Developmental Shifts in Children's Categorizations of the Earth

Stella Vosniadou (svosniad@phs.uoa.gr)
Cognitive Science Lab
Department of Philosophy and History of Science
University of Athens
University Town, Ilisia 157 71 Athens – Greece

Irini Skopeliti (eskopel@phs.uoa.gr)
Cognitive Science Lab
Department of Philosophy and History of Science
University of Athens
University Town, Ilisia 157 71 Athens – Greece

Abstract

In this paper we present the results of an empirical study which investigated the hypothesis that there is a theory change in children's categorizations of the earth. Fifth graders categorize the earth as a solar object but this is not the case for first graders. Sixty-two children, 43 ranging in age from 6 to 7 years and 19 ranging in age from 10 to 11 years, were interviewed individually using a Categorization Task and an Earth Shape and Gravity Task. The results showed a developmental shift from the categorization of the earth as a physical object to the categorization of the earth as a solar object. High correlations were also obtained between the categorization of the earth and the understanding of its spherical shape.

Introduction

A great deal of the cognitive science literature on the development of categorization has focused on the debate between similarity-based vs. theory-based accounts (Fisher & Sloutsky, 2004; Gelman & Markman, 1986; Goldstone, 1994; Sloutsky & Fisher, 2004). There seem to be two assumptions or "dogmas" (Keil, Smith, Simons, & Levin, 1998) that embody this controversy: (a) that children initially have only a similarity-based component for learning concepts and that the theory component develops later on, based on the similarity component, or, alternatively, (b) that the theory component is present from the start, but for some reason (e.g. lack of adequate prior knowledge) does not influence young children's inductive generalizations, which are based on similarity judgments instead (for example, Carey, 1985).

In the present paper we will not be concerned with this debate in itself. Rather, we will assume that at some point children construct domain-specific conceptual knowledge which is theory-based. The purpose of our research is to investigate whether there is evidence for theory change in the development of children's categorizations.

More specifically, Vosniadou and her colleagues (e.g. Vosniadou & Brewer, 1992; 1994; Vosniadou, Skopeliti, & Ikospentaki, 2004; in press) have argued that the main reason why children have difficulty understanding the spherical shape of the earth is because they spontaneously categorize the earth as a physical object (rather than as a solar object) and apply to it all the presuppositions that apply to physical objects in general (i.e. solidity, stability, up/down organization of space, up/down gravity, etc., see Spelke, 1991). There has been indirect evidence for the existence of such presuppositions from children's verbal explanations and representations (drawings and play-dough models). Several cross-cultural studies that were conducted in Samoa, India, Greece, and native Indian-American children in South Dakota showed that children in different parts of the world form models of the earth that reveal these presuppositions of solidity and stability (Samarapungavan, Vosniadou, & Brewer, 1996; Vosniadou, Archontidou, Kalogiannidou, & Ioannides, 1996; Diakidoy, Vosniadou, & Hawks, 1997). However, the hypothesis that children categorize the earth as a physical object has not been investigated directly.

The research reported in this paper examined 1st and 5th graders categorizations of the earth in relation to their beliefs about the shape of the earth. We hypothesized that by grade 1 most children will have formed the distinction between solar and physical objects and that they will tend to categorize the earth as a physical object. Further, we expected a developmental shift in children's theory-based categorizations of the earth from the earth as a physical object to the earth as a solar object. We also hypothesized a high correlation between children's categorizations and their beliefs about the shape of the earth. According to our theory, the shift from categorizing the earth as a physical object to categorizing it as a solar object should be a prerequisite to a full understanding of the spherical shape of the earth.

Method

Participants

The sample consisted of 62 Greek children, students in two middle-class schools of central Athens. Forty-three of them attended 1st grade and their age ranged from 6 to 7 years

(Mean age 6 years and 3 months) and 19 of them attended 5th grade and their age ranged from 10 to 11 years (Mean age 10 years and 5 months).

Procedure

The children were interviewed individually in a separate classroom in their school by two experimenters. One experimenter posed the questions and the other kept detailed notes of children's responses during the interview. In the first part of the interview the children were given the Categorization Task, which was followed after a 5 minutes break by an astronomy (Earth Shape and Gravity) Questionnaire. Each interview lasted approximately 25-30 minutes. The interviews were recorded and the scoring was done on the transcribed data. Half of the data were scored by two experimenters who agreed on the scoring key. Then, two independent scorers used the key to score all the data. Agreement was high (96%). All disagreements were resolved after discussion.

