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Mental Models of the Earth: A Study of Conceptual Change in Childhood

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This paper presents the results of an experiment which investigated elementary school children's conceptual knowledge about the earth. First-, 3rd-, and 5th-grade children were asked a series of questions about the shape of the earth. Children's responses to these questions revealed considerable apparent inconsistency. For example, many children said that the earth is round but also stated that it has an end or edge from which people could fall. A great deal of this apparent inconsistency could be explained by assuming that the children used, in a consistent fashion, a mental model of the earth other than the spherical earth model. Five alternative mental models of the earth were identified: the rectangular earth, the disc earth, the dual earth, the hollow sphere, and the flattened sphere. It is argued that these models are constrained by certain presuppositions which children form based on interpretations of their everyday experience. Some of these models (the rectangular earth and the disc earth) seem to be initial models children construct before they are exposed to the culturally accepted information that the earth is a sphere. In the process of knowledge acquisition, children appear to modify their initial models to make them more consistent with the culturally accepted model by gradually reinterpreting their presuppositions. Synthetic models (such as the hollow sphere and the flattened sphere) are generated by children

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as a solution to the problems arising from the inconsistency between their initial model of a flat earth and the culturally accepted, scientific model of a spherical earth. Children come to understand that the earth is a sphere only when the presuppositions that gave rise to their initial models have been reinterpreted.

The purpose of this paper is to investigate the development of children's conceptual knowledge about the earth's shape. We are interested in understanding the nature of children's initial knowledge about the shape of the earth and in finding out how this knowledge changes during the elementary school years as children are exposed to the culturally accepted information that the earth is a sphere.

Children and Adults Construct an Intuitive Understanding of the World

Research in cognitive science, science education, and developmental psychology during the last decade has shown that children and adults construct an intuitive understanding of the world which is based on their everyday experience. Although different terms have been used to refer to this type of knowledge—such as preconceptions (Ausbel, 1968), misconceptions (Novak, 1987), alternative frameworks (Driver & Easley, 1978), mental models (Collins & Gentner, 1987; White & Frederiksen, 1986), folk theories (Kempton, 1987), and intuitive theories (McCloskey & Kargon, 1988)—there is general agreement that this intuitive knowledge provides explanations of natural phenomena which are frequently different from the currently accepted scientific explanations and which tend to be resistant to change.

For example, Kempton (1987) argues that many adults use a folk theory in dealing with home heating thermostats. These individuals hold a "valve theory" and appear to believe that the thermostat controls the rate of heat flow just as an automobile gas pedal controls the amount of gas that is fed into the engine. Thus they think that the higher a thermostat is set the more heat will flow and the faster a house will heat.

In the domain of light many individuals believe that their eyes perceive objects directly and that color is a property of the objects themselves (Anderson & Smith, 1986). In addition, it appears that young children believe that the currently perceived color is a property of the object itself, even when they have seen the experimenter change the object's apparent color with a color filter (e.g., Flavell, Green, & Flavell, 1986). Some novices in the area of electricity believe that a switch is like the trigger of a gun; it sends an impulse to a battery to trigger current flow from the battery to a light bulb (Collins & Stevens, 1984). Finally, in the area of mechanics, many students, even after studying high school or university physics, do not understand Newtonian principles of motion, but interpret

motion phenomena using principles which are closer to everyday experience (diSessa, 1982; White, 1983).

Naive Theories versus Fragmented Knowledge

Some researchers believe that children's intuitive knowledge can be conceptualized as consisting of a coherent and systematic set of ideas which deserve to be called a theory (e.g., Brewer & Samarapungavan, 1991; Carey, 1985; McCloskey, 1983; Wellman, 1990; Wiser & Carey, 1983). In some cases the ideas of novices are found to resemble earlier theories in the history of science. For example, Clement (1982) and McCloskey (1983) argue that in the domain of mechanics many adults hold a systematic conception of motion which bears a striking resemblance to a pre-Newtonian theory known as impetus theory.

Other researchers think that naive physics consists of a fragmented collection of ideas which do not have the systematicity that is typically attributed to a scientific theory (e.g., diSessa, 1983, 1988; Solomon, 1983). According to diSessa (1988), naive physics consists of certain phenomenological principles, which are simple abstractions of everyday experiences. These phenomenological principles are, however, fragmented and shallow. Their fragmentation becomes apparent when children give different responses to questions which are fundamentally similar from the point of view of a physicist but differ in superficial characteristics (e.g., are phrased in different ways or are presented in slightly different contexts).

