Constraints on Knowledge Acquisition: Evidence from Children's Models of the Earth and the Day/Night Cycle[1]

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Abstract

First, third, and fifth grade children were asked questions about the shape of the earth and about the day/night cycle. The majority of the children used a small number of well-defined mental models of the earth, the sun, and the moon to explain the day/night cycle. The younger children formed initial mental models which explained the day/night cycle in terms of everyday experience (e.g., the sun goes down behind the mountains; clouds cover up the sun). The older children constructed synthetic mental models (e.g., the sun and moon revolve around the stationary earth every 24 hours; the earth rotates in an "up/down" direction with the sun and moon fixed at opposite sides) which are attempts to synthesize aspects of the scientific 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. The children's models of the shape of the earth provided strong "second-order" constraints on their models of the day/night cycle (e.g., children with flat earth models do not explain the day/night cycle in terms of the movement of the earth). The changes in the children's models with age was explained in terms of the gradual reinterpretation of a set of presuppositions, some of which are present early in the child's life, and others which emerge later out of previously acquired knowledge.

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Introduction

In a recent study (Vosniadou & Brewer, 1992) we reported data on children's knowledge about the shape of the earth. We found that most of the children in our sample used, in a consistent fashion, a small number of well-defined mental models of the earth. The younger children tended to have an *initial* model of a flat earth, which had the shape of a disc or a rectangle and which was supported by ground. These "flat earth" mental models are consistent with everyday experience and are not influenced by the scientific model of a spherical earth. The older children in our sample tended to form the culturally accepted *scientific* model of a spherical earth, surrounded by space. We also found a large number of *synthetic* models, such as the model of a dual earth, a hollow sphere, or a flattened sphere. Children with a dual earth model believe that there are two earths--a flat one on which people live and a round one that is up in the sky. Children with the hollow sphere model believe that people live on flat ground deep inside the spherical earth and children with the flattened sphere model believe that people live on the top and bottom of a flattened sphere. We hypothesized that these intermediate models were attempts by the children to synthesize aspects of the scientific view with aspects of their initial models. One goal of the present study was to see if the framework in terms of initial models, synthetic models, and scientific models that we developed to understand the shape of the earth could be used to understand children's models of the day/night cycle.

A number of recent researchers in child development (Gelman, 1990; Spelke, 1990) have argued that in acquiring knowledge children start with a few, probably innate, domain-specific principles, which are organized in theory-like structures and which constrain the knowledge acquisition process. Our data from older children in a domain that contains a number

of objects that appear to interact in complex ways allow us to explore the possibility that development of knowledge in one area may constrain the acquisition of knowledge in another area.

In order to explore these issues in the present paper we have compared the data on earth shape from Vosniadou and Brewer (1992) with data on the day/night cycle obtained from the same sample of children (cf. Vosniadou & Brewer, in press).

Method

Subjects

The subjects in this study were 60 children: 20 first graders (mean age 6 years, 9 months); 20 third graders (mean age 9 years, 9 months); 20 fifth graders (mean age 11 years, 0 months). The children attended an elementary school in Urbana, Illinois. They came from predominantly middle-class backgrounds. Approximately half of the children were girls and half were boys.

Materials

The materials consisted of a 48-item questionnaire. The questionnaire was designed to provide information about children's knowledge of a range of concepts in observational astronomy. There were 15 questions dealing with the shape of the earth (cf. Vosniadou & Brewer, 1992) and 13 questions dealing with the day/night cycle. The day/night questions included questions such as: "Where is the sun at night?" and "Does the moon move?"

Procedure

The children were interviewed individually for 30 to 45 minutes. The experimenter made detailed notes of the children's responses, and the children's responses were tape recorded.

Model Construction

The general procedure for assigning children to models was to generate a set of possible explanations for the phenomena asked about in the questions. These explanations were derived from previous research in this area and from initial examinations of the data. Then, for each model we generated the pattern of responses to our questions which would be expected assuming that the children applied the model in a consistent fashion across all the questions. W compared the expected pattern of responses with th pattern of obtained responses to the relevant question and, then, if children's answers fit the hypothesize pattern they were assigned to the appropriate model.

Results

Day/Night Cycle

The children's responses to the day/night question were used to classify the children into 16 differen models. The criteria used to classify the children are given in Table 1. The number of children who were classified into each model type for each grade are given in Table 2. In the next section the basic results for each model type will be discussed.

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 to the questions about the disappearance of the sun during the night and in the questions requiring an explanation of the day/night cycle.

The next set of models (Models 2-6) are all based on the assumption that the alternation of day and night happens because the sun and moon move up/down.

Model 2: The sun and moon move up/down on the ground. The seven children placed in this category 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; and that the day/night alternation occurs because the sun goes down in response to the questions regarding the explanation of the day/night cycle.