Materials

The materials for the Categorization Task consisted of 10 cards with the words SUN, MOON, STAR, EARTH, PLANET, HOUSE, CAT, ROCK, TREE and CAR. The experimenter read the cards with the child and made sure that she/he understood the meaning of each word. Then she asked the child the three categorization questions that appear on Table 1. Each categorization question was followed by a justification question (Why did you put these things together?) as shown in Table 2. The Earth Shape and Gravity Questionnaire was administered last. It was based on the Vosniadou & Brewer (1992) Astronomy Questionnaire and appears on Table 3.

Results

Categorization Task

Children's responses to the three categorization questions were grouped in four main categories: (1) Distinguishes solar from physical objects (either in two or more categories in the case of the first question) and groups the earth with the solar objects, (2) Distinguishes solar from physical objects (either in two or more categories in the case of the first question) and groups the earth with the physical objects, (3) Does not distinguish solar from physical objects, and (4) No response.

Children's responses to all the categorization questions were marked as 3 for the categorization of the earth as a solar object, 2 for the categorization of the earth as a physical object, 1 when the child made no distinction between solar and physical objects, and 0 when there was no response. The total scores were subjected in an one way ANOVA which, as expected, showed main effects for grade ($F(1,60)=18,487$, $p<.001$) in favor of the 5th graders (1st grade mean score: 5,605; 5th grade mean score: 8,185).
A chi-square was also used to compare 1st and 5th graders final categorizations of the earth. This analysis showed statistically significant results in favor of the 5th graders [$x^2(2)= 11,630$, $p<.005$]. The categorization differences between the 1st and 5th graders' responses in the last categorization question can be seen more clearly in Figure 1. Unlike the 1st graders, practically all the 5th graders distinguished physical from solar objects and categorized the earth with the solar.

Table 1: Children's Responses in the Categorization Questions as a Function of Grade (Percent)

Questions	**Response Type**	1st Grade N=43	5th Grade N=19
1. I want you to put together the things that you think should go together, belong to the same group.	1a. Distinguishes solar from physical-two categories-Earth with solar. (3)	21%	47%
	1b. Distinguishes solar from physical-many categories-Earth with solar. (3)	13%	32%
	2a. Distinguishes solar from physical-two categories-Earth with physical (2)	6%	-
	2b. Distinguishes solar from physical-many categories-Earth alone or with physical. (2)	14%	5%
	3. Does not distinguish physical from solar objects. (1)	44%	16%
	4. Don't know. (0)	2%	-
2. Could you make only two groups from these things?	1. Distinguishes solar from physical-Earth with solar. (3)	27%	79%
	2. Distinguishes solar from physical-Earth with physical. (2)	11%	5%
	3. Does not distinguish physical from solar objects. (1)	36%	16%
	4. Don't know (0)	16%	-
3. Could you put in one group the things that go with the EARTH and in another the things that do not?	1. Distinguishes solar from physical-Earth with solar. (3)	42%	90%
	2. Distinguishes solar from physical-Earth with physical. (2)	35%	10%
	3. Does not distinguish physical from solar objects. (1)	23%	-

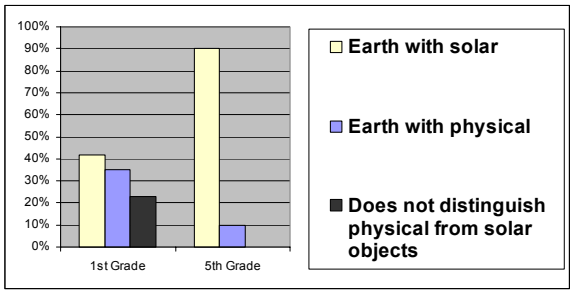

Figure 1: Children's Responses in the Last Categorization Question as a Function of Grade (Percent)

Children's justifications were also grouped in four categories as shown in Table 2: (1) Theory-based, if the child referred to the distinction between solar and physical objects (eg. All these are planets and they are found on the sky. The others are found down here.), (2) Similarity-based, if the child referred to functional similarity or similarity in shape, brightness or position, (eg. All these have the same shape (round) but the others have different shapes), (3) Arbitrary, if the child mentioned idiosyncratic grounds for the categories (e.g., the cat goes with the tree because cats like climbing trees), and (4) No response.

