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KNOWLEDGE ACQUISITION IN OBSERVATIONAL ASTRONOMY

Stella Vosniadou

University of Illinois at Urbana-Champaign and
Aristotelian University of Thessaloniki/Greece

April 1989

Center for the Study of Reading

TECHNICAL REPORTS

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
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Abstract

In this paper we present preliminary findings from research on knowledge acquisition in observational astronomy to demonstrate the kinds of intuitive models of astronomy children form and to show how these models influence the acquisition of science knowledge. In this study 60 children of approximate ages 6, 9, and 12 were given a questionnaire to investigate their knowledge of the size, shape and motion of the earth and the sun and the notion of gravity. The results showed that children form an intuitive understanding of the world around them according to which the earth is flat and stationary rather than a rotating sphere, things fall in a downward direction rather than toward the center of the rotating sphere, things fall in a downward direction rather than toward the center of the spherical earth, and the sun and the moon move in an up/down or east/west direction, causing the day/night cycle. Children eventually change their intuitive understanding as they are exposed to the Copernican theory of the solar system. The process of conceptual change is a slow and gradual one and one that goes through different levels of understanding.

KNOWLEDGE ACQUISITION IN OBSERVATIONAL ASTRONOMY

Phenomenal Models in Observational Astronomy

Research in cognitive science and science education over the last decade has documented the importance of prior knowledge in learning and problem solving. In science domains this prior knowledge often comes in the form of intuitive models or alternative frameworks of the physical world which are based on people's interpretations of everyday experience (diSessa, 1982; Driver & Easley, 1978; McCloskey, 1983; Novak, 1977; Osborne & Wittrock, 1983). These models are usually quite robust and difficult to extinguish. For example, even after a few years of high school physics, or after taking a university physics course, adults do not seem to understand Newtonian principles of motion but rather interpret motion phenomena using principles appropriate to an Aristotelian theory of motion which is closer to everyday experience (diSessa, 1982; White, 1983). In addition to being a significant finding in itself, the discovery that people acquire such intuitive models raises important questions about the acquisition, the assessment and the instruction of science knowledge. How and when are such phenomenal models acquired, how are they restructured, and how do they influence further learning in a domain?

In this paper we present some preliminary findings from research on the acquisition of knowledge in the domain of astronomy (Vosniadou & Brewer, 1987; Vosniadou & Brewer, submitted), to demonstrate the kinds of intuitive models of astronomy children form and to show how these models influence the acquisition of science knowledge.

Knowledge Acquisition in Astronomy

We assume that in the course of interacting with the physical world and through instruction individuals develop mental models which allow them to deal with the observed world in an efficient way (Collins & Stevens, 1984; Gentner & Stevens, 1983; Johnson-Laird, 1983). Mental models are assumed to be incomplete and unstable systems which are continuously modified, but do not lack some systematicity and coherence. Because they are constructed on the basis of an individual's experience with the physical world they come to mirror many of the constraints of this world. These constraints give mental models some predictive power.

One class of mental models is intuitive models. The defining characteristic of intuitive models is that they give an account of the observed world as it is experienced through the human perceptual/cognitive apparatus. Thus young children believe that things are perceived directly (Anderson & Smith, 1986), that matter is solid (Novick & Nussbaum, 1978), and that objects fall down (Nussbaum & Novak, 1976). As children are exposed to scientific theories they develop scientific models which frequently involve a theoretical framework which, initially, appears to deviate from the world as phenomenally experienced. Thus, children must shift from initial phenomenal models to scientific models according to which things are perceived by reflected light, objects respond to gravitational fields, and matter is composed of particles.

Although experience with astronomical phenomena is not as direct as the behavior of objects in the physical world, it is nevertheless more than enough to create strong beliefs about the size, shape, composition and movement of the earth, the sun, the moon, and the stars, and to give rise to certain kinds of explanations of natural phenomena such as the day/night cycle, the seasons, and the phases of the moon. In this research, we hypothesized that children create an intuitive model of observational astronomy which is based on the "common sense" view that the earth is flat and motionless, that gravity operates along an up/down gradient, that the sun and moon move and exchange positions during the day/night cycle, and that the earth is in the center of the universe.

