Reasoning with External Representations in Elementary Astronomy

Irini Skopeliti (eskopel@phs.uoa.gr) &
Stella Vosniadou (svosniad@phs.uoa.gr)
Cognitive Science Lab
Department of Philosophy and History of Science
National and Kapodistrian University of Athens
Ano Ilissia, 157 71, Greece

Abstract

This experiment investigated the effect of the presentation of two culturally accepted external representations of the earth -a map and a globe- on children's reasoning in elementary astronomy. Eighty four children from grades 1 and 3 were interviewed individually. First, the children were given a pre-test which determined their internal representations by asking them to make drawings and play-dough models of the earth and indicate where people live. The children were then divided in two experimental groups: Half of the children were presented with a globe, and half with a map. In both groups the children were asked to answer another set of questions about the earth, in order to determine how the external representations influenced their responses. In the pre-test children constructed relatively consistent models of the earth. However, when an external model was presented the children used this model to reason with. This often resulted in internally consistent responses as students relied on their incompatible prior knowledge to answer questions the answers to which could not be provided directly from the external model. We concluded that the use of an external representation is not an act of 'direct cultural transmission', but a constructive process during which the information that comes from the culture is interpreted and influenced by what is already known.

Introduction

The purpose of the experiment presented in this paper is to examine how two different external representations of the earth –a map and a globe– influence the way children reason in elementary astronomy. Previous studies investigating elementary school children's reasoning about the earth, showed that young children had sophisticated knowledge of the physical tools provided and could accomplish complex reasoning about the earth and gravity using them (Schoultz, Saljo, & Wyndhamn, 2001; Ivarsson, Schoultz & Saljo, 2002). It was thus concluded that in the presence of cultural artifacts and appropriate questionnaires children do not have any problems understanding the scientific information about the earth. (Nobes, Moore, Martin, Clifford, Butterworth, Panagiotaki & Siegal, 2003; Siegal, Butterworth, Newcombe, 2004).

The results of these studies have challenged the argument by Vosniadou and her colleagues (Vosniadou & Brewer, 1992, 1994; Vosniadou, Archontidou, Kalogiannidou, & Ioannides, 1996; Diakidoy, Vosniadou, & Hawks, 1997) that elementary school children have difficulty understanding scientific information about the earth.

We agree with Schoultz et al. (2001) that the presence of a globe can facilitate children's reasoning about the earth because it can, in fact, be used as a prosthetic device to help children think, fulfilling in this way its role as a cultural tool. However, we claim that the process of appropriation or internalization of an external representation is not a passive act involving simple and direct transmission, but a constructive process during which information coming from the outside is interpreted in the light of prior knowledge. Therefore this process is likely to be characterized by distortions or misinterpretations.

The purpose of the present study was to investigate this hypothesis. In the first part of the experiment, the children were asked to indicate verbally, in drawing, and in play-dough models, the shape of the earth and where people live. In the second part of the experiment the children were presented either with a map or with a globe and were asked a second series of questions about the earth and where people live. We hypothesized that: (1) the children would construct relatively internally consistent models of the earth in the 1st part of the experiment, (2) they would use the externally provided models in the 2nd part of the experiment, and (3) intrusions from incompatible prior knowledge would create internal inconsistency in their responses to the inferential questions in the 2nd part of the experiment.

Method

Subjects

The sample consisted of 84 children, students in two middle-class schools of central Athens. Forty children attended 1st grade and their age ranged from 5 years and 6 months to 7 years (M= 6 years and 1 month) and 44 attended 3rd grade and ranged in age from 7 years and 6 months to 10 years (M= 8 years and 5 months).

Materials

A two-part earth shape questionnaire was used, based on the original Vosniadou & Brewer (1992) study. It consisted of a total of 22 questions. In Questionnaire Part I (QPI), each child was asked to indicate the shape of the earth and where people live on the earth both verbally, in drawings, and in play-dough models. In Questionnaire Part II (QPII), the child's own drawings and play-dough models were removed and s/he was presented either with a globe (diameter 30cm) or with a map (94cm x 63cm). Both parts of the questionnaire are shown in Table 1 that follows.