Children's responses to the justification questions were marked as 3 for the theory-based responses, 2 for the similarity-based responses, 1 for arbitrary justifications, and 0 when there was no response. The total scores were subjected to an one way ANOVA which showed main effects for grade [$F(1,60)=7,670$, $p<.01$] in favor of the 5th graders (1st grade mean score: 6; 5th grade mean score: 7,632).

Table 2: Children's responses to the Justification Questions as a Function of Grade (Percent)

Questions	Response Type	1st Grade N=43	5th Grade N=19
Justification Question for Categorization Question 1	1. Theory-based (3)	26%	53%
	2. Similarity-based (2)	21%	-
	3. Arbitrary (1)	46%	47%
	4. Don't know. (0)	7%	-
Justification Question for Categorization Question 2	1. Theory-based (3)	47%	84%
	2. Similarity-based (2)	9%	
	3. Arbitrary (1)	21%	5%
	4. Don't know. (0)	23%	10%
Justification Question for Categorization Question 3	1. Theory-based (3)	74%	100%
	2. Similarity-based (2)	14%	-
	3. Arbitrary (1)	12%	-

As can be seen in Table 2, children start by giving justifications that belong to all the previously mentioned categories but, by the end of the interview, they give mainly theory-based justifications. In other words they say that they grouped the objects following the physical/solar objects distinction. A close examination of the data showed that all the children who placed the earth either with the solar or with the physical objects gave a theory-based justification, with the exception of one 1st grader who grouped the earth with the solar and gave an arbitrary justification.

A chi-square that compared 1st and 5th graders' final justifications showed statistically significant results [$x^2(2) = 6,575$, $p<.05$]. This difference can be seen more clearly in Figure 2 where we compare children's responses to the last justification question.

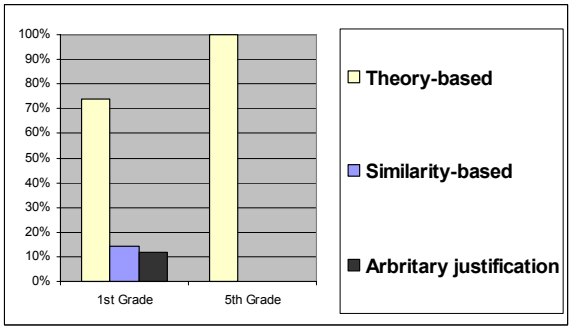

Figure 2: Children's Responses to the Last Justification Question as a Function of Grade (Percent)

Earth Shape and Gravity Task

Table 3 shows children's responses in all the earth shape and gravity questions. Children's responses to all the earth shape and gravity questions were marked as 3 for responses consistent with the scientifically expected answer (spherical shape of the earth with people living all over its surface, etc.), 1 for responses consistent with an initial flat model of earth (flat model of the earth and people living only on the top of the model, etc.) 2 for responses consistent with an alternative model of the earth (neither spherical, nor flat), and as 0 when there was no response to the question asked. The way the responses were scored can be seen in more details in Table 3. The total scores of these marks were subjected in an one way ANOVA which showed main effects for grade [$F(1,60)=11,003$, $p<.005$]. The frequency of the scientifically correct responses increased with age and thus the 5th graders had a higher mean score (17,684) compared to the 1st graders (13,372).

The earth shape and gravity questions were scored following the procedures described in Vosniadou & Brewer (1992) and the children were assigned to earth shape models using their responses to four questions as described in Vosniadou, Skopeliti, & Ikospentaki (2004). The four

Table 3: Children's Responses in the Earth Shape and Gravity Questionnaire as a Function of Grade (Percent)