Such an intuitive model is very different from the currently accepted Copernican model. According to the Copernican model, the earth is a sphere which moves around its axis and around the sun, gravity operates towards the center of the earth, the day/night cycle is caused by the earth's rotation rather than by the movement of the sun or the moon, and the sun is in the center of our solar system. In Vosniadou and Brewer (1987) we have argued that the change from an intuitive geocentric model of a flat, stationary earth to a Copernican heliocentric model in which the earth is conceptualized as spherical, rotating around its axis and revolving around the sun meets all the criteria for radical theory change as defined by Carey (1985) and Wiser and Carey (1983).

We were interested in finding out whether children do indeed form such an intuitive model of observational astronomy on the basis of everyday experience and in understanding how this model changes with exposure to the Copernican model. We decided to start by studying children's rather than adults' ideas about astronomy because the Copernican model is so much a part of our basic cultural knowledge that one would not expect to find many adults carrying uncontaminated phenomenal models as is the case with Newtonian mechanics which is largely unknown to physics-naive individuals. In fact we had to test children as young as 3 years of age in order to find a population not exposed to the idea that the earth is a rotating sphere.

We have investigated children's and adults' models of astronomy in a series of experiments with preschool and elementary school children as well as with adults. In addition to studies conducted in the United States (Vosniadou & Brewer, submitted), our findings have been confirmed in cross-cultural experiments in Greece, India, and Samoa (e.g., Vosniadou & Brewer, in press). In this paper we will refer only to results from our first elementary school experiment, and a few results from an experiment with preschool children.

Method

Subjects

The subjects of the elementary school study included 60 children ages 6, 9, and 12 coming from middle-class families and attending the same school in a small midwestern town. The preschool study included 46 children, ages 2 to 5 coming from middle-class families and attending two day care centers in the same small midwestern town.

Materials

Children's knowledge of observational astronomy was examined using an elaborate verbal questionnaire which included questions about the shape, size, composition and motion of the earth, the sun, the moon, and the stars. Table 1 presents a list of the concepts investigated, while Table 2 shows the expected responses for the intuitive and Copernican models for the concepts having to do with the relative size of the earth, the sun, the moon and the stars, the earth's shape and gravity, the earth's and sun's motion, and the explanation of the day/night cycle.

[Insert Tables 1 & 2 about here.]

For many of the questions investigated, the questionnaire included *factual questions*, designed to test children's knowledge of facts (e.g., "What is the shape of the earth?", "Does the earth move?"), *explanation* questions, designed to lead the child to explain these facts (e.g., "Why is the earth round?"), and *generative* questions, designed to capture the child's generative model (e.g., "If you were to walk for many days would you ever reach the end of the earth?" "Is there an end to the earth?").

Results

Relative size. The percentage of responses to the questions regarding the relative size of the Earth, Sun, Moon, and Stars is presented in Table 3. As predicted, the majority of the first grade children (70%) and quite a few of the third grade (45%) and fifth grade children (30%) responded in agreement with some intuitive model (where the earth is assumed to be bigger than the sun, moon and stars). The percentage of the children who were willing to say that the sun is larger than the Earth increased with age, but it is interesting to note that many fifth grade children (35%) still considered the stars to be the smallest in relative size.

[Insert Table 3 about here.]

Earth's shape. Table 4 presents children's responses to the question "What is the shape of the earth?" and the question "Draw a picture of the earth so that its real shape shows." At first look these data do not appear to support the intuitive model hypothesis. All but one first grade child said that the earth is either "a circle" or "round" and drew a circle to indicate the earth's shape. Of course, the verbal response "circle" is ambiguous. It is not clear whether the younger children use "circle" because they do not know the word "round" or "sphere," because they actually mean "circle" (i.e., a flat disc), or because they think that the word "circle" means "round." Similarly, when children draw a circle to depict the earth one does not know whether this circle is meant to represent a round sphere or a flat disc.