Table 1: Earth Shape Questionnaire

Earth Shape Questionnaire: Part I
1. What is the shape of the earth?
2. *(If child says round, then ask :)* If the earth is round, does it look like a circle or like a ball?
3. How do you know that the earth is …… *(Use child's word)*?
4. *(If the child said round, then ask:)* Here is a picture of a house. The house is on the earth. How come here the earth is flat but before you said it is round?
5. Please make a drawing of the earth.
6. Draw where you think people live on the earth.
7. Draw where you think the sky and the stars are located.
8. Please make the shape of the earth using this play-dough?
9. Show me where people live on your play-dough model.
10. Show me where you think the sky and stars are located.
Earth Shape Questionnaire: Part II
1. Here is a globe. *(If the child before said that the earth is not round, ask:)* You said that the earth is…. But here the earth is shown to be round. Can you explain that?
OR
1. Here is a map. *(If the child before said that the earth is not flat, ask:)* You said that the earth is…. But here the earth is shown to be flat. Can you explain that?
2. If you walked for many days in a straight line, where would you end up? Is there an end to the earth? Would you ever reach the end of the earth?
3. Would you fall off that end? Why/Why not?
4. Can people live down here? Why? / Why not?
5. If a little girl lived down here and she had a ball and the ball fell from her hands, show me where it would fall.
6. Is there something that holds the earth up?
7. Finally, what do you think is the real shape of the earth?
(If the child changes his/her response, then we ask the following questions)
8. Take this play-dough and make the model of the earth as you finally think it really is.
9. If the earth is as you have now made it, then why did you made it differently before?
(If the child made a spherical earth then ask 10.)
10. Here is a picture of a house. This house is on the earth, isn't it? How come here the earth is flat but before you said it is round? Can you explain this a little more?
11. Where do you think people live on the earth?
12. Can people live down here? Why? / Why not?

Procedure

The children were assigned to an experimental group on the basis of their responses in QPI. Most of the children who gave responses consistent with a flat, rectangular or disk model of the earth in QPI were assigned to Experimental Group 1 (EG1), and where shown the globe as the external representation of the earth. Most of the children who gave spherical earth responses in QPI, were assigned to Experimental Group 2 (EG2), and where shown the map. We did this in order to be able to investigate how the presence of an external representation would affect children's responses in situations where the external representation came in conflict with the child's internal representation of the earth.

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 case children's responses were not clear the experimenter asked the child to clarify his/her response. Testing took place in two parts. QPI was administered first, followed by QPII. Children's own representations of the earth were removed and an external representation (map or globe) was provided in QPII. The interviews were audio-recorded and video-taped and children's play-dough models were photographed. Each interview lasted approximately 20 – 25 minutes.

Scoring

Children's responses were scored for both QPI and QPII in ways that made it possible to retain information that could be diagnostic of alternative representations of the earth. The authors of the paper scored half of the data independently. Then they met and agreed on a scoring key. All responses that were consistent with the spherical model of the earth were marked as scientific. The responses that were consistent with a flat model of earth were marked as initial. The remaining responses were marked as alternative responses. Using the scoring key, the remaining half of the data was scored independently. Then, the scorers met again, discussed the scoring and revised the scoring key as needed until agreement was achieved. The agreement between the two scorers at this point was very high (98%). Subsequently, an independent researcher used the scoring key to independently score the same data. At the end the whole team met to discuss disagreements. The agreement between the initial scoring of the two researchers and that of the independent scoring of the third researcher was high (96%). All disagreements were discussed until resolved.

Results

Questionnaire Part I (QPI): For a quantitative analysis of QPI all scientifically correct responses were scored as 2, alternative earth responses as 1, and flat earth responses as 0. The sum of the total scores for each child was then subjected to a 2 (grade) x 2 (experimental group) ANOVA. The data followed a normal distribution and the homogeneity tests showed that the dependent variables were equal across groups. The analysis showed significant main effects for grade [$F(3,80)=7,880$, $p<.01$], which was due to the fact that the older children gave more scientifically correct responses than the younger children.