Questions	**Response Type**	1st Grade N=43	5th Grade N=19
1. Take this play-dough and make the shape of the earth as you think it really is.	1. Sphere (3)	53%	90%
	2. Vertical Ring (2)	12%	-
	4. Two shapes (spherical and flat) (2)	7%	-
	5. Flat Disk (1)	14%	10%
	6. Flat Rectangular (1)	14%	-
2. Show me in your play-dough model where the people live.	1. All around the sphere (3)	18%	63%
	2. On the top of the sphere (2)	35%	26%
	3. Inside the vertical ring (2)	12%	-
	4. On the top of the second (flat) shape (1)	7%	-
	5. On the top of the disk (1)	14%	10%
	6. On the top of the rectangular earth (1)	14%	-
3. (*If the child made spherical model of earth, ask* :) Can people live here, at the bottom of the earth?	1. Yes (3)	19%	68%
	2. No (2)	35%	21%
	3. Not asked because the child made an alternative model of earth (2)	19%	-
	4. Not asked because the child made a flat model of earth (1)	28%	10%
4. If a little girl was here (at the bottom of the earth) and held a ball and the ball fell, where would it fall?	1. To the earth (3)	16%	68%
	2. Far away from the earth (2)	2%	-
	3. Not asked because the child said that people cannot live at the bottom of the model (2)	35%	21%
	4. Not asked because the child made an alternative model of earth (2)	19%	-
	5. Not asked because the child made a flat model of earth (1)	28%	10%
5. (*If the child did not make flat model of earth, ask*:) This is the picture of a house. This house is on the earth, isn't it? How come here the earth is flat but before you made it round?	1. The earth is very big and we cannot see that it is round. If you see the earth from space you can see that it looks like a sphere (3)	14%	52%
	2. Earth has flat surfaces on it (2)	12%	16%
	3. Inside the earth it is flat (2)	7%	-
	4. Not clear answer (1)	9%	5%
	5. The child changed the shape from sphere to disk (1)	2%	-
	6. Not asked because the child made a flat model (1)	28%	11%
	7. Don't know (0)	28%	16%
6. If you walked for many days in a straight line, where would you end up? Is there an end/edge to the earth?	1. Not asked because the child made a sphere (3)	49%	73%
	2. No (2)	9%	11%
	3. Yes (1)	30%	11%
	4. Don't know (0)	12%	5%
7. Would you fall off that end/edge?	1. Not asked because the child made a sphere (3)	49%	73%
	2. Not asked because the child said there is no end (2)	9%	11%
	3. No (2)	12%	-
	4. Yes (1)	19%	11%
	5. Don't know (0)	12%	5%

questions were the following: Q1 about the model of the earth, Q3 about the people living at the bottom of the spherical earth, Q6 about the end of the earth, and Q7 about the people falling from the end of the earth. Table 4 shows the frequency and percent of children placed in scientific, alternative, and initial models of the earth in relation to their final categorization.

An examination of Table 4 shows a high correlation between categorization responses and earth shape models. Most of the 1st graders with initial models of the earth categorized the earth as a physical object, while the great majority of the 5th graders and the 1st graders with spherical earth models categorized the earth as a solar object. In fact, there were only three children who constructed a spherical model of the earth and who did not, at the same time, categorize the earth with the solar objects.

Table 4: Relations between Children's Categorizations and their Models of the Earth

	Earth Shape					
	Scientific		Alternative		Initial	
Final Categorization	1st Grade **(N=6)**	5th Grade **(N=11)**	1st Grade **(N=26)**	5th Grade **(N=7)**	1st Grade **(N=11)**	5th Grade **(N=1)**
Earth with solar	4/6 (66%)	10/11 (90%)	14/26 (54%)	7/7 (100%)	1/11 (10%)	1/1 (100%)
Earth with physical	1/6 (17%)	1/11 (10%)	3/26 (12%)	-	7/11 (64%)	-
Does not distinguish physical from solar objects	1/6 (17%)	-	9/26 (34%)	-	3/11 (27%)	-

The correlation between categorizations and earth shape models was statistically significant, r_s= 0.444; n=62; p<0.001. It appears that the theory-shift from earth as a physical to earth as a solar object precedes children's full understanding of the earth as a spherical object and constitutes almost a necessary, although not sufficient, condition for the spherical earth model.

Discussion

The results of the categorization task are not conclusive with respect to the debate between similarity-based vs. theory-based accounts (Keil et al., 1998). Children from both grades, but particularly the 1st graders, distinguished solar from physical objects and categorized the earth either as a solar object or as a physical object. Or, they did not distinguish solar from physical objects and categorized the earth on other grounds. Their justifications were either theory-based, similarity-based, or arbitrary. Nevertheless, the developmental differences in the categorizations of the 1st graders compared to the 5th graders, and particularly the differences in the last question of the categorization task in which they were asked explicitly to make two groups with "the things that go with the earth and the things that do not" clearly support our hypothesis for a shift from one theory-based to another theory-based categorization. At grade 1, 35% of the children categorized the earth as a physical object and 42% as a solar object (providing appropriate theory-based justifications), while at grade 5 only 1 child categorized the earth as a physical object and all others (90%) as a solar object (again, providing appropriate theory-based justifications). These results agree with previous arguments about theory-based changes in children's conceptual knowledge (eg. Carey, 1985, Chi, 1992).

