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Elementary Students' Mental Models of the Solar System

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Abstract

This research project aimed to identify and analyze Mexican primary school students' ideas about the components of the solar system. In particular, this study focused on conceptions of the solar system and representations of the dynamics of the solar system based on the functional and structural models that students make in school. Using a Euclidean distance-based cluster analysis, six different models of the solar system were identified. The results of this study suggest that these models do not specifically correlate to one school grade. The identified models vary in complexity, not only by the number of components but also by the dynamic interactions and distributions of the elements that comprise the models. This diversity of models shows that students do not simply reproduce the diagrams in their textbooks or the diagrams that they have access to in their environment. Though the oldest children's models approach textbook diagrams in the more complex models, up and down movements are still present in children's explanations of their models.

1. INTRODUCTION

Elementary education places great emphasis on the solar system. Aspects such as day and night, the seasons, and planets and their orbits are taught to children during their elementary school years. When being taught about the solar system, it is very common for students to be presented with drawings or diagrams of the earth and its rotation and revolution movements, as well as diagrams representing the solar system as a whole. In these diagrams, students can see characteristics of the planets including their relative sizes, their satellites and their orbits.

The assumptions behind teaching students about the solar system using diagrams is that the students are able to build a mental model of the solar system from these depicted representations. However, building a mental model is not as simple as reproducing a pictorial diagram. In the educational materials provided to students (e.g., texts, drawings, and diagrams), the information provided by the descriptions in the texts or the descriptions provided by the teachers (propositional representations) are not more extensive than the images or diagrams and do not contain more elements than these representations themselves. These conditions, as stated by Schnotz and Bannert (2003), are not sufficient for constructing mental models.

Vosniadou (2010) has warned the academic community of the intrinsic difficulty that exists in moving from an external schematic or graphical representation to the construction of a model that implies functionality, as the interpretation of that external representation is determined in part by children's conceptions and conceptual elements, such as their previous ideas. In other words, the interpretation of an external representation is created from the subject's conceptual referents.

We also found that drawings and diagrams of the solar system and the earth are built from an outer space perspective. This requires a complex level of abstraction, whereby the student *sees* from a position in space that is outside the earth. This construction is not easily achieved and requires complex mental processes that have been developed over a long period of time.

The solar system's dynamic processes must be considered as well, as students do not have phenomenological referents for these processes and diagrams cannot fully describe them. For example, comprehension of the fact that the processes occur simultaneously is required, as well as comprehension of spatial conditions that are outside the students' metrics. In particular, the decentralization of the earth and the orbital movements of the satellites and planets that result from the movements of the sun and moon (day and night cycle, phases of the moon) as perceived by students based on their visual referents imply the construction of a new reference system and a structural-functional base model that are extraordinarily complex, as shown by the history of science (Kuhn 1957).

The problems described herein regarding the construction of a solar system model lead to some questions: How do elementary school students build their solar system representations or models? What are the characteristics of these models? How do these model characteristics transform as the student moves through successive school years? How do these model characteristics vary? Moreover, what pieces of the information presented in school are relevant?

To answer some aspects of the questions above and broaden the scope of previous research (Calderón *et al*. 2006; Sharp and Kuerbis 2005), this document presents an analysis of the evolution of the solar system models that students build during their elementary education.

2. CHILDREN'S IDEAS OF THE SOLAR SYSTEM: A BRIEF REVIEW

The first research study concerning children's ideas of astronomy was performed by Piaget (1929/1984). His study focused on ideas about the origin of heavenly bodies such as the sun and moon. His conclusions highlight several stages. The first stage describes the children's artificialism, i.e., the conception that natural objects (in this case, heavenly bodies) are created by humans. In the second stage, heavenly bodies have a partial origin; they are considered to be constructed by a natural process but from artificial substances. Finally, children reach a stage in which they believe heavenly bodies to be completely natural, with their origins attributed to nature itself. While the richness of Piaget's work and its historical value cannot be denied, the study does not provide an analysis of the children's conceptions of the functioning of the solar system or of the relationships between the solar system's components.

