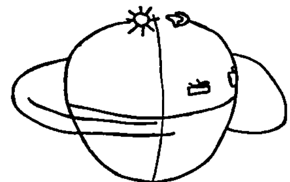
Drawing No. 9



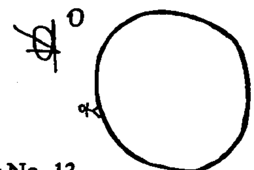
Drawing No. 10



Drawing No. 11



Drawing No. 12



Drawing No. 13

both, that the sun went *down to the other side of the earth.* The three children placed in this category made drawings such as the one shown in Figure 3, depicting the sun going down to the other side of the earth, and also said that the sun goes down, under, or to the other side of the earth. Two of these children also said that the moon goes up when the sun goes to the other side of the earth. An example of this type of response is protocol number 5, Table 4 and drawing number 5, Figure 4.

In explanation type 7 (*the sun and the moon revolve around the earth*), the alternation of day and night is caused because the sun and the moon revolve around the earth every 24 hours. Since the sun and moon are conceptualized as being located at two diametrically opposed sides in their orbital path, this explanation nicely accounts for the alternation of day and night for the different parts of the earth.

The criteria for explanation type 8 (*the earth revolves around the sun*) were either an unambiguous drawing showing the earth revolving around the sun or a verbal explanation indicating revolutionary movement of the earth, or both. Note that the model according to which a nonrotating earth revolves around the sun in 24 hours generates the appropriate day/night cycle. Children who gave a revolution explanation but a rotation drawing were placed in the mixed category. The four children placed in this category said explicitly that the earth goes around the sun in their verbal explanations and made a drawing which was not inconsistent with this explanation. An example of this type of response is protocol number 8, Table 4 and drawing number 8, Figure 4.

Explanation type 9 (*the earth rotates up/down and the sun is fixed*) is one of a class of rotation explanations which is characterized by the up/down rotation of the earth (i.e., rotation around an axis through the equator instead of through the poles). The children placed in this category all said that the earth turns around and the sun stays in one place. Information about the direction of the rotation was obtained from their drawings. Up/down rotation was indicated either with an arrow or by placing the figure at the bottom of the earth to make it night time (see drawings a and b respectively for explanation type 9, Figure 3). An example of this type of response is given in Table 4, protocol 9 and Figure 4, drawing 9. Children who said that the earth turns, spins, or rotates but made a neutral drawing with respect to the direction of rotation were placed in explanation type 13.

Examination of explanation type 9, Figure 3, shows that there is another possible interpretation of the up/down arrow. One could imagine that one is viewing the earth from above the north pole and that the figure is standing on the equator. If one adopts this perspective then the arrow that we are interpreting as "up/down" would actually be west/east (i.e., rotation around a polar axis). We understand that this is a logically consistent interpretation of the drawing by an adult. However, our experience with children carrying out the drawing task suggests that they interpret the figure in our drawing as standing on the "top" of the earth (i.e., at the north pole). It is possible that this preference is related to problems children have with gravity. In addition, we have unpublished data in which children are given a sphere with a person on it and are asked to make it day or night for the figure. When manipulating the models the children tend to carry out an up/down rotation, not a west/east rotation of the earth. On the basis of these observations, we have concluded that the best interpretation of the type of drawings given in Figure 3, explanation type 9, is up/down rotation.

Explanation type 10 (*the earth rotates up/down and the sun and moon are fixed at opposite sides*) is similar to explanation type 9 with the additional constraint that the sun and moon are fixed at two opposite sides of the earth. The information that the sun and moon are fixed at opposite sides could come either from an unambiguous verbal explanation or from an unambiguous drawing or from both. The drawings expected for this explanation type are shown in Figure 3 and are of two kinds: (1) they depict the sun and the moon fixed at the top and bottom of the earth at least 90° apart, or (2) they depict the sun and the moon to be fixed at the left and right sides of the earth at least 90° apart *and* indicate up/down rotation of the earth by the use of an arrow or by the placement of figures on the bottom parts of the earth. This additional information is required when the sun and the moon are fixed at the left and right sides of the earth because in this case their position alone does not provide information about the direction of the rotation. An example of one of these responses is protocol 10, Table 4, and drawing 10, Figure 4.

There were some children who could not be classified into one of the 13 explanation types previously described. These children were placed either in explanation type 14 (mixed) or in explanation type 15 (undetermined). The children placed in explanation type 14 (mixed) provided evidence for two conflicting interpretations of the day/night cycle in their responses. Sometimes the conflict existed in the inconsistency between the drawing and the verbal explanation, such as in subject number 15, who drew an arrow showing the earth to rotate up/down but said that the earth turns around the sun. At other times the conflict existed in the inconsistency between children's responses to Questions 25 and 26a, and what was said later in the interview. For example, subject number 46 started with a perfectly clear earth up/down rotation explanation and changed to a sun up/down explanation at the end of the interview. Another type of inconsistent explanation was a combination of occlusion of the sun versus sun up/down movement. The children who were placed in explanation type 15 (undetermined) did not provide a mechanism for the day/night cycle in their responses.

Examination of Figure 3 shows that, as predicted, most of the first grade children explain the day/night cycle in terms of the up/down movement of the sun and moon, while most of the fifth grade children use a rotation of the earth explanation.

The Movement of the Moon

Children's ideas about the movement of the moon were determined by looking at the pattern of their responses to the four moon movement questions which appear in the top row of Table 5 (p. 157). Eight categories of explanation types for moon movement responses were obtained and these are also shown in Table 5. Protocol examples for some of these categories appear in Table 6 (p. 158).

Children who said that the moon does not move to all the relevant questions (Q30, Q31, and Q32) were placed in explanation type 1. In Question 30 some children said that the moon appears to move because the earth moves but that it does not *really* move. Similarly, some children mentioned, in response to Question 31, that the moon appears to move along with you when you go for a walk but that it does not *really* move. One child said spontaneously that the moon stays where it is and the reason why you don't see it during the day is because clouds cover it up. Question 33, "Why does the moon move?", was not asked for these children because they said that the moon does not move. See protocol 1, Table 6 for an example of this type of response.

The children classified in explanation type 2 all said that the moon moves in an up/down fashion, in response to Questions 30 and 32. Some of these children claimed that the moon moves in a "hydraulic" relation with the movement of the sun, that is, the moon goes down in the morning when the sun goes up, and later, when the sun goes down the moon goes up. Most children said that the moon does not move along with you when you go for a walk (Q31) although some acknowledged that it may appear to do so. Finally, all the children explained the movement of the moon (Q33) in relation to the day/night cycle. See protocol 2, Table 6 for an example of this type of response pattern.

A number of children said that the moon revolves around the earth in response to Questions 30 and 32, and that it does not move along with you, although it may seem so, in response to Question 31. These children were placed in explanation type 4. Most of the explanations of the revolution of the moon in Question 33, "Why does the moon move?" were given in terms of the day/night cycle—"to make it night." An example protocol is given in Table 6 (protocol 4). No gravity explanations were given in this category as they were given in the previous one. The absence of the scientific types of explanations in this category suggests that the revolution of the moon around the earth was not understood in terms of the scientific model but was seen as causally implicated in the day/night cycle.