The Process of Knowledge Acquisition

Depending on how intuitive knowledge is conceptualized, different implications about the knowledge acquisition process can be drawn (see Vosniadou, 1991b). Researchers who view children's knowledge as fragmented and nonsystematic see the process of knowledge acquisition mainly as a process of collecting and unifying these knowledge fragments into consistent wholes (diSessa, 1988). Researchers who think that intuitive knowledge has the status of a theory see the process of knowledge acquisition in the context of theory change.

There are several distinct views on how theory change can occur during knowledge acquisition (see Vosniadou, 1989, and Vosniadou & Brewer, 1987, for a discussion of this issue). According to Keil (1979, 1983, 1986), children's initial theories consist of some skeletal but principled distinctions at the ontological level. Ontological knowledge becomes more differentiated and hierarchically integrated as children become older (see also Gelman, 1990). Similar approaches to the problem of theory change in terms of the increasing differentiation and hierarchical integration of

existing structures are common in the expert/novice literature (e.g., Chi, Feltovich, & Glaser, 1981; Larkin, 1981).

Carey (1985, 1986) has called this type of theory change "weak restructuring" to distinguish it from a different kind of theory change which she calls "radical restructuring." As an example of radical restructuring, Carey (1986) suggests that children might start with two theories (e.g., an intuitive physics embodying physical causality and an intuitive psychology embodying intentional causality) from which new theories emerge, in ways analogous to radical theory change in the history of science (e.g., Hanson, 1958; Kuhn, 1970, 1977).

Unresolved Issues

Many questions remain unanswered about the exact nature of intuitive understanding and about the knowledge acquisition process. First, it is not clear whether children's intuitive knowledge can be best characterized as fragmented knowledge or in terms of internally consistent naive theories. Although there seems to be converging evidence that individuals form certain principled distinctions which are based on their everyday experience (Nerssesian & Resnick, 1989; Vosniadou, 1989, 1991a; Vosniadou & Ortony, 1989), it must still be shown that they are capable of applying and coordinating these distinctions in a consistent and systematic way. Even if we assume that intuitive knowledge has the status of a theory, it is not clear how these theories change in the course of knowledge acquisition. In order to answer these questions, we need detailed descriptions of the knowledge acquisition process in a number of specific knowledge domains.

The Domain of Observational Astronomy

The present study was undertaken in the context of a larger project which investigated the process of knowledge acquisition in astronomy. Observational astronomy was chosen because it is a relatively rich knowledge domain composed of a number of concepts with complex causal relations. It is therefore an area where there is the potential for developing rich domain-specific theories. In addition, children's everyday experience provides them with enough information to develop an intuitive understanding of many of the phenomena that are part of the domain of scientific astronomy (e.g., the shape of the earth, the day/night cycle, the phases of the moon, etc.). Finally, theories in astronomy have undergone several major restructurings in the course of the field's development (Berry, 1961; Kuhn, 1957, 1970; Toulmin & Goodfield, 1961). We thought that by selecting a domain of knowledge which has undergone radical restructuring in its historical development as a science we would maximize our chances of finding similar radical changes in children acquiring knowledge in this domain.

The Concept of the Earth in the History of Astronomy

The concept of the earth is a core construct in any theory of astronomy and has been involved in a number of revolutions in the history of science. The earliest recorded conceptions about the earth were that it was flat and that it stood in the center of the universe. The earth was hypothesized to be flat in early Egypt (Kuhn, 1957; Plumley, 1975), in Sumeria (Lambert, 1975), in early Greece (Toulmin & Goodfield, 1961), and in early India (Gombrich, 1975).

In the historical development of cosmological theories, the view that the earth was flat was eventually replaced by the view that it is a sphere. Aristotle, in his book *On the Heavens,* offered a number of arguments for the position that the earth is a sphere (see Kuhn, 1957). One of the arguments was based on the position of the North Star. The Greeks knew from their travels that the North Star appeared lower in the sky when viewed from a location in the south than from a location farther north, a change which is difficult to explain if one assumes that the earth is flat. Another argument was based on Aristotle's explanation of the eclipses of the moon. Aristotle hypothesized that the eclipses of the moon were caused by the earth's shadow on the moon. Since this shadow was always round, he argued that the earth must be spherical.

The view that the earth is a sphere was fully elaborated by Ptolemy in the *Almagest* (1984). According to Ptolemy, the earth was a sphere which stood motionless at the center of the universe. It was surrounded by eight spheres on which the sun, the moon, the five planets known at the time, and the stars were attached. The sun, moon, and planets moved around the earth in orbits that were perfect circles. The stars were attached to the outermost sphere, which rotated around the earth. The Copernican revolution retained the view that the earth is a sphere, but required a shift from a geocentric to a heliocentric universe and with it the rejection of the belief that the earth does not move.