Previous studies have presented the ideas that students build, from alternative ideas or misconceptions, mental models or frameworks of conceptions and do so through conceptual change and acquisition. These studies (Lelliott and Rollnick 2010) primarily cover topics related to the shape of the earth, the earth-sun-moon system, the day and night cycle, the phases of the moon (Afonso López *et al*. 1995; Baxter 1989, 1995; De Manuel 1995; Kikas 1998; Klein 1982; Mali and Howe 1979; Nussbaum 1979; Samarapungavan, Vosniadou, and Brewer 1996; Schoults, Säljö, and Wyndhamn 2001; Sneider and Pulos 1983; Valanides *et al*. 2000; Vosniadou 1994a, 1994b; Vosniadou and Brewer 1992, 1994; Vosniadou, Skopeleti, and Ikospentaki 2004), and to a lesser extent, students' ideas regarding the solar system, the stars and the sun and the concepts of size and distance in the solar system (Calderón *et al*. 2006; Candela 1991; Sharp 1995, 1996; Sharp and Kuerbis 2005; Sharp and Sharp 2007). Compared to other astronomical objects such as the sun and moon, researchers have investigated children's ideas of the solar system considerably less often.

One of the first studies to report on children's ideas of the solar system was conducted by Sharp (1995). In his research, he interviewed 20 boys and girls between the ages of six and seven to identify their ideas on the shape of the earth; the relative sizes of the sun, the moon, and the stars; the day and the night; the phases of the moon; the solar system and the Universe. The children's ideas were analyzed based on the categories proposed by Vosniadou (1991). After their ideas about the sun and the moon were determined, the children were asked what they thought existed in space beyond the earth. Along with answering the questions posed by the interviewer, the children created a drawing representing outer space and were shown other drawings to identify which drawing corresponded to the solar system. The results of this study show that the planets are the primary elements that are recognized as being part of space, and Jupiter was the planet that the children mentioned most frequently.

Generally, the children remembered between three and four planets. Four children out of the twenty said that they did not know of more objects in space aside from the observable ones (the sun, the moon, and the stars). Although in the interviews, the children did not provide further information on the things they thought were beyond the solar system, they added elements in their drawings that the authors have interpreted as representing wider knowledge of the solar system. These drawings or intuitive models, as the authors named them, include stars, planets, astronauts, etc.

In a later study, Sharp (1996) interviewed children between the ages of 10 and 11 and determined that these students were able to report on elements that are part of the solar system: planets (most frequently Mars, Saturn and Jupiter), meteors, comets, black holes, and galaxies. However, the students could not fully explain the movement of the heavenly bodies and did not present concrete ideas about the causes of these movements. Sharp also found that the majority of children knew that the earth, the sun, and the moon are spherical bodies and were able to locate them in the correct order and size. However, students had only vague ideas about the stars. In general, Sharp's results indicate than more than 50% of the children studied still had "scientific models" of the solar system. The rest of the children had a series of synthetic models (Vosniadou 1994a and 1994b).

In a study performed in Mexico (Candela 1991), children's ideas were analyzed from a sociocultural perspective, both inside the classroom and by using discourse analysis. The study was performed in a classroom with children from the fifth grade (10–11 years old). The solar system had been taught to these students previously, and a class on the subject was observed for one month. The author considered the interactions inside the classroom as an example of discourse within a natural context that can be used to investigate the students' conceptions. In this sense, Candela states that the students' conceptions depend more on the children's individual thought processes than on the teacher's dynamics or demands (Candela 2001). In her work, the author presents several fragments of the children's speech, from which we can see that the children posed questions during class that followed the dynamics proposed by the teacher (during discussion of the planets' movements), but the children also posed questions that broke the class logic, introducing questions directly related to their individual notions. For example, students posed questions such as: "Why don't we fall?" and "What holds the earth?"