Table 5 shows the frequency of moon movement responses as a function of grade. There is a clear shift from seeing the moon as moving at first grade to seeing it as stationary at grades 3 and 5. Thus, the movement question gives a very interesting U-shaped function. The young children tend to say the moon does move, the older children tend to say that it does not move,

TABLE 5

Explanation Types for the Movement of the Moon Questions and Their Frequency as a Function of Grade[a]

Type of Movement	Does the moon move? Q30	Does the moon move along with you when you go for a walk? Q31	Does the moon move when you are asleep in your bed? Q32	Why does the moon move? Q33
1. No, with or without explanation (2, 7, 8=17)[b]	No No—the earth moves and makes it seem as if it moves	No or Yes No, it *seems* to move; it does not really move	No	Not relevant
2. Yes, Up/down (3, 0, 2=5)	Yes Up and Down	No or Yes, it seems to move	Yes—it moves up/down or No—it moves at dawn so the sun can get up to make day	To make day/night
3. Yes, movement unspecified (11, 3, 4=18)	Yes	No or Yes, it seems to move but does not really	Yes or No—because it moves some other time	I don't know To make day/night Because of the earth's gravity
4. Yes, revolution around earth (0, 4, 2=6)	Yes, with or without mentioning revolution	No or Yes, it seems to move	Yes—it goes around the earth	To make night
5. Yes, mixed (0, 0, 1=1)	Yes	No	No	The moon does not move. The earth does.
6. Yes, undetermined (1, 2, 2=5)	Yes	No	No	I don't know
7. No, mixed (1, 2, 0=3)	No	No	Yes	I don't know
8. No, undetermined (2, 2, 1=5)	No	Ambiguous response (e.g., the sun was following us when my mom and I were going to see my grandpa)	Ambiguous response (e.g., the moon is on another planet during the daytime)	I don't know

[a] $n=60$

[b] The numbers in parentheses give the frequency of explanation type for each grade. The first number is the frequency for Grade 1, the second for Grade 3, and the third for Grade 5. The last number gives the frequency across grades.

TABLE 6

Protocol Examples from the Questions Investigating the Movement of the Moon

1. No, with or without explanation.	2. Yes, up/down.	3. Yes, movement unspecified
Joshua (No. 1, Grade 5) E: Does the moon move? C: Yes. No cross that out. It doesn't move. It's you that's moving. And it looks like the moon is moving. It's still while you're moving. E: Does the moon move along with you when you go for a walk? C: No. E: Does the moon move when you are asleep in your bed? C: No. It stays in the same place. The earth moves.	Quinten (No. 44, Grade 1) E: Does the moon move? C: Only up and down. E: Does the moon move along with you when you go for a walk? C: No. E: Does the moon move when you're asleep in your bed? C: No. E: Why does the moon move? C: Cause when the sun's gonna come up it gotta go down, when the sun goes down it gotta come up.	Luther (No. 13, Grade 5) E: Does the moon move? C: Yes. E: Does the moon move along with you when you go for a walk? C: No. E: Does the moon move when you are asleep in your bed? C: Yes. E: Why does the moon move? C: Because it's attracted to the earth's gravity. And it moves with the earth.
4. Yes, revolution around the earth.		
Josh (No. 32, Grade 3) E: Does the moon move? C: Yes. E: Does the moon move along with you when you go for a walk? C: No. E: Does the moon move when you are asleep in your bed? C: Yes. It moves around the earth. E: Why does the moon move? C: So that when the sun comes up here it will be night on the other half.		

and adults say it does move (unpublished data from undergraduate subjects). Our detailed categorization of the different types of moon movement provides a very good explanation for the progression of these different answers to the same verbal question with age. When the young subjects say the moon moves they tend to mean that it moves in an up/down fashion with respect to the earth's surface. When the older subjects say that it does *not* move they are typically operating with a rotating earth model with the moon fixed in one position. When adult subjects say the moon moves they are reflecting the scientific model in which the moon revolves around the earth. This analysis of responses to questions about the movement of the moon shows the power of the mental model approach in providing an explanation of data that, at first glance, appear quite puzzling.

The Disappearance of the Stars During the Day

Children's explanations of the disappearance of the stars during the day were explored by asking the three questions which appear in the top row of Table 7 (p. 160). The various explanation types and their frequencies are shown in Table 7. Protocol examples from each category are shown in Table 8 (p. 161). The data presented in Table 7 show that the first-grade children give a wide range of explanations of the disappearance of the stars during the day—they are occluded by clouds during the day, they move down on the ground, they move to the other side of the earth. These are similar to their explanations of the disappearance of the sun at night. However, the largest group of children (24 out of 60) said that the stars stay where they are during the day and that the reason we cannot see them is because of the brightness of the sky due to the light coming from the sun. This explanation is particularly common among the fifth-grade children (12 out of 20).

Overall Mental Models of the Day/Night Cycle

Children were placed in the various explanation types already discussed if they met the criteria for logical consistency which we developed on a priori basis and which were previously described. In this section we describe the criteria used to assign children to an "overall mental model of the day/night cycle." In order to be assigned to an overall model of the day/night cycle a given child had to have been placed in explanation categories in the four sets of questions previously discussed which were not logically inconsistent with each other.

The criteria for assigning children to mental models are described in Table 9 (pp. 162–163) and are discussed in detail in the following section according to model numbers. The frequency of occurrence of each model type by grade is also given in Table 9.

Model 1: The Sun is Occluded. The four children placed in this category all said that something (usually clouds or darkness) blocks the sun, in response

TABLE 7

Explanation Types for the Disappearance of the Stars During the Day Questions and Their Frequency as a Function of Grade[a]

Type of Explanation	Where are the stars at night? Q36a	Where are they during the day? Q36b	Do the stars move? Q37
1. The stars are occluded by clouds (3, 5, 3=11)[b]	In the sky	Behind Clouds	Yes or No
2. The stars move out into space (2, 2, 1=5)	In the sky	Move away, into space	Yes
3. The stars go down on/in the ground (behind hills) (1, 0, 1=2)	In the sky	Behind hills	Yes
4. The stars move down, under the earth (3, 1, 1=5)	In the sky	They go under or the other side of the earth	Yes
5. The stars move down, unspecified as to which side of earth (2, 0, 0=2)	In the sky	They go down	Yes
6. The stars move somewhere else (1, 0, 0=1)	In the sky	Another city, country	Yes
7. The stars disappear (1, 0, 0=1)	In the sky	They are gone—disappear	I don't know
8. The stars stay where they are (3, 9, 12=24)	In the sky	They are still up on the sky. You can't see them because of the sun's light	No, they don't move
9. Undetermined (4, 3, 2=9)	In the sky	No response, I do not know, irrelevant or ambiguous response	Yes or No

[a] $n=60$

[b] The numbers in parentheses give the frequency of explanation type for each grade. The first number is the frequency for Grade 1, the second for Grade 3, and the third for Grade 5. The last number gives the frequency across grades.