In the present study we have examined only the changes in children's views about the shape of the earth. We intend to present data about other aspects of children's views of observational astronomy (e.g., the day/night cycle) in future papers.

Children's Ideas about the Shape of the Earth

A number of science educators have investigated children's knowledge about the shape of the earth and gravity and have concluded that children hold various "notions" about the shape of the earth. This evidence comes

from studies conducted by Nussbaum (1979), Nussbaum and Novak (1976), Sneider and Pulos (1983), and Mali and Howe (1979).

Nussbaum and Novak (1976) showed that 2nd-grade children say that the earth is round, but under more detailed questioning give answers consistent either with a flat earth view or with a number of other alternative views regarding its shape. Five such alternative notions about the earth were discovered. Notion 1 was ascribed to the children who said that the earth is round but answered all other questions as if they believed that the earth is really flat. Notion 2 was ascribed to the children who thought that the earth is round like a ball but who lacked the idea of unlimited space; these children thought that there is ground or ocean which bounds the space below the earth and sky which bounds the space above the earth. The children who held notion 3 lacked the idea of gravity; they believed that objects placed on the "bottom" of the spherical earth would fall. The children who held notion 4 knew that objects placed on the "bottom" of the spherical earth do not fall but did not have a full understanding that Earth's gravity operates by pulling things toward the center of the earth. Finally, the children who held notion 5 provided the culturally accepted responses to the earth-shape and gravity questions.

Nussbaum (1979) further tested the validity of these notions in a developmental study involving Israeli children. The results suggested that notions 1 and 2 should be combined. He also uncovered a new notion according to which the earth was like a huge ball consisting of two hemispheres: an upper hemisphere made up of air or sky and a lower hemisphere consisting of the ground where people live.

These results were further validated in a study by Sneider and Pulos (1983) which showed that most children who were below 10 years of age (grades 3 and 4) held notions 1, 2, or 3, that most of the children aged 13 and over held notions 4 and 5, and that the widest spread of notions was found among 11- and 12-year-olds.

Mali and Howe (1979) investigated the development of the earth shape and gravity concepts among Nepali children coming from urban and rural regions. They note that in Nepal the traditional belief of adults who have no schooling is that the earth is a flat object supported on each of four corners by an enormous elephant. However, the children are taught at school that the earth is a sphere. Mali and Howe tested children ages 8, 10, and 12 with tasks similar to those used by Nussbaum and Novak (1976). Their results showed that the Nepali children formed notions of the earth similar to those of the American children but that they tended to occur at later ages.

However provocative the existing research on children's ideas regarding the shape of the earth may be, many questions are left unanswered about the exact nature of these notions. One important limitation of the existing studies is that they do not make explicit the exact criteria used to identify children's ideas. Neither do these studies provide us with information regarding the systematicity, consistency, and robustness of children's notions about the shape of the earth. In other words, we do not know how children were classified as holding a given notion and whether these notions were used in a consistent and systematic fashion by the children who were assigned to them.

The Present Study

The purpose of the present study was to further investigate the nature of children's intuitive knowledge about the shape of the earth and to understand how this knowledge changes as children are exposed to the culturally accepted information that the earth is a sphere. We wanted to further investigate the hypothesis that children develop alternative notions about the shape of the earth and to find out whether these notions were well defined and used by the children in a consistent manner.

Two specific hypotheses guided our research efforts. The first was that children start the knowledge acquisition process by assuming that the earth is flat. The view that the earth is flat is supported by everyday experience and agrees with prior research regarding children's ideas about the earth.

The second hypothesis was that children will have difficulty understanding the information that the earth is a huge sphere, surrounded by space. The idea that we live all around on the outside of a spherical earth is counter-intuitive and does not agree with everyday experience. In the history of science, the spherical earth view was often attacked by proponents of the flat earth view, for example, on the grounds that people "on the other side" of the earth would fall off (Kuhn, 1957).

The hypothesis that children will find the information regarding the spherical shape of the earth difficult to believe is consistent with reports regarding the construction of alternative notions about the shape of the earth found in the existing research literature. Alternative notions can be seen as attempts on the part of the children to reconcile the information coming from adults that the earth is a sphere with an original naive conception of a flat earth. This view has been an implicit hypothesis in some of the work on students' alternative conceptions in science, but the research to support it has not been done (see Wiser & Carey, 1983, for a discussion of this issue). For example, Piaget (1929, p. 296) reports an interesting case of an "alternative notion" formed by children attempting to understand the phenomenon of the day/night cycle. These children had been given an explanation of the day/night cycle in terms of the rotation of the earth; they had been told that when it was night in Europe it was day in America. They interpreted this information, in the context of their