In another study, Sharp and Kuerbis (2005) researched the conceptual framework of mental models in astronomy (Vosniadou 1991, 1994a). The participants of this study were 31 children between 9 and 11 years old. As part of this study, an intellectual maturity test and a scientific curiosity test were given to the participants. Later, a multiple-choice questionnaire was used as an interview. The questionnaire included making drawings and identifying objects in a diagram. The study also included an intervention. The children took an astronomy class (which emphasized the solar system) with their teacher, and the effect of this class was later measured. An experimental group participated in this class, and a control group did not participate. The intervention was performed by teachers and consisted of two-hour sessions for 10 weeks. The results showed that, in the interview before the intervention, the percentage of correct answers given was similar in both groups. After the intervention, differences between groups and genders were observed. From the drawings made by the children, nine different mental models representing the solar system were identified. These models included three versions of the heliocentric model (complete/correct, complete/incorrect and incomplete/incorrect), the spiral model, the progression model, the geocentric model, the geocentric model in progression form, the random model and the earth-moon-sun model. The results also show that after the intervention the children in the experimental group produced heliocentric models more frequently. In addition, these heliocentric models included much more description and more elements than the students' previously produced models. For the authors, the changes in the students' answers after the intervention represent radical and weak conceptual change (Vosniadou and Brewer 1987). The answers represent *weak* restructuring because the students know the names of the planets or can mention their characteristics and *radical* restructuring because the students are able to recognize that the solar system is heliocentric and not geocentric.

3. THE SOLAR SYSTEM IN AN ELEMENTARY SCHOOL IN MEXICO

Within the curriculum of elementary school (Secretaría de Educación Pública [SEP] 1993), the topic of the solar system formally appears in the 4th grade in the subject of geography, although some information about the sun is taught in natural science classes in the first and second grades (see Table 1). In 2010–2012, a new curriculum was implemented (SEP 2009) in which topics related to astronomy belong to the subject of natural sciences. Unlike the previous curriculum, the new proposal covers more topics and distributes these topics throughout elementary education (Appendix). However, this expansion of astronomy topics and the difference in the

Table 1. Topics in the 1993 curriculum

1993 Curriculum	
Natural sciences	**Geography**
First grade	*Second grade*
The Sun as a source of light and heat.	Sunrise and sunset.
Activities during the day and at night.	The Earth: comparison of its size with respect to the sun and the moon.
Second grade	*Fourth grade*
Natural and artificial sources of light.	The Earth and the solar system: location of the earth, its rotation and revolution movements, Solar and Lunar eclipses.
	Fifth grade
	The Universe and the earth.
	General characteristics of the solar system.

sequence of their presentation do not necessarily imply a modification of the teachers' teaching strategies. A similar phenomenon occurs in the students' textbooks. The presentation of content in the textbooks is different, and the textbooks have a different approach toward the student's role, as his or her participation is more active in the development of certain activities. Although the images in the students' books are more "realistic," they are similar to those presented in the previous curriculum. The students that participated in this study were using the 1993 curriculum.

In Mexico's elementary education, as in many other countries (for example, the National Curriculum in England or the New Zealand Curriculum), astronomy is a primary topic. However, little is known about the development and evolution of the solar system models of elementary school children, as shown by previous research. This paper focuses on discovering children's ideas about the components of the solar system and their conceptions and representations of the dynamics of the solar system based on the functional and structural models that students make throughout elementary school.

4. METHODS

4.1. Participants

The participants in this study were 39 boys and girls in elementary school. In first grade, 6 girls and 7 boys aged 6 to 7 years old participated. In third grade, 6 girls and 7 boys aged 8 to 9 years old participated, and in sixth grade, 6 girls and 7 boys aged 11 to 12 years old participated (see Table 2). All the participants were enrolled in a public school located in the east zone of the Distrito Federal in Mexico City. The children involved in this study had already participated in astronomy activities at school.

4.2. Instruments

To investigate the children's ideas, a semistructured interview was conducted with the students. The interview consisted of 41 questions related to the following topics: the earth, the moon, the sun, planets, and the solar system. Students were asked about shapes, sizes, relative distances, and movement.