Our next step was to see if the children could be assigned to a qualitative earth model on the basis of their responses. We distinguished 9 questions which were found in previous studies to critically differentiate among the different possible representations of the earth. Based on the findings of previous research, we defined the expected pattern of responses to these questions for six common models of the earth, independently of children's obtained responses. (For a more detailed description of this process, please refer to Vosniadou, Skopeliti, Ikospentaki, 2005.) The criteria for placement in a model category were as follows: For the

spherical model we expected children to say that the earth is round, that it does not have an end/edge, to construct a sphere, and to say that the people can live at the bottom of the earth. For the sphere without gravity, we expected children to give responses similar to the sphere model, for all the questions except the last. In the hollow sphere model we expected children to say that the earth is round and that it does not have an end, to construct a sphere, a vertical ring, or a cylinder and to clearly say that people live inside the earth, and to also say that people cannot live at the bottom of the earth. For the dual earth model we expected children to say that the earth is round and construct two earth models: a spherical one and a flat earth on which people live. We also expected these children to say that there is an end/edge to the earth and that people cannot live at the bottom of the earth. For the disc earth we expected the children to construct a flat disc model say that there is an end/edge to the earth and that people cannot live at the bottom of the earth. For the flat models we expected children to say that the earth is flat and construct a flat rectangle or square. These children were also expected to say that there is an end/edge to the earth and that people cannot live at the bottom of the earth.

In order to be assigned to a model category a child should provide responses consistent one of the above mentioned patterns of responses. As can be seen, in Table 2, most of the children constructed relatively consistent models of the earth and were placed in a well defined model category in QPI. Only 15% of the 1st graders and 14% of the 3rd graders were not assigned to a model category.

Table 2: Frequency/Percent of Children in the EGI & II Placed in Model Categories as a function of Grade

Model Categories	1st Grade	3rd Grade
1. Sphere	8 (20%)	13 (31%)
2. Sphere without gravity	2 (5%)	4 (10%)
3. Hollow sphere	10 (25%)	10 (24%)
4. Dual Earth	-	-
5. Flattened Sphere	1 (2,5%)	1 (2%)
6. Disk	10 (25%)	8 (19%)
7. Flat Earth	3 (7,5%)	-
8. Mixed	6 (15%)	6 (14%)

Questionnaire Part II: First we analyzed responses to Question 1 which asked children to explain discrepancies between their representations of the earth and those provided by the external model. Tables 3 and 4 show the categories of responses for Q1 for the two experimental groups. In the case of the globe, 85% of the 1st graders and 46% of the 3rd graders were asked Q1 because only these children had not constructed a spherical model. In the case of the map, 95% of the 1st graders and 91% of the 3rd graders were asked to explain the inconsistency between their model and the model presented because only these children had not constructed a flat model of the earth.

Table 3: Frequency/Percent of Responses to Q1 of QPII in EGI (Globe) as a function of Grade

Q.1: Here is a globe. *(If the child before said that the earth is <u>not round</u>, ask:)* You said that the earth is…. But here the earth is shown to be round. Can you explain that?		
Response	**Gr.1 N=17 (85% asked)**	**Gr.3 N=10 (46% asked)**
1) Not asked. The child had made a spherical earth model.	**3/20 (15%)**	**12/22 (54%)**
2) I've made a mistake The earth is round (change).	5/17 (30%)	1/10 (10%)
3) I wanted to make it like that, but I couldn't (change).	4/17 (23%)	5/10 (50%)
4) People make the earth round to represent all countries (no change).	2/17 (12%)	1/10 (10%)
5) There is another earth, where people live and looks like my model (no change).	-	1/10 (10%)
6) The earth looks like the one I made (no change).	2/17 (12%)	-
7) Don't know (no change).	4/17 (23%)	2/10 (20%)

A chi-square analysis showed that the difference in children's responses about the shape of the earth before and after the presentation of the external representation reached statistical significance in EG1 (globe) [$x^2(2)=7,845$, $p<.05$], but not in the case of EG2 (map).

Table 4: Frequency/Percent of Responses to Q1 of QPII in EGII (Map) as a function of Grade

Here is a map. *(If the child before said that the earth is <u>not flat</u>, ask:)* You said that the earth is…. But here the earth is shown to be flat. Can you explain that?		
Response	**Gr.1 N=19 (95% asked)**	**Gr.3 N=20 (91% asked)**
1) Not asked. The child had made a flat earth model.	**1/20 (5%)**	**2/22 (9%)**
2) People make the earth flat in order to represent all countries (no change).	6/19 (32%)	13/20 (65%)
3) The map is a piece of paper; it can't be round (no change).	5/19 (26%)	2/20 (10%)
4) The map shows us the inside part of the earth (no change).	-	1/20 (5%)
5) The earth looks like the one I made (no change).	2/19 (10%)	-
6) Don't know (no change).	6/19 (32%)	4/20 (20%)

In EG1 (globe) most of the children changed their initial non-spherical earth answer and accepted the globe as a better model of the earth, while in the case of EG2 (map) most of the children retained their initial answer of a

spherical earth. This result shows that different external representations can have different effects on children's responses. Children filter the external representations presented and do not accept them regardless of their content.