The predicted theory-change in children's categorizations are consistent with claims by Vosniadou and colleagues (Vosniadou & Brewer, 1992; Vosniadou, 1994) that children's difficulties in understanding the spherical shape of the earth can be explained by assuming that children categorize the earth as a physical object and apply to it all the presuppositions that apply to physical objects in general. Presuppositions such as solidity, stability, up/down gravity, etc., can stand on the way of understanding the spherical shape of the earth. The results of the present experiment also provide further support to the hypothesis that the categorization shift may be a prerequisite for a full understanding of the scientific explanation of the earth.

The results of the research presented in this paper open up new ways of viewing the relationship between conceptual development and categorization and have important implications for the diagnosis of students' misconceptions in science as well as for instruction.

Acknowledgments

This publication is part of a Ph.D. dissertation which is financially supported by the grant IRAKLEITOS - Fellowships for Research of NKUA- from the Greek Ministry of Education.

References

Carey, S. (1985). *Conceptual Change in Childhood*. Cambridge, MA: Bradford Books.

Chi, M.,T.,H. (1992). Conceptual change within and across ontological categories: Examples from learning and discovery in science. In R. Giere (Ed.) *Cognitive models of science: Minnesota studies in the philosophy of science*, University of Minnesota Press, Minneapolis, MN.

Diakidoy, I.A., Vosniadou, S., & Hawks, J. (1997). Conceptual change in astronomy: Models of the earth and of the day/night cycle in American-Indian children. *European Journal of Education, XII*, pp. 159-184.

Fisher, A.,V. & Sloutsky, V.,M. (2004). The Development of Induction: From Similarity-Based to Category-Based. In K. Forbus, D. Gentner, & T. Regier, (Eds.), *Proceedings of the twenty-Sixth Annual Conference of the Cognitive Science Society*, Chicago, Illinois.

Gelman, S.,A. & Markman, E.,M. (1986). Categories and induction in young children. *Cognition, 23*, pp. 183-209.

Goldstone, R.,L. (1994). The role of similarity in categorization: providing a groundwork. *Cognition, 52*, pp.125-157.

Keil, F.,C., Carter Smith, W., Simons, D.,J., & Levin, D.,T. (1998). Two dogmas of conceptual empiricism: implications for hybrid models of the structure of knowledge. *Cognition, 65*, pp. 103-135.

Samarapungavan, A., Vosniadou, S., & Brewer, W.F.,(1996). Mental models of the earth, sun and moon:

Indian children's cosmologies. *Cognitive Development, 11*, pp. 491-521.

Sloutsky, V.,M. & Fisher, A.,V. (2004). Induction and Categorization in Young Children: A Similarity-Based Model. *Journal of Experimental Psychology: General, Vol. 133*, No. 2, pp.166-188.

Spelke, E.,S. (1991). Physical knowledge in infancy: Reflections on Piaget's theory. In S. Carey & R. Gelman (Eds.), *The Epigenesis of Mind: Essays on biology and cognition*. Hillsdale, NJ: Erlbaum.

Vosniadou, S. (1994). Capturing and modelling the process of conceptual change. *Learning and Instruction, 4*, pp. 45-69.

Vosniadou, S. & Brewer, W.,F. (1992). Mental Models of the Earth: A Study on Conceptual Change in Childhood. *Cognitive Psychology, 24*, pp. 535-585.

Vosniadou, S. & Brewer, W.,F. (1992). Mental Models of the day/night cycle. *Cognitive Science, 18*, pp. 123-183.

Vosniadou, S., Archontidou, A., Kalogiannidou, A., & Ioannides, C.,(1996). How Greek children understand the shape of the earth: A study of conceptual change in childhood. *Psychological Issues, 7*(1), pp. 30-51 (in Greek).

Vosniadou, S., Skopeliti, I., & Ikospentaki, K. (2004). Modes of knowing and ways of reasoning in elementary astronomy. *Cognitive Development, 19*, pp. 203-222.

Vosniadou, S., Skopeliti, I., & Ikospentaki, K. (in press). Reconsidering the role of Artifacts in Reasoning: Children's Understanding of the Globe as a Model of the Earth. *Learning and Instruction*.