Table 2. Distribution of the participants

Grade	Girls	Boys	Total
First	6	7	13
Third	6	7	13
Sixth	6	7	13
Total	18	21	39

Some questions required the students to simulate movements or make three-dimensional models (scale models) of the solar system. To that effect, 90 polystyrene balls were provided (9 balls in different sizes, 10 of each size). This number of balls was chosen to give the children the opportunity to choose different or similarly sized balls for the elements in the solar system, therefore avoiding the suggestion that there are a variety of sizes of elements in the solar system. A platform covered with black felt was also provided, and this stage functioned as a base for the scale model the children built. Additionally, a set of six solar system drawings was provided (including acentric, heliocentric and geocentric with orbits, and acentric, heliocentric and geocentric without orbits models). The drawings were used to identify whether the students could recognize the solar system in two different images. Therefore, several versions were presented, taking into consideration the students' possible answers of the locations of the elements in the solar system. The orbits were eliminated in some of the drawings to avoid the possibility that the orbits influenced the organization of the planets' locations. Using various materials during the interview was intended to allow students, if necessary, to demonstrate what they thought, rather than simply answering the interviewer's questions. We believe that the introduction of different materials allows children to respond by not simply repeating the information, but instead using the information available to generate a model of the concept or phenomenon addressed (Vosniadou 1994a).

4.3. Procedure

Each classroom's teacher was asked to select one of her students. The interview was conducted in a separate classroom provided by the school. Before the interview, the children were asked to provide their names and ages. The students were interviewed individually for approximately 45 min each. With every question, the interviewer asked the student to clarify or elaborate on his or her answer. All interviews were video-recorded and transcribed after the interview. Along with their verbal answers, the actions performed by the interviewees to answer some of the questions were described in the interview transcript (for example, movements and scale models made with the balls).

4.4. Data Analysis

The students' answers were grouped into five categories corresponding to the topics and tasks presented in the interview, and category components were established based on the children's answers to the interview questions (see Table 3). A value for each category component was then assigned. Table 3 presents each category and its definition.

The assignments of the students' responses to categories were validated by two additional researchers. Classifications of student responses within the categories helped to organize the models that students built of the solar system. A Euclidean distance-based cluster analysis was performed to identify the models that the children built of the solar system. This analysis provided a more complete overview of the types of representations that were built, as it integrated all the elements (definition, configuration, relative distances and movements' explanation).

5. RESULTS

The results of this study are presented in two sections: First, the analysis of the interviews is presented, based on the categories used for data analysis. The subjects' results are presented in percentages, and they are grouped by school grade. In the second section, we present the models identified from the cluster analysis. As mentioned, this analysis was performed to identify the diversity of models that the subjects built. The models built represent the structure of the solar system, the elements that are part of the solar system, the location of these elements and their movements.

5.1. First Section

The categories used for the analysis of the students' answers (see Table 4) are presented here:

5.1.1. Composition

The answers to the question "Do you know what the solar system is?" were grouped into three types: (a) Does not know what the solar system is, (b) It is the sun, and (c) It is the set of the planets and their order. As we can see in Table 5, the highest percentage corresponded to the last answer (planets' order). In their descriptions, children defined the solar system as a group of planets that includes the sun, the moon and the earth. They also added other elements to their descriptions, such as stars and asteroids, and they placed moons on other planets.

Table 3. Categories and definitions

Category	Definition	Category components
1. Composition	What the children think of the solar system, what they think it is and what elements it comprises.	1. I do not know 2. The solar system is the sun 3. Planet order
2. Representation with balls	The organization the children make, with the polystyrene balls on a platform, to represent the solar system.	Configuration 1 to Configuration 7
3. Distance	The distances between the elements of the solar system and the explanation given for their location. For example, the distances from the sun to the earth and from the moon to the earth.	1. I do not know 2. Far 3. Close
4. Movements	The description recorded of the type of movement of every element (Earth, Sun, Moon and Planets) that students included in their solar system models.	1. Up and down 2. Rotation 3. Revolution 4. Both
5. Structure	The drawing that each student chose as representing the structure of the solar system (with orbits and without orbits), as well as the explanation provided for that choice.	1. Heliocentric 2. Acentric 3. Geocentric

Notably, although the highest percentage corresponds to the last response category, differences can be observed by grade in the students' answers. Most of the first graders do not know what the solar system is, while most sixth graders do know what it is, and the third graders' answers are distributed among the three response categories. These answers could be directly linked to the information the children receive at school (for example, drawings or diagrams in text books).