Children's responses to the remaining questions of QPII were scored as 2 for each scientifically correct response, as 1 for each alternative earth response, and as 0 for each flat earth response. The sum of the total scores was then subjected to a 2 (grade) x 2 (experimental group) ANOVA. The analysis showed a significant main effect for grade [$F(3,80)=8,429$, $p<.005$] only, with third graders doing significantly better than first graders. There was no statistically significant difference between the two experimental groups.

In a second analysis, we examined how each external representation (globe vs. map) separately affected children's responses by comparing pre and post scores within experimental group. A 2 (grade) x 2 (pre/post test score) mixed ANOVA was used. In the case of EG1 (globe), the analysis showed main effects for the pre/post test score [$F(1,40) = 11,575$, $p<.005$] which was due to the fact that more scientifically accepted responses were produced in the post-test, after the presentation of the globe, compared to the pre-test. There were also main effects for grade, [$F(1,40) = 8,304$, $p<.01$] due to the fact that the third graders systematically outperformed the first graders.

As can be seen in Figure 1, before the presentation of the globe, the mean total score was 6,7 for the first graders and 9,4 for the third graders, while after the presentation of the globe the mean total score was 8,7 for the first graders and 11,05 for the third graders.

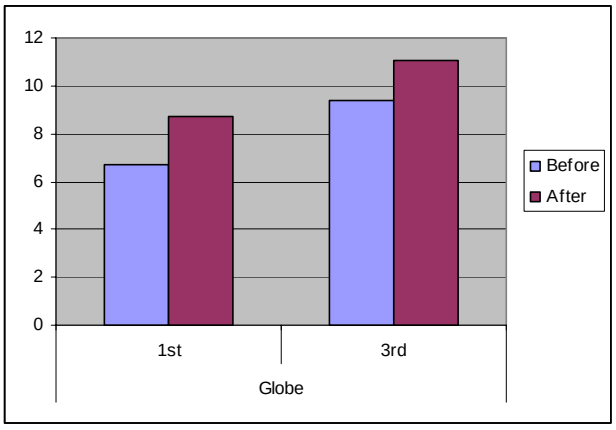

Figure 1: Children's Mean Total Score in EG1 (Globe) Before & After the Presentation of the Globe as a function of Grade

In the case of the EG2 (map), the ANOVA did not show main effects neither for the pre/post test score, nor for grade. As shown in Figure 2, the first graders before the presentation of the map had a high mean total score of 9,6 and after the presentation of the map had a slightly lower score of 9,2. The third graders before the presentation of the map had a mean total score 10,1 and after the use of the map they had a mean total score of 11.

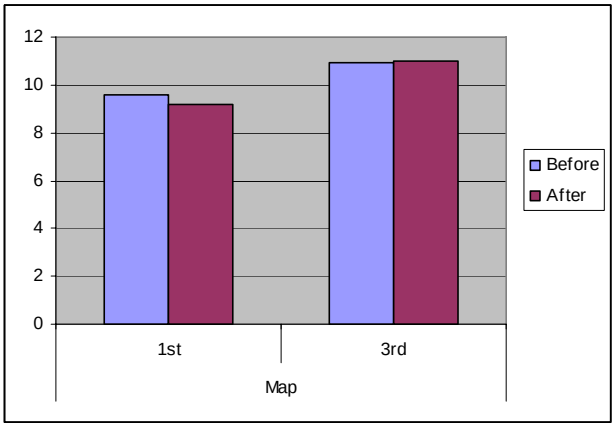

Figure 2: Children's Mean Scores in EG2 (Map) Before & After the Presentation of the Map as a function of Grade

Our next step was to see if the children could be assigned to well-defined model category on the basis of their responses in QPII. We used the pattern of responses described earlier. As can be seen in Tables 4 and 5, while most of the children were placed in a well defined model category in QPI, in QPII the number of children placed in the mixed category increased remarkably. More specifically, in QPI, before the use of the globe, 90% of the children (38/42) from both age groups gave internally consistent responses and were assigned to a model category. On the contrary, in QPII, after the use of the globe, the frequency of the internally consistent models decreased with only 35% of the 1st graders and 55% of the 3rd graders being assigned to a model category (see Table 5).