TABLE 8

Protocol Examples from the Questions Investigating the Disappearance of the Stars

1. The stars are occluded by clouds.	2. The stars move out into space.	3. The stars move down on/in the ground.	4. The stars move down under the earth.	The stars move down, unspecified as as to which side of the earth.
Bandy (No. 57, Grade 1) E: Where are the stars at night? C: In the sky. E: Where are they during the day? C: Behind the clouds. E: Do the stars move? C: Yes.	Margaret (No. 60, Grade 1) E: Where are the stars at night? C: Up in the sky. E: Where are the stars during the day? C: Way in space and when it gets daytime they go down. E: Do the stars move? C: Yes	Betsy (No. 53, Grade 1) E: Where are the stars at night? C: In the sky. E: Where are the stars during the day? C: Down behind the hills. E: Do the stars move? C: Only when it is daytime.	Brian (No. 43, Grade 3) E: Where are the stars at night? C: Up in the sky. E: Where are the stars during the day? C: Under the earth. E: How did this happen? C: When the sun comes out the stars go down and the moon goes down. E: Do the stars move? C: Yes	Donald (No. 49, Grade 1) E: Where are the stars at night? C. Up in the sky. E: Where are the stars during the day? C: Down here. They went down. E: Down where? C: Down some place. E: Do the stars move? C: Yes

6. The stars move somewhere else.	7. The stars disappear.	8. The stars stay where they are	9. Undetermined.
Autumn (No. 51, Grade 1) E: Where are the stars at night? C: In the sky. E: In the day? C: Into another city. E: Do the stars move? C: Yes.	Russel (No. 59, Grade 1) E: Where are the stars at night? C: They are in the sky. E: During the day? C: In the day they are gone. Disappear E: Do the stars move? C: I don't know.	Danielle (No. 4, Grade 5) E: Where are the stars at night? C: They are in space. E: Where are the stars during the day? C: They are still in space. E: Can we see them? C: No. E: Why? C: Because we're facing the sun and the sun gives us too much light and we can't see them. E: Do the stars move? C: No.	Irvin (No. 55, Grade 1) E: Where are the stars at night? C: In space. E: Where are the stars during the day? C: They are not there. E: Where are they? C. I don't know. E: Do the stars move? C: Yes. E: How. C: Once in a while they move with you when you walk or ride a bike or when riding a car

TABLE 9

Overall Mental Models of the Day/Night Cycle and Their Frequency as a Function of Grade[a]

Type of Model	The Disappearance of the Sun Questions	Explanations of the Day/Night Cycle	The Movement of the Moon	The Disappearance of the Stars During the Day
1. Sun is occluded by clouds or darkness (2, 1, 1=4)[b]	Sun is occluded clouds or darkness	Sun is occluded by clouds or darkness	Moon moves unspecified or does not move	Stars are occluded or move behind clouds
2. Sun and Moon move up/down on the ground (7, 0, 0=7)	Sun moves down on the ground	Sun goes down on the ground and moon goes up	Moon moves up/down or unspecified	Stars disappear—occluded by clouds or hills—move into space
3. Sun and moon move *up/down to the other* side of the earth (2, 0, 0=2)	Sun moves down to *the other side of the* earth	Sun goes down to the *other side of the* earth and moon goes up	Moon moves up/down or unspecified	Stars go down to the other side of the earth
4. Sun and moon move up/down unspecified (3, 0, 0=3)	Sun moves down unspecified	Sun goes down unspecified and moon goes up	Moon moves up/down or unspecified	Stars move unspecified
5. Sun moves out into space (1, 1, 0=2)	Sun moves out into space	Sun moves out into space	Moon moves unspecified	Stars move out into space
6. *Sun and moon revolve* around earth every day (0, 1, 0=1)	*Sun revolves around* earth	*Sun revolves around* earth	*Moon revolves around* earth	Stars stay where they are
7. Earth and moon revolve around the sun every day (0, 1, 0=1)	Earth revolves around the sun	Earth revolves around sun and moon	Moon moves unspecified	Stars stay where they are
8. Earth rotates up/down; sun and moon fixed at opposite sides (1, 3, 7=11)	Earth turns and sun is fixed	Earth turns in up/down direection	Moon does not move	Stars stay where they are, move into space, or are occluded

(continued)

TABLE 9 (Continued)

9. Earth rotates up/down; sun is fixed but moon moves (0, 1, 3=4)	Earth turns and sun is fixed	Earth turns in up/down direction	Moon moves unspecified or revolves around earth	Stars stay where they are
10. Earth rotates around axis; sun and moon fixes at opposite sides (0, 1, 1=2)	Earth turns around axis or unspecified	Earth turns around axis	Moon does not move	Stars are occluded
11. Earth rotates around axis; sun is fixed but moon moves (0, 1, 0=1)	Earth turns around axis and sun is fixed	Earth turns around axis	Moon moves unspecified or revolves around earth	Stars stay where they are
12. Earth rotates in unspecified direction (1, 1, 1=3)	Earth turns unspecified	Earth turns unspecified	Move moves or does not move	Stars stay where they are
13. Mixed: Earth rotates and sun moves up/down (1, 0, 4=5)	Mixed: earth rotates and sun moves up/down	Mixed: earth rotates and sun moves up/down	The moon moves or mixed	Anything
14. Mixed: earth rotates and revolves (1, 2, 2=5)	Mixed: earth rotates and revolves	Mixed: earth rotates and revolves	Moon moves *or* does not move	Anything
15. Mixed: general (0, 5, 1=6)	Mixed: sun occluded and moves up/down and earth rotates	Mixed	Moon moves or does not move	Anything
16. *Undetermined* (1, 2, 0=3)	*Undetermined* or God made it that way	*Undetermined* or God made it that way	*Moon moves or does not* move	*Anything*

[a] $n=60$

[b] The numbers in parentheses give frequency of explanation type for each grade. The first number is the frequency for Grade 1, the second for Grade 3, and the third for Grade 5. The last number gives the frequency across grades.

to the questions regarding the disappearance of the sun during the night and in the questions requiring an explanation of the day/night cycle. Two of these children said that something also blocks the moon and the stars during the day, but the remaining two said that the moon and the stars move in an unspecified way or move in order to go behind the clouds which then cover them.

We distinguished a class of mental models (Models 2 to 6) which are based on the assumption that the alternation of day and night happens because the sun and the moon move up/down and exchange positions. These models were further differentiated with respect to exactly *where* the sun and the moon move: Model 2: *on the ground*; Model 3: *to the other side of the earth*; Model 4: *unspecified*; Model 5: *out in space*; and Model 6: *revolve around the earth.*

Model 2: The Sun and the Moon Move Up/Down on the Ground. The seven children placed in Mental Model 2 all said that the sun moves down on the ground, in response to the questions regarding the disappearance of the sun; that the moon moves up/down or unspecified, in response to the questions regarding the movement of the moon; that the day/night alternation occurs because the sun goes down with additional possible reference to the moon going up, in response to the questions regarding the explanation of the day/night cycle; and that the stars disappear in various ways—undetermined, occluded by clouds or hills, or move into space, in response to the questions regarding the disappearance of the stars during the day.

Model 3: The Sun and the Moon Move Up/Down to the Other Side of the Earth. Two children were placed in this mental model. They both said that the sun moves up/down to the other side of the earth, that the moon moves up/down or unspecified, that the day/night cycle happens because the sun moves down to the other side of the earth and the moon moves up, and that the stars also move to the other side of the earth during the day.

Model 4: The Sun and the Moon Move Up/Down But Unspecified with Respect to Earth Side. The three children placed in this category all said that the sun and moon move up/down but differed from the children placed in the previous category in that they did not give information as to whether the sun moves down on the ground or to the other side of the earth.

Model 5: The Sun Moves Out in Space. Two children were placed in this category. They both said that the sun moves out into space during the night and that the same happens to the stars during the day. These children also explained the day/night cycle in terms of the sun's movement into space and said that the moon moves in response to the moon movement questions.

Model 6: The Sun and the Moon Revolve Around the Earth Every Day. Only one child was placed in this interesting model in which the sun and the moon (at opposite sides) revolve around the earth every day: When the sun is on our side of the earth, the moon is on the other side. According to this model the stars remain where they are during the day and the reason we cannot see them is because of the brightness of the sun's light.