5.1.2. Representation of the solar system with balls

In this part of the interview, the interviewers asked the participants to arrange balls to create a model that represented their solar system idea or model. The children were free to choose the number and size of the balls they would use. All the interviews were videotaped; therefore, upon transcription we recovered all of the organization of the balls that the children produced, and from these data, we determined the different configurations the children established. From the manner in which the children organized the balls on the platform, we grouped their representations into 7 different configurations.

Configuration 1. There is no representation with balls because the student does not know what the solar system is.

Configuration 2. The sun is located at one end or at the center of the platform, and the moon and the earth are the only elements that were added.

Configuration 3. The sun is located at the center, and the earth, the moon and some planets were added.

Configuration 4. The sun is at the center and at one end the students placed the planets without defining lines or orbits.

Configuration 5. The sun is located in the center, and the planets are located around it in a circle.

Configuration 6. The sun is located at one end and from there the planets are distributed along a straight line.

Configuration 7. The sun is located at one end of the platform, and the planets are placed to define specific orbits. The moon is located next to the earth.

Table 4. Categories and category components used in the data analysis

Category	Category components			
1. Composition	1. I do not know 2. The solar system is the sun 3. Planet order			
2. Representation with balls	Configuration 1 to Configuration 7			
3. Distance	A. From the sun to the earth 1. I do not know 2. Far 3. Close		B. From the moon to the earth 1. I do not know 2. Far 3.Close	
4. Movements	A. Earth 1. Up and down 2. Rotation 3. Revolution 4. Both	B. Sun 1. Up and down 2. Rotation 3. Revolution 4. Both	C. Moon 1. Up and down 2. Rotation 3. Revolution 4. Both	D. Planets 1. Up and down 2. Rotation 3. Revolution 4. Both
5. Structure	A. Drawing of the solar system with orbits 1. Heliocentric 2. Acentric 3. Geocentric		B. Drawing of the solar system without orbits 1. Heliocentric 2. Acentric 3. Geocentric	

The percentages corresponding to each configuration are presented in Table 6. In the first grade, most children cannot make a model with the balls because they say they do not know what the solar system is (61.5%), whereas 39.7% of students identified the solar system as the sun, the moon, and the earth. In the third grade, a majority of students (53.8%) places the sun at the center and adds the moon, the earth and some planets to the model. Finally, in sixth grade, most students (46.1%) build configuration six. The model configurations coincide with models reported in other studies (Sharp and Kuerbis 2005), and although these authors identified 9 models, the configurations they describe are similar to the configurations described in this work. The simplest representations are created by children in the first grade, while the most sophisticated representations, those that include more elements and try to show organization, are created by third graders and sixth graders. This finding coincides with the information the children receive at school. Notably, although third graders have not received formal instruction on the solar system, they have received enough information to create a representation.

5.1.3. Distance

The answers to the questions on the children's ideas of the relative distances from the sun and the moon to the earth are presented in Table 7.

Children in all three grades assume that the moon and the sun are far away from the earth, but in third grade, this idea captures the highest percentage. Children provided different explanations for their responses, including "*The Sun is far away from the earth because if it were close, everything would get burned or we would die*" (43.5%), and "*It would be very hot*" (10.2%). The students who think the sun is close to the earth say that "*if the sun were*

Table 5. Percentage of answer by grade to the question: What is the solar system?

Grade	He/she does not know	The Sun	Planet order
First	69.2%	30.7%	—
Third	30.7%	23%	46.1%
Sixth	7.6%	7.6%	84.6%
Total	35.8%	20.5%	43.5%

Note: Dashes indicate no response

Table 6. Percentage per grade for the different solar system model configurations constructed with balls