Table 5: Frequency/Frequency of Subjects in the Scientific, Alternative & Mixed Model Categories in EG1 Before & After the Use of the Globe

Model Categories	Before the Use of the Globe		After the Use of the Globe	
	1st Grade	3rd Grade	1st Grade	3rd Grade
Scientific	3 (15%)	6 (27%)	5 (25%)	11 (50%)
Alternative	15 (75%)	14 (64%)	2 (10%)	1 (5%)
Mixed	2 (10%)	2 (9%)	13 (65%)	10 (45%)

Similarly, before the use of the map 80% of the 1st graders and 90% of the 3rd graders in EG2, gave internally consistent responses and were assigned to a model category, while, after the use of the map, the frequency of the internally consistent models decreased with only 30% of the 1st graders and 40% of the 3rd graders being assigned to a model category (see Table 6). The use of the globe (EG1) resulted in an increase in the number of sphere models and also of mixed models and a dramatic decrease in the number of alternative models. In EG2 (map) the number of scientific models remained the same, while the

number of mixed models increased remarkably and alternative models almost disappeared. A close look revealed that the use of the map did not result in an increase of the flat representations of the earth. However the presentation of the map influenced children's responses to some of the questions as it will be later shown in the discussion section.

A chi-square comparing the frequency of sphere, alternative, initial, and mixed model categories before and after the use of the external models gave statistically significant results for both cases, (for the globe: [$x^2(2)=36,455$, $p<.001$], for the map: [$x^2(2)=31,004$, $p<.001$]).

Table 6: Frequency of Subjects in the Scientific, Alternative and Mixed Model Categories in EG2 Before and After the Use of the Map

Model Categories	Before the Use of the Map		After the Use of the Map	
	1st Grade	3rd Grade	1st Grade	3rd Grade
Scientific	5 (25%)	8 (36%)	5 (25%)	8 (36%)
Alternative	11 (55%)	12 (54%)	1 (5%)	1 (5%)
Mixed	4 (20%)	2 (9%)	14 (70%)	13 (59%)

Discussion

The results of the present study replicated previous findings by Vosniadou and colleagues (Vosniadou & Brewer, 1992; 1994; Vosniadou, Archontidou, Kalogiannidou, & Ioannides, 1996; Diakidoy, Vosniadou, & Hawks, 1997; Vosniadou, Skopeliti & Ikospentaki, 2004; 2005) that in the absence of an external representation, children construct relatively consistent models of the earth, which they can externalize through drawings and play-dough models and which they use to reason with.

The results also showed that the external representations provided (globe and map) influenced children's responses differently. The presentation of the globe caused a dramatic change in children's responses regarding the shape of the earth, with most children abandoning their previous representation of the earth and adopting the culturally accepted representation. On the contrary, in the case of the map, none of the children who had previously constructed a spherical model of the earth changed their original responses regarding the shape of the earth to construct a flat representation of the earth. Also children who initially constructed alternative models of the earth and changed their responses in QPII mostly gave responses that were not consistent to a certain representation of the earth and were grouped in the mixed model category.

The finding that the globe influenced children's responses in a different way from the map shows that the children were not just accepting the external representation passively, but were interpreting it on the basis of what they already knew. This finding is consistent with a constructivist approach and does not agree with a radical socio/cultural perspective that denies the usefulness of prior knowledge (Vosniadou, in press).

The non-spherical earthers who changed their responses in the presence of the globe possible did so because the external model reminded them of the scientifically correct and culturally accepted model to which they had probably been exposed. This interpretation is consistent with the results of other studies that show increase in scientific responses regarding the shape of the earth when a globe is provided (Schoultz et al., 2001; Ivarsson et al., 2002; Vosniadou et al., 2005), or when a forced-choice questionnaire is used (Nobes et al., 2003; Siegal et al., 2004; Vosniadou et al. 2004). These results have been interpreted to show that the recognition of scientifically correct responses is easier than their recall (Vosniadou et al., 2004).

Results such as these have led us to argue that there are different modes of knowing a scientific fact or an explanation, ranging from their simple repetition to their generative use. It appears that there is not a clear cut dichotomy between 'knowing' and 'not knowing', but rather a long process of learning science which often results in the creation of synthetic models and misconceptions (Vosniadou et al., 2004). The above agree with a view of concepts not as fixed and unchanging structures, but rather as malleable and flexible entities greatly affected by context.