We identified six different mental models (Models 7 to 12), which used the movement of the earth as the basis for forming an explanation of the day/night cycle. These mental models were differentiated with respect to the type of movement of the earth (e.g., Table 9, revolution - Model 7; rotation - Models 8, 9, 10, 11 and 12). The rotation models were further differentiated with respect to the type of rotation (up/down or west/east) as well as with respect to the movement of the moon (moon fixed or revolving around the earth).

Model 7: The Earth and the Moon Revolve Around the Sun Every Day. Only one subject was found to have formed Model 7 according to which the earth and the moon revolve around the sun every 24 hours, and the stars stay where they are.

Model 8: The Earth Rotates Up/Down; the Sun and the Moon are Fixed at Opposite Sides. The 11 children who were placed in this classification all explained the disappearance of the sun at night by saying that the earth turns and that the sun is fixed. These children also said that the moon does *not* move in response to the questions regarding the movement of the moon. The day/night cycle was explained in terms of the up/down rotation of the earth. They gave a variety of explanations of the stars (e.g., the stars stay where they are and we cannot see them because of the sun's light, they are occluded by clouds or move out in space during the day).

Model 9: Earth Rotates Up/Down; the Sun is Fixed But the Moon Moves. This mental model is similar to the previous one with only one exception. The moon is not fixed at the opposite side of the earth from where the sun is located but moves either in an unspecified way or revolves around the earth. Four children were placed in this category.

Model 10: Earth Rotates Around Axis; the Sun and the Moon are Fixed at Opposite Sides. Two children were placed in this category. They both said or indicated in their drawings that the earth turns around its (north/south) axis in response to the questions regarding the disappearance of the sun at night and/or the questions requiring an explanation of the day/night cycle. In addition, they said that the moon does not move and that the stars, which also do not move, are occluded by clouds during the day.

Model 11: Earth Turns Around Axis; the Sun is Fixed, But the Moon Moves. Only one child was identified as having this model. This child said that the earth turns around its axis, the sun is fixed, the moon revolves around the earth, and the stars stay where they are.

Model 12: Earth Turns in Unspecified Direction; Sun is Fixed But Moon May or May Not *Move.* The children placed in this category did not specify how the earth moves. Some of these children said that the moon moves and others thought it is stationary. Three children were placed in this model.

A number of mixed mental models of the day/night cycle were identified. We differentiated the models which presented a combination of earth rotation *and* sun moves up/down explanations (Model 13) from those which confused rotation and revolution (Model 14). All others were placed in a general mixed model. The children who did not provide enough information to be placed in a mental model were put in the undetermined category.

Model 13: Mixed. Earth Rotates and Sun Moves Up/Down. The five children placed in this model thought that the earth rotates *and* the sun moves up/down at the same time. Most of these children thought that the moon also moves and provided different kinds of explanations regarding the disappearance of the stars at night (e.g., stay where they are, move down, are occluded).

Model 14: Mixed. Earth Rotates and Revolves. Another five children explained the day/night cycle sometimes in terms of the earth's rotation and sometimes in terms of its revolutionary movement.

Model 15: Mixed General. This category included various mixed explanations of the day/night cycle. Some children attributed the day/night cycle both to the occlusion of the sun by clouds *and* its movement down to the ground. Some children mentioned in addition to these two explanations that the earth rotates or revolves. One child first gave an explanation of the day/night cycle in terms of the up/down movement of the sun and the moon and later an explanation in terms of the revolution of the sun and the moon around the earth. Six children were placed in this category.

Model 16: Undetermined. The three children in this category gave undetermined responses to the questions regarding the disappearance of the sun during the day and the questions requiring an explanation of the day/night cycle, or said that "God made it that way" in one of them.

The frequency of the mental models of the day/night cycle as a function of grade is shown in Table 9. We again see a shift from an initial model of an up/down moving sun and moon to earth rotation explanations with increasing grade.

TABLE 10
Relationship Between Children's Overall Models of the Day/Night Cycle and their Models of the Shape of the Earth[a]

Subject No.	Model No. & Description
Rectangular Earth	
49	4. Sun and moon move up/down unspecified
Dual Earth	
42, 51	1. Sun is occluded by clouds or darkness
53, 57, 59	2. Sun and Moon move up/down on the ground
31, 52	5. Sun moves out into space
Hollow Sphere	
9	1. Sun is occluded by clouds or darkness
2	8. Earth rotates up/down; sun and moon fixed at opposite sides
13	9. Earth rotates up/down; sun is fixed but moon moves
20, 33	10. Earth rotates around axis; sun and moon fixed at opposite sides.
Flattened Sphere	
43	3. Sun and moon move up/down to the other side of the earth
11	11. Earth rotates around axis; sun fixed but moon moves
Sphere	
24	1. Sun is occluded by clouds or darkness
39	7. Earth and moon revolve around the sun every day
1, 3, 4, 7, 18, 19, 26, 28, 29, 58	8. Earth rotates up/down; sun and moon fixed at opposite sides
5, 6, 36	9. Earth rotates up/down; sun is fixed but moon moves

[a] Only subjects who have well specified models of *both* earth shape and day/night.

Relationship Between Children's Overall Mental Models of the Day/Night Cycle and Mental Models of the Earth

In the introduction we described some of the constraints that mental models of the earth impose on mental models of the day/night cycle (see Figure 2). Since we had independently assigned the children who participated in this study to mental models of the earth (see Vosniadou & Brewer, 1992), we had the information required to examine the relationship between their mental models of the day/night cycle and their models of the earth. As Table 10 shows, this comparison indicated that the children with rectangle, disc, and dual earth models provided explanations of the day/night cycle in terms of the up/down movement or occlusion of the sun (Models 1, 2, 4, or 5), or had mixed or undetermined models.

We did not observe any cases where a fundamentally flat model of the earth was associated with an explanation of the day/night cycle in terms of the revolution or rotation of the earth, or even the explanation according to which the sun goes down to the other side of the earth (Table 9, Model 3).

On the other hand, children with spherical or synthetic models of the earth typically gave rotational explanations and only occasionally gave explanations of the day/night cycle in terms of occlusion or of the up/down movement of the sun and the moon. We carried out an analysis of the data presented in Table 10. The children who held flat models of the earth were compared with the overall sample of children with specified earth models with respect to the number who held "no rotation" models (Models 1, 2, 4, & 5) versus other models of the day/night. The children with flat earth models were reliably different from the overall sample, χ^2 (1, N = 8) = 16.00, $p < .001$. These results are consistent with our predictions that the mental model of a spherical earth surrounded by space is a necessary, but not sufficient, condition for the acquisition of the scientific explanation of the day/night cycle.

DISCUSSION

Mental Models of the Day/Night Cycle

The results of the present study showed that 38 out of the 60 children in our sample could be assigned to a coherent mental model of the day/night cycle. A graphic representation of the subset of models that the children in our sample constructed (not including undetermined or mixed models), is presented in Figure 5.

The mental models of the day/night cycle which we obtained were similar to the explanations identified in previous research (e.g., Baxter, 1989; Sadler, 1987). The children provided accounts of the alternation of day and night in terms of the sun going down behind the hills or being covered by clouds, or they gave explanations based on the notion that the sun revolves around the earth or that the earth revolves around the sun or rotates around its axis. There was one explanation identified by Sadler and by Baxter (according to which the moon blocks the sun at night) which was not identified in the present sample, but which has appeared in some of our text comprehension studies (see Vosniadou, 1991b).

There was also noticeable similarity between children's mental models of the day/night cycle and the kinds of explanations of the day/night cycle found in the history of astronomy. Like the early astronomers, the young children in our sample explained the day/night cycle in terms of the sun moving to distant parts of the earth, hiding behind hills or mountains, or setting under the earth in the west to rise in the east.