Grade	C1	C2	C3	C4	C5	C6	C7
First	61.5%	30.7%	—	7.6%	—	—	—
Third	23%	7.6%	53.8%	7.6%	—	—	7.6%
Sixth	15.3%	7.6%	—	7.6%	7.6%	46.1%	15.3%
Total	33.3%	15.3%	17.9%	7.6%	2.5%	15.3%	7.6%

far away, we would not be able to see it" (7.6%), or "*It would be very cold*" (2.5%). The explanations provided by the children are based on the perception that the sun is only a heat source. The other participants do not know how to explain their answers. The participants think that the moon is far away because "*If the moon were close to the earth, it would be bright all night*" (12.8%); but some also said, "*If the moon were far away from the earth, it would be very cold*" (7.6%). Again, the explanations provided by the children are based on the perception that the moon is also a source of light and heat. The rest of the students could not provide an explanation for their answers. Only one participant in the second grade said that the sun and the moon are close and far. That is, during the day the sun is close and at night it is far away, which is why we cannot see it. The moon is close at night and far away during the day. This explanation is based on the same perception that light and heat are received from these heavenly bodies.

5.1.4. Movements

The children's responses regarding the movements of the earth, the sun, the moon and the planets are presented in Tables 8 and 9. The highest percentage (41%) of students responded that the earth has *rotational* movement, but the participants thought that the earth only rotates about its own axis. Notably, listing the data according to grade, most of the first graders think that the sun does not move, the third graders consider only rotational movement, and the sixth graders consider both rotational movement and revolutions. According to most of the students, the sun does not move (56.4%), although in first grade, half of the students think it moves up and down. The results obtained for the moon are much the same. Although the majority of students think that the moon does not move, in a previous study (Calderón *et al*. 2006) when an explanation of the day and night cycle was requested, the students reported movement of the moon. Finally, for 46.1% of the students, planets do not move, although in sixth grade some students think that planets only revolve (23%), while other students think that planets both rotate and revolve (23%). The rationale of the children in these cases is based on the similarity they note between the earth and other planets.

5.1.5. Structure

To conclude the interview, the students were shown different diagrams of solar system configurations. These drawings or diagrams showed acentric, geocentric and heliocentric solar systems, each with two versions: one with orbits and one without orbits. Students were asked to pick the drawing that, from their point of view, represented the solar system. They were also asked for an explanation of their choice. From the drawings with orbits, 30.7% of all the students interviewed chose the geocentric model; that choice corresponded primarily to third graders. The majority of sixth graders chose the heliocentric model, and first graders did not know which

Table 7. Percentage response per grade of the distance between the sun and the earth and between the moon and the earth

	Sun from Earth			Moon from Earth		
Grade	I do not know	Far	Close	I do not know	Far	Close
First	23%	23%	53.8%	38.4%	38.4%	23%
Third	—	92.3%	7.6%	7.6%	76.9%	15.3%
Sixth	15.3%	30.7%	53.8%	23%	23%	53.8%
Total	12.8%	48.7%	38.4%	23%	46.1%	30.7%

Table 8. Percentage response per grade on the earth's and Sun's movements

	No movement		Up and down		Rotation		Revolution		Both	
Grade	**Earth**	**Sun**	**Earth**	**Sun**	**Earth**	**Sun**	**Earth**	**Sun**	**Earth**	**Sun**
First	76.9%	46.1%	—	46.1%	15.3%	—	7.6%	7.6%	—	—
Third	23%	69.2%	7.6%	23%	69.2%	7.69%	—	—	—	—
Sixth	7.6%	53.8%	7.6%	7.69%	38.4%	23%	—	15.3%	46.1%	—
Total	35.8%	56.4%	5.1%	25.6%	41%	10.2%	2.5%	7.6%	15.3%	—

model to choose. When shown drawings with no orbits, the first graders did not know which one to choose, and the third and sixth graders chose the acentric model. The results of the selection are shown in Table 10.

The explanations given by the children regarding their choice varied depending on their grade, but did not reference the information they received from their school curriculum. This indicates that their preferences for a model were based on their ideas of what heavenly body or what planet must be in the center of the solar system. Therefore, 76.9% of first graders did not know why the drawing they selected represented the solar system, and only 23% thought that the sun was in the center. These percentages improved in later school years; 61.5% of third graders could not provide an explanation for the model they chose, and 30.7% said that they chose a representation because the sun was located in the center, while 30.7% said they chose a representation because the earth must be located in the center. Finally, sixth graders explain their selections as follows: 46.1% do not provide an explanation and 53.8% says it is because the sun is at the center of the solar system.