Model 3: The sun and moon move up/down to the other side of the earth. Two children were placed in this category. They both said that the sun moves up/down to the other side of the earth and that the day/night cycle happens because the sun moves down to the other side of the earth and the moon moves up.

Model 4: The sun and moon move up/down but unspecified with respect to side of earth. 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.

Table 1. Overall Mental Models of the Day/Night Cycle

Type of Model	Disappearance of the Sun	Explanation of the Day/Night Cycle	Movement of the Moon
1. Sun is occluded by clouds or darkness	Sun is occluded by clouds or darkness	Sun is occluded by clouds or darkness	Moon moves unspecified or does not move
2. Sun and moon move up/down on the ground	Sun moves down on the ground	Sun goes down on the ground & moon goes up	Moon moves up/down or unspecified
3. Sun and moon move up/down to the other side of earth	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
4. Sun and moon move up/down unspecified	Sun moves down unspecified	Sun goes down unspecified and moon goes up	Moon moves up/down or unspecified
5. Sun moves out into space	Sun moves out into space	Sun moves out into space	Moon moves unspecified
6. Sun and moon revolve around the earth every day	Sun revolves around the earth	Sun revolves around the earth	Moon revolves around the earth
7. Earth and moon revolve around the sun every day	Earth revolves around the sun	Earth revolves around the sun	Moon moves unspecified
8. Earth rotates up/down; sun & moon fixed at opposite sides	Earth turns and the sun is fixed	Earth turns in up/down direction	Moon does not move
9. Earth rotates up/down with the sun fixed but the moon moves	Earth turns and the sun is fixed	Earth turns in up/down direction	Moon moves unspecified or revolves around the earth
10. Earth rotates on axis; sun & moon fixed on opposite sides	Earth turns on axis or unspecified	Earth turns on axis	Moon does not move
11. Earth rotates on axis with the sun fixed but the moon moves	Earth turns on axis and the sun is fixed	Earth turns on axis	Moon moves unspecified or revolves around the earth
12. Earth rotates in unspecified direction	Earth turns unspecified	Earth turns unspecified	Moon moves or does not move
13. Mixed: earth rotates and sun moves up/down	Mixed: earth rotates and sun moves up/down	Mixed: earth rotates and sun moves up/down	The moon moves or mixed
14. Mixed: earth rotates and revolves	Mixed: earth rotates and revolves	Mixed: earth rotates and revolves	Moon moves or does not move
15. Mixed: general	Mixed: sun occluded and moves up/down and earth rotates	Mixed	Moon moves or does not move
16. Undetermined	Undetermined or God made it that way	Undetermined or God made it that way	Moon moves or does not move

Table 2. Day/Night Models and Earth Shape Models by Grade

	Grade				
Type of Model	**1st**	**3rd**	**5th**	**Total**	**Earth Shape Models[a]**
1. Sun is occluded by clouds or darkness	2	1	1	4	Dual earth 2; Hollow sphere 1 Sphere 1
2. Sun and moon move up/down on the ground	7	0	0	7	Dual earth 3
3. Sun and moon move up/down to other side of earth	2	0	0	2	Flattened sphere 1
4. Sun and moon move up/down unspecified	3	0	0	3	Rectangular 1
5. Sun moves out into space	1	1	0	2	Dual earth 2
6. Sun and moon revolves around earth each day	0	1	0	1	
7. Earth and moon revolve around the sun every day	0	1	0	1	Sphere 1
8. Earth rotates up/down; sun and moon fixed at opposite sides	1	3	7	11	Hollow sphere 1 Sphere 10
9. Earth rotates up/down with sun fixed but moon moves	0	1	3	4	Hollow sphere 1 Sphere 3
10. Earth rotates on axis; sun & moon fixed on opposite sides	0	1	1	2	Hollow sphere 2
11. Earth rotates on axis with sun fixed but moon moves	0	1	0	1	Flattened sphere 1
12. Earth rotates in unspecified direction	1	1	1	3	Hollow sphere 2 Sphere 1
13. Mixed: earth rotates and sun moves up/down	1	0	4	5	Hollow sphere 1 Sphere 3
14. Mixed: earth rotates and revolves	1	2	2	5	Hollow sphere 2; Flattened sphere 1; Sphere 2
15. Mixed: general	0	5	1	6	Dual earth 1; Hollow sphere 1 Sphere 2
16. Undetermined	1	2	0	3	Disc 1; Hollow sphere 1 Flattened sphere 1
Totals	20	20	20	60	

[a] Only children who had a well specified earth shape model (**n** = 49)

Model 5: The sun moves out into space. The two children placed in this category 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 (placed at opposite sides) revolve around the earth once a day.

The next set of models (Models 7-12) used the movement of the earth as the mechanism for explaining the day/night cycle.