Three Kinds of Mental Models: Initial, Synthetic and Scientific

Our theoretical framework led us to predict that we would find three kinds of mental models of the day/night cycle: (a) *initial models*—models consistent with the observations based on everyday experience; (b) *synthetic models*—representing attempts to reconcile the culturally accepted, scientific

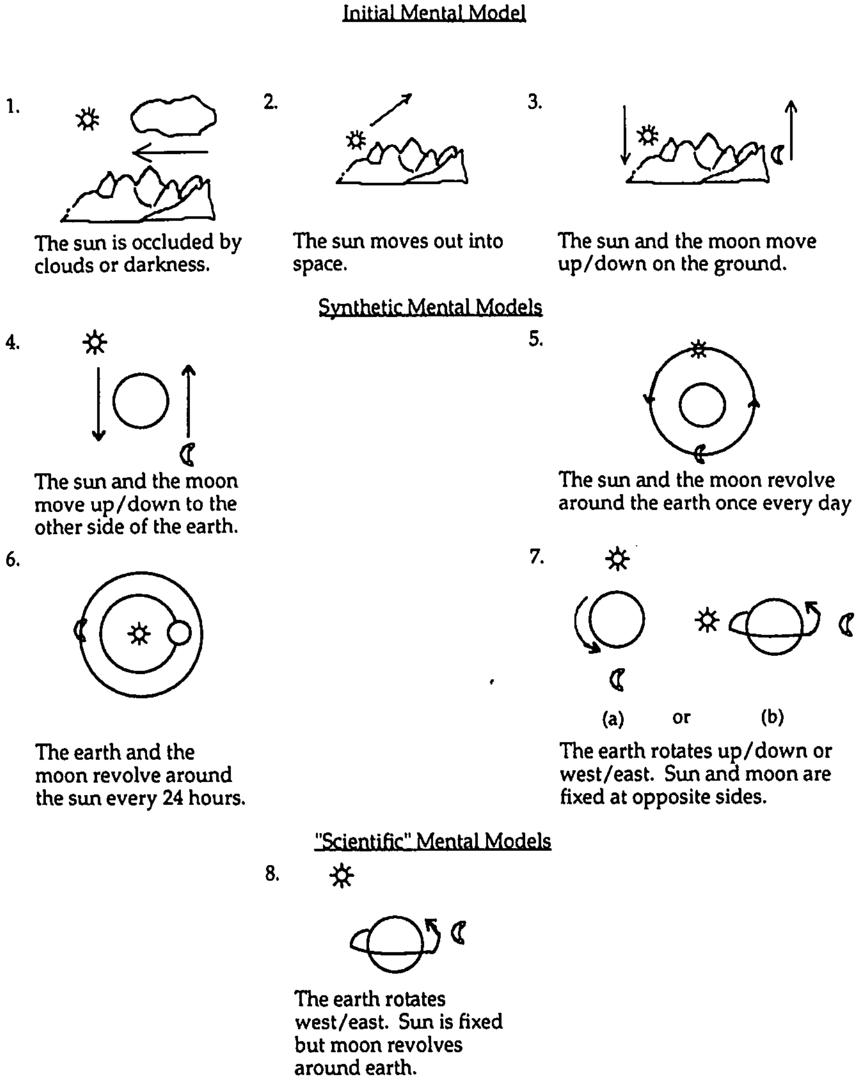


Figure 5. Mental models of the day/night cycle.

explanation of the day/night cycle with observations based on experience; and (c) *scientific models*—models which agree with the scientific view. The mental models of the day/night cycle we obtained in this study can indeed be grouped in these categories.

We consider the models which assume that the earth is stationary and that the sun is occluded by something, moves in an up/down direction, or moves far away (Models 1, 2, and 3 in Figure 5) to be clear examples of initial models. These models do not show any influence from the culturally accepted view in which the alternation of day/night is caused by the earth's axis rotation, nor do they include any other information which reflects exposure to other aspects of scientific information, such as, for example, information regarding the spherical shape of the earth or the revolution of the earth around the sun. Thirteen out of the 20 first-grade children in our sample provided initial models of the day/night cycle, while only two third-grade children and one fifth-grade child adopted an initial model. Analysis of these data shows that among the first-grade children there were reliably more children with initial models than with synthetic models, χ^2 (1, $N=16$) = 6.25, $p<.02$.

Synthetic models represent attempts to assimilate scientific information to an existing initial model. The obtained synthetic models (Models 4, 5, 6, and 7 in Figure 5) differed from the scientific explanation along three dimensions: what moves to produce the day/night cycle, how these objects move, and whether the moon is causally implicated in the day/night cycle. As we have seen, some children think that the day/night cycle results because the sun and the moon revolve around the earth, or because the earth revolves around a stationary sun. Older children think that the earth rotates up/down and that the sun and moon are fixed at opposite sides. A number of the third-grade children and a majority of the fifth-grade children in our sample provided synthetic models of the day/night cycle (grade 1: 3/20; grade 3: 7/20; grade 5: 11/20). Analysis of these data show that among the fifth-grade children there were reliably more children with synthetic models than with initial models, χ^2 = (1, $N=12$) = 8.33, $p<.01$.

The model which comes closest to the culturally-accepted scientific explanation is Model 8 (Figure 5), which includes a fixed sun, axis rotation of the earth, and revolution of the moon around the earth. Only one child, a third grader, formed this model.

The remaining 22 children either did not have coherent models or did not provide enough data for us to understand their models. Three children gave models in which the direction of the earth's rotation was unspecified (Model 12, Table 9), while three additional children were placed in a category in which the day/night model was completely undetermined (Model 16, Table 9). Finally, 16 children were placed in a mixed model category. Five of them used both the up/down movement of the sun and the rotation of the earth to explain the day/night cycle (Model 13, Table 9). Another five used both the earth's revolution around the sun and the earth's rotation to explain the day/night cycle (Model 14, Table 9). The six remaining children used a variety of mechanisms in their explanations (Model 15, Table 9).

Age Trends in Mental Model Construction

Although the present study was cross-sectional and not longitudinal, the results clearly show that the majority of first-grade children enter school having formed an initial model of the day/night cycle. During the elementary school years they appear to replace the initial model with a synthetic model. By the end of their elementary school years, some children have replaced their synthetic model with the scientific model.

It is interesting to note that the likelihood of children's models being inconsistent *increases* after the first grade. This finding is in agreement with the hypothesis that the mixed models are a product of children's failed attempts to reconcile their initial models with the culturally accepted model rather than some overall inability to form coherent models.

Constraints on Children's Mental Models of the Day/Night Cycle

In the Introduction we discussed how mental models of the day/night cycle are constrained by a hierarchy of constraints (presuppositions, beliefs, and mental models of the earth and the sun). These constraints were described in the hypothetical knowledge acquisition process shown in Figure 1. The mental models we have obtained in this study are in agreement with this hypothesized conceptual structure.

Presuppositions

The hypothesis that certain ontological and epistemological presuppositions constrain children's mental models was confirmed. The results suggested that the children honored several epistemological presuppositions. All the children were capable of understanding that the alternation of day and night constitutes a phenomenon that requires an explanation. In addition, almost all of the children in our sample provided mechanistic/causal explanations of this phenomenon. Only one child said that "God makes it happens," and none of the children in this sample gave animistic explanations. It should be noted that the scientific explanation of the day/night cycle does not require the revision of these epistemological presuppositions. It does, however, require the revision of some ontological presuppositions which influence children's mental models of the day/night cycle indirectly through their mental models of the earth. These constraints will be discussed in the section titled "Mental Models of the Earth."