Children's difficulties with the earth shape concept become apparent in the responses to the generative question "If you were to walk for many days would you ever reach the edge of the earth?" "Does the earth have an edge?" Sixty percent of the 6-year-old children and 20% of the 8-year-old children answered this question by saying that the earth has an edge. These results indicate that many of the children who had been exposed to the information that the earth is a sphere and drew a circle to demonstrate the earth's shape, could not use this information generatively. These children converted to an intuitive model when asked the question about the earth's edge.

Responses to the explanation question "How come the earth we live on is flat, but the one you made is round?" revealed several misconceptions of the earth shape concept. In response to this question, many children said that we live on a disk, or on the flat top of a truncated sphere, or on flat ground inside the earth, or that there are two earths: a flat one on which we live and a spherical one which is in the sky! (See Vosniadou & Brewer, submitted, for a more detailed discussion of these misconceptions.)

Since the children could not have obtained such information from adult sources, we can safely assume that these misconceptions represented attempts to assimilate the adult information that the earth is a sphere to the intuitive model of a flat earth. In this respect, misconceptions are indirect confirmations of the presence of an intuitive model. Finally, direct confirmation for the phenomenal model is obtained in the preschool data (Table 5). As can be seen in Table 5, 42% of the 4-5 year old children and 22% of the 3-4 year old children produced some kind of a flat earth drawing (26% of the 2-3 year old children produced unintelligible scribbles).

[Insert Tables 4 & 5 about here.]

Gravity. Children's responses to the gravity questions confirmed the intuitive model hypothesis more directly. As can be seen in Table 6, the percentage of correct responses to the gravity question increased with age. Many first grade children (30%) thought that the man pictured at the bottom of the earth would fall down, supporting the intuitive model hypothesis that things fall in a downward direction. Furthermore, many of the children who responded correctly to this question changed their mind when asked where the ball that the man supposingly drops from his hands would fall (Table 6, question 2). Seventy-five percent of the 6-year-old children and 35% and 30% of the 8-year-old and

10-year-old children respectively said that the ball would fall away from the earth, revealing in this way an intuitive gravity concept.

[Insert Table 6 about here.]

The motion of the earth and the sun. Table 7 presents the children's responses to the question regarding the motion of the earth and the sun. As in the case of gravity, we see a clear developmental shift from the predicted intuitive model (that the earth is stationary and the sun moves) to a variant of the Copernican model (that the earth moves and the sun remains stationary), with age. Again, it is interesting to note that many 5th grade children (10/11-year-olds) did not know about the sun's rotational movement. As expected, not all of the children exposed to the idea that the earth moves were able to use it generatively. Thus, only 20% of the 6-year-old children, 50% of the 8-year-old children and 70% of the 10-year-old children attributed the day/night cycle (Table 8) to the earth's movement, despite the fact that 50% of the 6-year-old children, 80% of the 8-year-old children and 100% of the 10-year-old children thought that the earth moves either in a rotational or in an unspecified way.

[Insert Tables 7 & 8 about here.]

Discussion

The preliminary results reported above, support the hypothesis that children form intuitive models of the world around them the same way they form intuitive models of the behavior of physical objects (diSessa, 1982; McCloskey, 1983). According to these intuitive models, the earth is flat rather than a sphere, things fall in a downward direction rather than toward the center of the spherical earth, the earth is stationary and the sun moves (usually in an up/down direction).

Support for the intuitive model in the case of the relative size, and the earth gravity and motion concepts was rather direct. Many children, particularly the younger ones, said that the earth is bigger than the sun, moon and stars, that it does not move, and that things fall in a downward direction. The support for the intuitive model hypothesis in the case of the earth's shape, was direct in the case of the preschool children but indirect in the case of the elementary school children. While the elementary school children had been exposed to the idea that the earth is a sphere, many had interpreted this information to indicate that the earth is circular but flat (like a disc), or that we live inside the spherical earth, or that there is another earth which is a sphere while the one we live on is flat. All of these misconceptions were motivated by the same purpose. They all represented an attempt to assimilate the adult information that the earth is a sphere to the intuitive model of a flat earth.