Model 7: The earth and the moon revolve around the sun every day. One child formed a model in which the earth and the moon revolve around the sun once a day (note, that as long as the earth does not rotate this model would, in fact, give an explanatory account of the day/night cycle).

Model 8: The earth rotates up/down with the sun and moon fixed at opposite sides. The eleven children who were placed in this classification all explained the disappearance of the sun at night by saying that the earth turns in an up/down fashion (i.e, rotates around an axis through the equator) 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.

Model 9: The earth rotates up/down with sun fixed but the moon moves. This mental model is similar to the previous one except that the moon moves either in an unspecified way or revolves around the earth. Four children were placed in this category.

Models 10 and 11. Model 10 was the same as Model 8 except that the earth was said to rotate around its north/south axis (i.e., in a west/east direction) while Model 11 was the same as Model 9 except the earth was said to rotate on its north/south axis. There were two children in Model 10 and one child in Model 11.

Models 12, 13, 14, 15, and 16. The children placed in these models gave either unspecified responses (Model 12), mixed models (Models 13, 14, & 15), or undetermined responses (Model 16). Three children were placed in Model 12, five children in Model 13, five children in Model 14, six children in Model 15, and three children in Model 16.

Relationship of Day/Night Cycle and Earth Shape

Table 2 gives the relationship between the children's models of the earth shape (as determined in Vosniadou & Brewer, 1992) and their models of the day/night cycle. Examination of Table 2 shows that all of the children with flat earth models (rectangular, disc, dual earth) provided explanations of the day/night cycle in terms of the up/down movement of the sun/moon (Models 2, 4, & 5) or by occlusion of the sun (Model 1). Children with spherical models of the earth (hollow sphere, flattened sphere, sphere) typically gave rotational explanations and only occasionally gave explanations of the day/night cycle in terms of the occlusion or the up/down movement of the sun and moon.

Discussion

Our study of children's beliefs about the day/night cycle shows that young children have a remarkable ability to create novel explanatory models of the physical world. The data showed that 38 of the 60 children in our sample could be assigned to a coherent mental model of the day/night cycle (e.g., Models 1-11). These results are consistent with views that suggest that young children can develop internally coherent explanatory models of the physical world (e.g., Vosniadou and Brewer, 1992) and are not consistent with the view that young children's knowledge consists of a large number of loosely organized phenomenological principles which represent minimal abstractions of common events (e.g., diSessa, 1988).

These models also fit the knowledge acquisition framework outlined in Vosniadou and Brewer (1992). A number of the younger children hold *initial* models (Models 1, 2, 4, & 5) in which the earth is stationary and the sun is occluded by something, moves in an up/down direction, or moves far away. These models do not show any influence from the scientific view of the day/night cycle. Another group of children hold *synthetic* models (Models 3, 6, 7, 8, 9, & 10). Some of these children think that the day/night cycle occurs because the sun and moon revolve around the earth or because the earth revolves around a stationary sun. Other children think that the earth rotates up/down (i.e., around an axis through the equator) and that the sun and moon are fixed at opposite sides. Only one child produced a model close to the scientific model (Model 11). Thus, the data on the day/night cycle support the view that children learning a physical domain will first construct initial models from their everyday experience; then as they pick up information

about the culturally accepted scientific models of the domain, they will construct synthetic models that attempt to incorporate aspects of the initial models and the scientific models; eventually the child gives up the presuppositions underlying the initial model (such as the belief that the ground is flat and that unsupported things fall to the ground) and comes to hold the scientific model.

The data on the relationship between the children's models of the earth and the day/night cycle suggest that the children's beliefs about the shape of the earth constrain their models of the day/night cycle. It seems to us that children with flat earth models of the earth should find it difficult to conceptualize this flat earth that is rooted in the ground as spinning in space or revolving around the sun. And consistent with this hypothesis we find that no child with a flat earth mental model (rectangular, disc, dual earth) formed a model of the day/night cycle that involved the movement of the earth or of the sun to the other side of the earth. Thus, we interpret our data as suggesting that the child's model of the earth provides a set of constraints on the possible models the child can generate to account for the day/night cycle.

The results of Vosniadou and Brewer (1992) on the development of knowledge about the shape of the earth and the results of the present study on the development of the day/night cycle support a general theory of knowledge acquisition. We assume that the process of acquiring knowledge about the physical world starts with a few domain-specific constraints as suggested by Gelman (1990) and Spelke (1990). However, we also hypothesize that as the child acquires knowledge in a particular domain, the initial models constructed by the child begin to operate as second-order constraints, which then constrain the set of additional possible models that the child can construct. In our view fundamental knowledge change occurs though a gradual process of giving up the presuppositions that underlie the initial models (e.g., the ground is flat, unsupported things fall) and the construction of new models that are necessary to account for both the child's initial observations and the information about the physical world provided by the adult culture.

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