Beliefs

Our results showed that most children inferred from their observations that the day/night cycle is causally related to the appearance and disappearance of *both* the sun and the moon. The erroneous belief that the moon is causally implicated in the day/night cycle appeared to be present in the synthetic models of the oldest children in our sample. It is not clear why this belief is so persistent. It could be related to the fact that in the usual presentations of the scientific explanation of the day/night cycle the role of the moon is not usually clarified. In an investigation of the astronomy units on the day/night cycle in four widely-used science series for elementary school students, we did not find any discussion of the role of the moon in the day/night cycle (Vosniadou, 1991a, 1991b).

The mechanism used to explain the appearance and disappearance of the sun and the moon relied either on the notion that their movement takes them somewhere where they cannot be seen, or on the notion that something comes and occludes them. We did not obtain any switch on/off explanations. The mechanism according to which the viewer turns (or, rather, that the earth turns) so the viewer cannot see the object anymore seems to be available but is not applied until the children can conceptualize the earth as rotating or revolving. As we have already seen, this does not happen until the children form the model of an earth surrounded by space, even though this model may not be the scientific model of a spherical earth with people living all around it on the outside.

Mental Models of the Earth

Some of the most interesting findings of the present study have to do with the constraints that mental models of the earth impose on the mental models of the day/night cycle. Mental models of the earth influence mental models of the day/night cycle in two ways:

First, consider the flat earth versus spherical earth distinction. Flat earth models are constrained by the presuppositions that the ground is flat and that unsupported things fall (cf. Vosniadou & Brewer, 1992). In Figure 2 we described how these presuppositions and the flat earth models they entail constrain children's mental models of the day/night cycle. Our results showed that these constraints were, in fact, observed. All the children in our sample with a flat earth mental model formed initial models of the day/night cycle (see Table 10).

In addition to the flat vs. spherical earth distinction, there were other aspects of children's specific mental models of the earth that appeared to impose constraints on how they explained the day/night cycle. An example of this can be found in children's alternative interpretations of the up/down movement of the sun depending on their particular mental model of the earth as shown in Figure 3, explanation type 4.

We also found that children with hollow sphere mental models had difficulty coming up with a coherent model of the day/night cycle. Seven of the 12 children with hollow sphere models gave unspecified, mixed, or undetermined day/night cycle explanations. There were only two examples of an up/down rotation mental model of the day/night cycle, a finding which is consistent with the hypothesis that these children have constructed the hollow sphere model under the constraints of an up/down gravity presupposition. Obviously, the up/down rotation of the earth is not a very viable solution for these children. A better solution of the day/night problem, given a hollow sphere model of the earth, is to assume a west/east rotation of the earth, which does not violate the up/down gravity presupposition. Two children with hollow sphere models selected this solution. The mental model of a west/east rotating hollow sphere is also a problem for children with hollow sphere models, however, because it does not easily explain the disappearance of the sun at night. In order to make the sun disappear at night some children create a "day side" of the earth and a "night side" of the earth. Given this model, the sun disappears from our sight when we move to the "night side" of the earth, as the earth rotates from west to east (see drawing number 12, Figure 4, and explanation type 12, Table 4).

Another interesting empirical relationship exists between the direction of the earth's rotation and children's earth shape and day/night cycle models. There were only three children who formed west/east rotation models of the earth. Two of them had a hollow sphere earth model and one a flattened sphere earth model. On the other hand, there were 23 children with spherical earth models, 13 of whom attributed the day/night cycle to the rotational movement of the earth. All of these 13 children conceptualized the earth as rotating in an up/down direction (i.e., rotation around an axis through the equator). There are a number of possible explanations of the preference spherical earth children show for an up/down rotation of the earth. One explanation is based on the similarities that exist in the model of a rotating earth and a fixed sun (model 7a, Figure 5), and the model of a stationary earth and an up/down moving sun and moon (see model 4, Figure 5). The two models are identical with the exception that in one the day/night cycle is explained in terms of the rotational movement of the earth (up/down rotation) whereas in the other it is explained in terms of the up/down linear movement of the sun and the moon. It appears that children with a spherical earth model who have formed model number 4 (Figure 5) may tend to move to model 7a, when they are told that the reason for the disappearance of the sun is the rotational movement of the earth.

Model 7a (Figure 5) is also consistent with the belief that the sun is located above the top of the spherical earth, rather than in the plane of the earth's equator. Such a belief may be a remnant of an initial model of the day/night cycle, based on everyday experience, which children continue to hold even when they have understood that the shape of the earth is spherical. Given such a belief, the creation of a model of the day/night cycle with explanatory adequacy requires an up/down rotation of the earth, so that the person located on the top part of the earth, facing the sun, will be away from the sun when it is night. Our analyses of the direction of the earth's rotation suggest that the up/down rotation of the earth is a rather subtle form of synthetic model construction.

To conclude, the results of the present study confirm our original hypothesis that children's mental models are influenced by a hierarchy of constraints, which we have called presuppositions, beliefs, and mental models, that operate simultaneously on the knowledge acquisition process. Some of these constraints (e.g., the ontological presuppositions we have identified, the belief that the sun moves, etc.), operate in a similar fashion in the case of children who grow up in different cultures (see Vosniadou, in press-b), as well as in the early astronomers who tried to explain the day/night cycle. The latter finding supports a limited form of recapitulation (cf. Brewer & Samarapungavan, 1991) to the extent that some of the presuppositions and beliefs constraining the construction of mental models in children and early astronomers are similar.

Explanations of the Construction of Synthetic Models of the Day/Night Cycle

In our previous work (Vosniadou & Brewer, 1992) we explained the formation of synthetic models of the earth as the products of the gradual lifting of the constraints which operate on initial models of the earth under the influence of the information provided by the culture. The results of the present investigation show that this analysis can also explain the formation of synthetic models of the day/night cycle.

For ease of exposition we will base this discussion on the subset of day/night models presented in Figure 5. The three initial day/night models (Models 1, 2, 3) are constrained by the initial earth shape model of a flat and stationary earth. In these models the day/night cycle is produced either by the up/down movement of the sun (moon) to the earth's surface or by the occlusion of the sun (moon).

The first fundamental change which allows the formation of synthetic models of the day/night cycle requires the lifting of the constraint imposed by the model of a flat earth, and, therefore, indirectly, of the constraints imposed by the ontological presuppositions that the ground is flat and that unsupported objects fall in a downward direction. By adopting the model of a spherical earth as an object (motionless) in space children can explain the day/night cycle by having the sun (moon) go down to the other side of the earth (Model 4).

Accepting the model of a spherical earth surrounded by space allows a number of additional synthetic day/night models. The children who hold Model 5 believe that the sun and moon revolve around the earth every 24 hours. This model is similar to Model 4 except that the postulated movement of the solar objects is revolution rather than up/down. It seems likely that the children holding Model 5 have been influenced by information from the culture about the revolution of the moon around the earth or of the earth around the sun which they have used to generate a classic geocentric model of the day/night cycle.

The children with Model 6 have given up the belief that the earth does not move. These children believe that the earth revolves around the sun every 24 hours. Note that if one assumes that the earth does not revolve on its axis, then this model provides an explanatory account of the day/night cycle. Nevertheless, we think it is unlikely that elementary school children have articulated their models well enough to understand this point and that it is more likely that most of these children have assimilated information about the earth's yearly revolution around the sun into their day/night model without developing a completely specified model.