In addition to confirming the intuitive model hypothesis, the present results provided information about the knowledge acquisition process. In particular, they supported the view that there are different levels of understanding a concept when that concept contradicts an intuitive model. At a first, superficial level, children (or adults) appear to simply memorize the adult/scientific model to which they are exposed without connecting it to the intuitive model. At this point, they can answer the equivalent of our factual questions correctly. In other words, they say that the earth is round (or a circle), that it moves, etc. Although this type of knowledge can probably generalize to a small number of similar cases, children rely predominantly on the intuitive model when it comes to answering new questions, questions not encountered before (such as the question regarding the end of the earth). At this level of knowledge, the scientific and intuitive models co-exist unconnected from each other and are used independently to answer different kinds of questions about phenomena that belong to the same fundamental class.

Something like this happens, for example, in the case of gravity. Apparently some children can hold the inconsistent belief that gravity operates for people (holding people on to the edge of a spherical earth so that they do not fall down), but not for balls. The independent co-existence of the two models seems to also be present in the case of the children who say that the earth rotates around its axis but explain the day/night cycle on the basis of the movement of the sun.

A second level of understanding comes when children become aware of the fact that there are two contradictory explanations for the same phenomenon and attempt to resolve them by assimilating the adult/scientific model to the existing intuitive model. This assimilation gives rise to various misconceptions, such as those encountered in the answers to the generative questions in the earth shape data. Similar misconceptions abound also in other domains (see Driver & Easley, 1978), and operate in children as well as in adults (Clement, 1983).

Finally, a third level of understanding of the adult/scientific model is achieved when this model starts being used in a generative way (although there may be various levels of generativity). The generative use of the adult/scientific model does not necessarily imply that the intuitive model is extinguished. The two models may still co-exist, but unlike the first level of understanding, the person is aware of their simultaneous existence and can make consistent use of them as the situation and/or need dictates.

The results of the present experiments have implications for science assessment. It is often the case that science assessment investigates factual knowledge rather than generative knowledge. Although factual knowledge is the vehicle through which generative knowledge will eventually be achieved, it is nothing more than the first necessary step in a tedious process of theory change. Assessing a child's factual knowledge of science, therefore, provides limited and sometimes erroneous information about the child's generative knowledge of science, that is, knowledge that the child can access and use to solve problems and answer questions. As the results from the astronomy studies amply demonstrate, knowing that the earth is a sphere or that it rotates around its axis, does not necessarily mean that this knowledge can be used to answer questions that the child has not encountered before. It is obvious that the assessment of science knowledge must go beyond the memorization of facts to examine the extent to which these facts have changed the child's intuitive models and can be used generatively.

The results of this study also demonstrate the importance of understanding students' intuitive models before proceeding to teach something new. Ignoring prior knowledge and beliefs will almost certainly result in unassimilated or misunderstood knowledge. Instruction should be built on a careful attempt to restructure students' intuitive models based on the findings of empirical research like the one described in this paper, as well as on research investigating the effects of various instructional methods and strategies.

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Table 1

Domain of Observational Astronomy

<u>Solar Objects</u>
Earth
Sun
Moon
Stars
Planets
<u>Phenomena</u>
Day/night Cycle
Phases of the Moon
Seasons
Eclipses
<u>Concepts</u>
Shape
Size
Movement
Composition
Distance
Location
Gravity

Table 2

Expected Responses for the Intuitive and Copernican Models

	Intuitive Model	Copernican Model
Size	Earth > Sun/Moon > Stars	Stars/Sun > Earth > Moon
Earth's Shape	Flat	Sphere
Gravity	Up/down	Toward the center of the earth
Earth's Movement	Stationary	Axis rotation and revolution
Sun's Movement	Up/down or east/west	Axis rotation
Day/night Cycle	Sun & Moon's movement	Earth's movement