Finally, our results showed that when an external representation is present, the frequency of internally inconsistent responses increases. It appears that the children used the external representation to answer questions the responses to which could be derived directly from the model provided. However, when the responses could not be derived directly from the external model, the children filled the gaps using their prior knowledge. This reduced the internal consistency in children's responses in the 2nd part of the questionnaire, when the external models were present.

This argument is supported by evidence derived from a more detailed examination of children's responses to some specific questions. For example, in Q4 the children were asked "can people live down here" showing the location of the South Pole. Both in the case of the map, and in the case of the globe, the scientific response is encouraged by the external representation and this was the response given by the majority of the children in QPII, although not in QPI. In the case of the map the flat representation of the earth poses no problem as far as the location of the South Pole is concerned. In the case of the globe, most of the children gave their responses only after bending to look if there is a country indicated at the place where the South Pole should be. Seeing that there is something like a country there, they answered in the affirmative.

However, interesting differences between the two groups emerged in Q5 ("If a little girl lived and she had a ball and the ball fell from her hands, where would it fall? Show me."). Almost all the children (90% of the 1st graders and 95% of the 3rd graders) in the EG2 (map) said that the ball would fall toward the earth. On the contrary, in case of the EG1 (globe), only 60% of the 1st graders and 64% of the 3rd graders said that the ball would fall towards the earth, even though 80% and 85% respectively had said that the people

could live “down here” in the South Pole in Q4. These differences suggest that both in the case of the globe and in the case of the map, the children are reasoning closely on the basis of the external representation to provide their responses. However, when the scientific response is not immediately obvious and can not be derived directly from the external model, incompatible prior knowledge might be used. Thus, the children relying on their previous knowledge that gravity operates in an up/down fashion causing people to fall from the ‘bottom of the earth’, they responded negatively in Q5, contradicting their positive response to Q4, and thus creating internal inconsistencies in their responses.

These findings are consistent with our previous arguments that the use of an external representation is not an act of ‘direct cultural transmission’ (e.g., Nobes et al., 2003; Siegal et al, 2004), but rather a constructive process during which the information that comes from the cultural artifacts is interpreted and sometimes actively distorted in the process of being made consistent with what the child already knows (Vosniadou et al., 2004, 2005).

The above also agree with the view that external representations can play a direct role in cognitive processing without the mediation of an internal representation (Zhang & Norman, 1994; Zhang, 1997) and that different representations differentially constrain or facilitate reasoning.

Acknowledgements

The project is co-financed within Op. Education by the ESF (European Social Fund) and National Resources.

References

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.

Ivarsson, J., Schoultz, J., & Säljö, R.(2002). Map Reading versus Mind Reading: Revisiting Children’s Understanding of the Shape of the Earth. In Limon, M. & Mason (Eds), L. *Reconsidering Conceptual Change: Issues in Theory and Practice*. Kluwer Academic Publishers.

Nobes, G., Moore, D., Martin, A., Clifford, B., Butterworth, G. Panayiotaki, G. & Siegal, M (2003). Children’s understanding of the earth in a multicultural community: mental models or fragments of knowledge? *Developmental Science 6*(1), 72-85.

Schoultz, J., Säljö, R., & Wyndhamn, J. (2001). Heavenly talk: discourse, artifacts, and children's understanding of elementary astronomy. *Human Development, 44*, 103-118.

Siegal, M., Butterworth, G., & Newcombe, P.A. (2004). Culture and children's cosmology, *Developmental Science, 7*:3, pp. 308-324.

Vosniadou, S. (in press). The Cognitive-Situative Divide and the Problem of Conceptual Change. *Educational Psychologist.*

Vosniadou, S., & Brewer, W.F. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology, 24*, pp. 535-585.

Vosniadou, S., & Brewer, W.F. (1994). 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. (2005). Reconsidering the role of Artifacts in Reasoning: Children’s Understanding of the Globe as a Model of the Earth. *Learning and Instruction, 15*, pp. 333-351.

Zhang, J. (1997). The nature of external representations in problem solving. *Cognitive Science, 21*, pp. 179-217.

Zhang, J. & Norman, D. A., (1994). Representations in distributed cognitive tasks. *Cognitive Science, 18*(1), pp. 87-122.