The children with Model 7 have also given up the constraint that the earth is motionless but use the earth's rotation (either up/down or west/east) to explain the day/night cycle. This model begins to converge on the scientific model but still contains an important synthetic component. The children with this model assume that the sun and moon are fixed in space at opposite sides of the earth and thus have generated an elegant solution to the day/night cycle.

The children with Model 8 have finally attained the essence of the culturally accepted scientific model with a rotating earth, a fixed sun, and the moon rotating around the earth. It seems likely that even children with this model have not articuluted their models fully to capture phenomena such as the time it takes the moon to rotate around the earth or the occurrence of the phases of the moon.

Contrary to our original hypothesis that the stars would also be causally implicated in the day/night cycle, this belief is not as strong as the belief that the moon is associated with night. While most of the young children provided explanations for the disappearance of the stars during the day, which were similar in kind to the explanations for the disappearance of the moon, the great majority of the children in our sample thought that the stars are stationary and knew that it is possible for them to be in the sky during the day but not to be seen because of the brightness of the sun's light.

Criteria Honored by Children in Constructing Mental Models

We will now examine children's mental models of the day/night cycle in terms of the criteria of accuracy, logical consistency, and simplicity.

Accuracy

The mental models of the day/night cycle that the children constructed were for the most part empirically accurate, in that they were consistent with children's observations. One of these observations is that the sun is in the sky only during the day. The other is the erroneous observation that the moon is in the sky only during the night. Note that empirical accuracy was present even in the case of the synthetic models, despite the fact that synthetic models are the products of significant misrepresentations of scientific information. In fact, it is often the case that the "errors" in the synthetic models actually increase their empirical accuracy, given the range of observations available to children. For example, the children with models 8 and 9 (Table 9), who assumed that the sun and the moon are fixed on the opposite sides of a rotating earth, formed models which were empirically accurate given the (erroneous) observation that the moon is present in the sky only during the night.

Logical Consistency

The 38 children assigned to a mental model of the earth gave logically consistent responses to the four sets of questions which investigated their explanations of the disappearance of the sun at night, the disappearance of the stars during the day, the movement of the moon, and the alternation of day and night. In addition, the obtained mental models of the day/night cycle were consistent with the hypothesized constraints imposed by children's mental models of the earth. Roughly a third of the children who were put in the mixed categories appeared to be in a transitory state from an initial model of an up/down moving sun to an earth rotation explanation (Model 13, Table 9). Another third appeared to be confusing the earth's revolution around the sun and the earth's rotation on its axis (Model 14, Table 9). The final third of the children with mixed models gave responses that were complex combinations of various models. The remaining children's responses were either unspecified (Model 12, Table 9) or underdetermined (Model 16, Table 9).

While our results may appear to contradict reports that not only young children but also high school and college students give internally inconsistent responses to questions tapping aspects of their knowledge of science (e.g., diSessa, 1988, 1993; Reif & Allen, 1992; Solomon, 1983), this may not be necessarily the case. In most of the existing research where such inconsistencies are noted, a student is considered to be internally inconsistent if he or she uses a given scientific concept correctly in some cases but not in others. The possibility that this student is using a representation which is different from the scientific one, but which is nevertheless well-defined and internally consistent and which can account for the obtained pattern of "correct" and "erroneous" responses, is usually not explored in a systematic fashion. Until more detailed analysis of students' mental representations in these other domains is carried out we will not know if the conflict between these literatures is apparent or real.

Simplicity

In the previous section we argued that we were able to account for a large percentage of our data by assuming that the children in our sample adopted well-defined mental models of the day/night cycle which they used consistently to answer a number of different questions related to this phenomenon. In addition to being sensitive to issues to logical consistency, the children also seemed to show some sensitivity to issues of simplicity in their explanations.

The term simplicity is used here to refer to the use of the same mechanism to account for different, although related, phenomena such as the disappearance of the sun during the night and the apparent disappearance of the moon and stars during the day. The findings of this study indicate that the majority of the children in our sample used the same mechanism to explain the disappearance of the sun and the disappearance of the moon. With the exception of the children assigned to the occlusion model (Model 1, Table 9), there was a strong relationship between the specific explanation given for the disappearance of the sun during the night and of the moon during the day. These relationships can be examined in detail in Table 9. As can be seen in this table, the children who asserted that the sun goes down behind the mountains or down to the other side of the earth also stated that the moon comes up when the sun goes down. We call this the "hydraulic model" because it is as if the two movements are dependent on each other. The downward movement of the sun causes the upward movement of the moon.

The interdependency of the movements of the sun and the moon is apparent in the other explanations of the day/night cycle. For example, the children who said that the sun revolves around the earth also mentioned revolution to be the movement of the moon. We did not find any models where the sun revolves around the earth but the moon moves in an up/down direction or the reverse. Finally, most of the children who adopted the explanation in which the day/night cycle is caused by the earth's rotation conceptualized both the sun and the moon as stationary. Again, we did not find any instances where the earth was seen as rotating around its axis, the sun was stationary, and the moon moved in an up/down direction, although we had the scientific model where the earth rotates around its axis, the sun is stationary and the moon revolves around the earth.

Note that children's model of an earth rotating in an up/down direction with the sun and moon fixed at opposite sides is a *simpler* model than the scientific model in which the moon revolves around the earth. It is the occurrence of models such as this that lend such strong support to the overall "constructivist" position.

Explanations of the disappearance of the stars at night were not as coordinated with the disappearance of the sun and the moon as was the case of the moon and sun themselves. With the exception of the children who attributed the day/night cycle to the up/down movement of the sun, of the moon, and of the stars on the other side of the earth, a different specific mechanism was used to explain the disappearance of the stars during the night than the one used to explain the disappearance of the sun and the moon. In addition, the great majority of the older children in our sample knew that the stars are present during the day but that we cannot see them because of the brightness of the sun's light and gave this as the explanation for their apparent disappearance during the day.

To conclude, the findings from the present study show that the majority of the children in our sample formed empirically accurate and logically consistent mental models of the day/night cycle. In addition, their models exhibited systematic relations between the mechanisms used to explain the disappearance of the sun and those used to explain the disappearance of the moon which showed considerable sensitivity to issues to simplicity. These findings agree in general with results obtained by Samarapungavan (1992) showing that when children choose between theories they prefer explanations which are empirically accurate and logically consistent. While children demonstrate considerable skills in constructing and modifying their mental models to fit the available data, the present results do not show that children have developed metaconceptual awareness and conscious control of their mental models (D. Kuhn, 1989).

The Nature of Conceptual Change

The initial models of the day/night cycle in which the sun moves down behind the mountains, goes out into space, or is occluded by clouds are very different from the culturally accepted model of a stationary sun, the earth rotating around its axis, and the moon revolving around the earth. Our results show that six-year-old children come to school having formed an initial model of the day/night cycle which, over a period of years, changes to a synthetic model and then to a scientific model. How can we best characterize the kind of conceptual change which takes place during the elementary school years as the cultural knowledge has a greater and greater impact on the children's models of the day/night cycle?

According to Spelke (1991), conceptions of physical objects do not undergo fundamental change with development, and knowledge of the sort we have called ontological presuppositions (e.g., the continuity and solidity of physical objects) continues to be entertained in adults' commonsense reasoning about physical objects. One kind of fundamental knowledge about the behavior of physical bodies relevant to the issues discussed in this paper is the concept of an up/down gravity. This is the knowledge that "unsupported things fall in a downward direction," which appears to be present even in 6-month-old infants (Needham & Baillargeon, 1993; Spelke, 1991). Our results show that children's presuppositions regarding an up/down gravity need to be revised and *are* revised by the elementary school children who provide scientific or even synthetic explanations of the day/night cycle. We interpret these results to indicate that the process of knowledge acquisition cannot be fully accounted for using the notion of enrichment (Spelke, 1991).