Table 3

Percentage of Responses to the Questions Regarding the Relative Size of the Earth, the Sun, the Moon and the Stars

Response	Ages		
	6-7	8-9	10-11
Earth > Sun/Moon > Stars	40	35	25
Earth > Moon > Stars > Sun	15	5	0
Earth > Stars > Sun > Moon	15	5	5
Sun > Earth > Moon > Stars	5	30	35
Sun/Stars > Earth > Moon	5	0	20
Other			

Table 4

Percentage of Responses to the Questions Regarding the Earth's Shape

Question 1: "What is the Shape of the Earth?"

	Age 6-7	Age 8-9	Age 10-11
Do not know	5	0	0
Circle	70	10	0
Round	10	85	90
Dual	0	0	5
Sphere, or round like a ball	15	5	5

Question 2: "Can you draw a picture of the earth so that its real shape shows?"

	Age 6-7	Age 8-9	Age 10-11
Straight line/Rectangle	5	0	0
Straight line but changes to circle after questioning	10	0	0
Circle	75	100	95
Circle within square frame	5	0	0
Oval	5	0	5

Question 3: "If you walked and walked for many days in a straight line would you ever reach the edge of the earth? Is there an edge to the earth?

	Age 6-7	Age 8-9	Age 10-11
Yes, there is an end/edge	60	20	0
Yes, there is an edge, but we cannot reach it because we are inside the earth	10	10	10
No, there is no end/edge	30	70	80

Table 4 (Continued)

Question 4: "How come here the earth is flat but before you made it round?"

	Age		
	6-7	8-9	10-11
Do not know	5	0	0
Child thinks the earth is flat or changes from round to flat	10	0	0
Child appears not to recognize the conflict	10	0	0
Earth is round like a disc, we live inside the earth, we live on flat pieces of land, there are two earths	35	55	40
Insists Earth is round but cannot explain	25	30	45
Provides adequate explanation	10	15	10
Other	5	0	5

Table 5

Percentage of Responses to the Request to Draw a Picture of the Earth so That Its Real Shape Shows

	Age	
	2-3 (N = 27)	4-5 (N = 19)
Some kind of flat drawing (line, rectangle, triangle, etc.)	22	42
Circle	48	52
No shape could be detected	26	0
Other, Missing, DNK	4	6

Table 6

Percentage of Responses to the Gravity Questions

Question 1: "Can this man live here at the bottom of the Earth?" "Why wouldn't he fall?

	Age 6-7	8-9	10-11
He would fall (up/down gravity)	30	5	0
He would fall, but we wouldn't because we are inside the Earth	25	25	20
He would not fall (correct gravity)	25	70	75
Do not know	20	0	5

Question 2: "If this person had a ball in his hand and dropped it, where would the ball go?"

	Age 6-7	8-9	10-11
Away from Earth (up/down gravity)	75	35	30
Towards center of Earth (correct gravity)	20	60	55
It would float around in space	5	5	15

Table 7

Percentage of Responses to the Earth & Sun Movement Questions

Question 1: "Does the Earth move?"

	Age 6-7	Age 8-9	Age 10-11
No	35	15	0
Yes, unspecified movement	45	65	35
Yes, rotational movement	15	20	65
Other	20	0	0

Question 2: "Does the sun move?"

	Age 6-7	Age 8-9	Age 10-11
Yes, up/down movement	65	25	30
No	30	70	70
Yes, revolution	0	5	0
Other	5	0	0

Table 8

Percentage of Responses to the Day/Night Cycle Questions

Question 1: "Where is the sun at night?"

	Age 6-7	8-9	10-11
Hides or something blocks it	60	40	15
On the other side of Earth	25	50	40
Stays where it is	5	5	35
Other or Missing	10	5	10

Question 2: "How does it happen?"

	Age 6-7	8-9	10-11
The sun moves (up/down)	30	15	5
The sun is at the other side of the Earth	10	25	10
The earth moves	20	50	70
Other or Missing	40	10	15

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