In an important recent book on conceptual change in science Thagard (1992) argues that concepts are organized in theories which are primarily structured via kind and part-whole hierarchies. Viewed in this way, conceptual change may involve the addition or deletion of concepts, or their transformations. The transformations can be simple—when they involve differentiation or coalescence; or complex—when they involve alterations in kind relations or part relations. Thagard calls one such change "branch jumping" since it involves the movement of a concept from one branch of

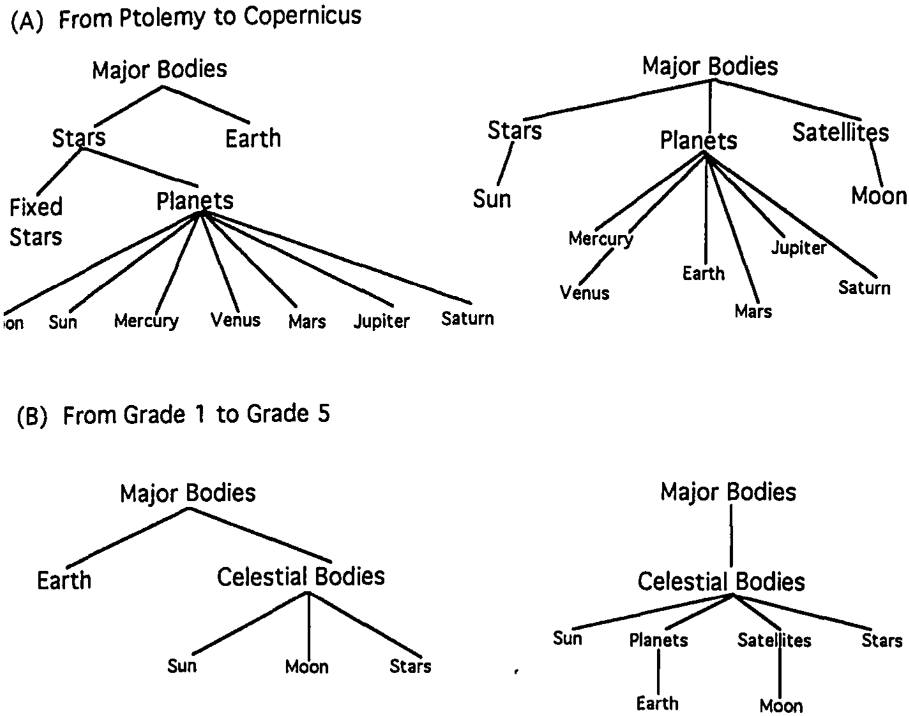


Figure 6. Changes in the system of categorization of the major astronomical bodies.

the kind-hierarchy to another. An example of branch jumping which, according to Thagard, is one of the most radical kinds of conceptual change characterizing scientific revolutions, is illustrated in Figure 6. This figure describes the move from the Ptolemaic system's classification of the celestial bodies (Figure 6a) to the modern, Copernican view. Copernicus reconceptualized the earth as a planet and reclassified the moon as a satellite of the earth. (The sun was not recognized as a star until around 1800.)

Another important recent approach to conceptual change is found in the work of Chi and her colleagues (Chi, 1992; Chi, Slotta, & de Leeuw, in press). Chi has described conceptual change in terms of a special kind of branch jumping which involves two ontologically distinct categories. According to this theory, conceptual changes take place when a concept belonging to one ontological category (e.g., matter) is re-assigned to a different ontological category (e.g., process) as was the case historically with the concept of heat.

The results of the present study support Thagard's (1992) and Chi et al.'s (in press) analysis. Children's categorization of astronomical objects seems to undergo a kind of branch jumping which is similar to the one which took place in the history of science. As shown in Figure 6b, six-year-old children with initial mental models of the day/night cycle think that the earth is a physical object while the sun and the moon are celestial objects. We have argued that the mental representation of the earth as a sphere surrounded by space is a precondition for understanding the scientific explanation of the day/night cycle. In the cosmology of the third grader who provides a scientific explanation of the day/night cycle, the earth has been reclassified as a celestial body, a planet, which rotates around its axis and revolves around the sun. At the same time, the sun, the moon, and the stars are clearly differentiated, the child having recognized that the moon is not causally related to the day/night cycle, and that the stars are different from the other celestial bodies. Thus, our data show that the development of children's cosmologies provide evidence for the same types of radical conceptual reorganizations that have occurred in the history of science.

One limitation of the Thagard (1992) and Chi et al. (in press) approaches, however, is that they do not explain *why* the reorganizations of knowledge which are characterized as branch jumping are so difficult for scientists in the development of science or for children acquiring new knowledge. Thagard (1992) acknowledges that branch jumping is the product of revolutionary changes in scientists' underlying systems of beliefs, but does not go further to explain the nature of these beliefs and their changes. In our work we have adopted a semantic rather than a syntactic description of conceptual change. We try to characterize the kinds of knowledge structures that underly children's mental models of the day/night cycle and to describe the changes that happen in these structures during the knowledge acquisition process. Fundamental to our way of thinking is the notion of constraint. We have argued that the reorganizations of knowledge taking place during the knowledge acquisition process occur via the reinterpretation of a hierarchy of constraints which differ in their degree of entrenchment. The deepest and most difficult constraints to change are those we term *presuppositions*. Presuppositions form the basis of an individual's ontology and epistemology and exert an enormous influence on the knowledge acquisition process.

In addition to the presuppositions, our theoretical framework includes a number of additional constructs such as beliefs and mental models which appear to act as second-order constraints on the knowledge acquisition process. Beliefs and mental models are examples of what Keil (1990) calls "acquired-domain-specific" constraints. These are the kinds of constraints which develop with the acquisition of expertise, as the structure of the information learned comes to exert its own unique influence on the knowledge acquisition process. Our data suggest that constraints of this type come to exert a powerful role in the child's understanding of complex physical phenomena.

The account of conceptual change presented in this paper is in some ways similar to the account of theory change developed by Carey (1985; 1991) but also differs from it in important respects. Carey proposes that children start by holding theory A and then switch to theory B which differs from the original theory in terms of its structure, the phenomena it explains, and the individual concepts it includes. In our approach the theory-like nature of the structures underlying children's performance is traced to a set of presuppositions, beliefs, and mental models which constrain the way a given child will represent a specific situation. Within this theoretical framework, conceptual change is a continuous process which happens as the different kinds of constraints mentioned above are reinterpreted during the knowledge aquisition process. One of the advantages of the present approach is that it can account for the gradual nature of conceptual change and for the formation of synthetic models of the world.

CONCLUSIONS

The research described in this article attempted to identify and characterize elementary school children's mental models of the day/night cycle. The results showed that the majority of the students in our sample (38 out of 60) used a well-defined mental model of the day/night cycle to answer our questions. These models were logically consistent and for the most part were also characterized by empirical accuracy and simplicity. Initial mental models showed no influence from the currently accepted scientific explanation of the day/night cycle, while synthetic mental models represented attempts to assimilate the scientific explanations to existing conceptual structures. A theoretical framework was outlined which is capable of explaining the formation of initial and synthetic models by postulating that there is a hierarchy of constraints—presuppositions, beliefs, and mental models—some of which are present early in the child's life and others which emerge later out of the structure of the acquired knowledge, and which guide the knowledge acquisition process.

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