5.2. Second Section

5.2.1. Solar System Models

The analysis presented in the first section reports some of the elements that students consider as part of the solar system. These elements only form an approximation of the children's ideas of the solar system, and a more detailed analysis that explains the integration of these elements and allows us to generate models to explain children's representations of the solar system is necessary. Therefore, Euclidean distance-based cluster analysis was used to group the students' answers. As previously mentioned, students' answers were grouped into categories and category components. To each category component a value was assigned (see Table 4) and analysis was performed with these values. The objective of this analysis was to identify different groups of responses and to infer or identify from them different solar system models used by the students. We also attempted to analyze whether the models built correlated with the school years of the interviewees. Six groups were identified by cluster analysis; each group corresponds to a model. Figure 1 shows the average of the responses identified for each group or model. For example: for model 2, the category *Composition* has a value of 2 for the category components, while for model 6 the value is 4. Similarly, the category *Representation with balls* has a value of 2 in model 3 and a value of 6 in model 5. Figure 1 shows each category and the value that corresponds to each of its components. Models will be described in this section, as well as the variables that determine their composition and that reference to the categories presented in the first section. The models are presented in order of increasing complexity. To determine the level of complexity, the models were organized in ascending order by two independent judges, achieving an agreement level of 90%. Along with a description of

Table 9. Percentage response per grade on the moon's and Planets' movements

	No movement		Up and down		Rotation		Revolution		Both	
Grade	**Moon**	**Planet**	**Moon**	**Planet**	**Moon**	**Planet**	**Moon**	**Planet**	**Moon**	**Planet**
First	38.4%	92.3%	61.5%	—	—	—	—	7.6%	—	—
Third	61.5%	7.6%	23%	15.3%	7.6%	15.3%	7.6%	—	—	—
Sixth	38.4%	38.4%	7.6%	7.6%	15.3%	7.6%	30.7%	23%	7.6%	23%
Total	46.1%	46.1%	30.7%	7.6%	7.6%	7.6%	12.8%	10.2%	2.5%	7.6%

Table 10. Percentage of respondents selecting a drawing representing the solar system with orbits and without orbits

	I don't know		Heliocentric		Acentric		Geocentric	
Grade	**Orbit**	**Without orbit**	**Orbit**	**Without orbit**	**Orbit**	**Without orbit**	**Orbit**	**Without orbit**
First	46.1%	23%	7.6%	15.3%	30.7%	15.3%	15.3%	—
Third	7.6%	15.3%	15.3%	30.7%	15.3%	46.1%	61.5%	7.6%
Sixth	—	—	46.1%	30.7%	38.4%	46.1%	15.3%	23%
Total	17.9%	28.2%	23%	25.6%	28.2%	35.8%	30.7%	10.2%

the components of the model, a graphic representation of the model is included. These representations show the organization of the elements and the movements that the children described.

5.2.2. Model 1

The participants using this model (28.2%) cannot define what the solar system is and cannot make a representation of it with balls. This model only includes the sun, the moon and the earth. The Moon and the sun are both located far away from the earth and the elements are static; they are not given any movement. The participants using this model were unable to choose a drawing from the ones presented to them, or to analyze their ideas of the structure of the solar system. Figure 2 shows the organization corresponding to this model.

5.2.3. Model 2

The participants using this model (7.69%) are unable to describe what the solar system is. The representations these participants made with balls include the sun, located at one end, and the moon and the earth. The distance from the sun and the moon to the earth is defined as close in some cases and far in others.

In this model, the earth does not have any movement; it is static. Unlike in the previous models, the sun and the moon move up and down (Figure 3). This is related to the children's perception of the movements of the sun and moon during the day and the night.

Drawings corresponding to the geocentric and acentric models are selected when the drawings have orbits. However, when the drawings do not have orbits, the students cannot choose a drawing. This appears to be related to the solar system representations that the children see in textbooks. However, the selection between a geocentric and an acentric model tells us that the children have a representation of the earth as a central element.

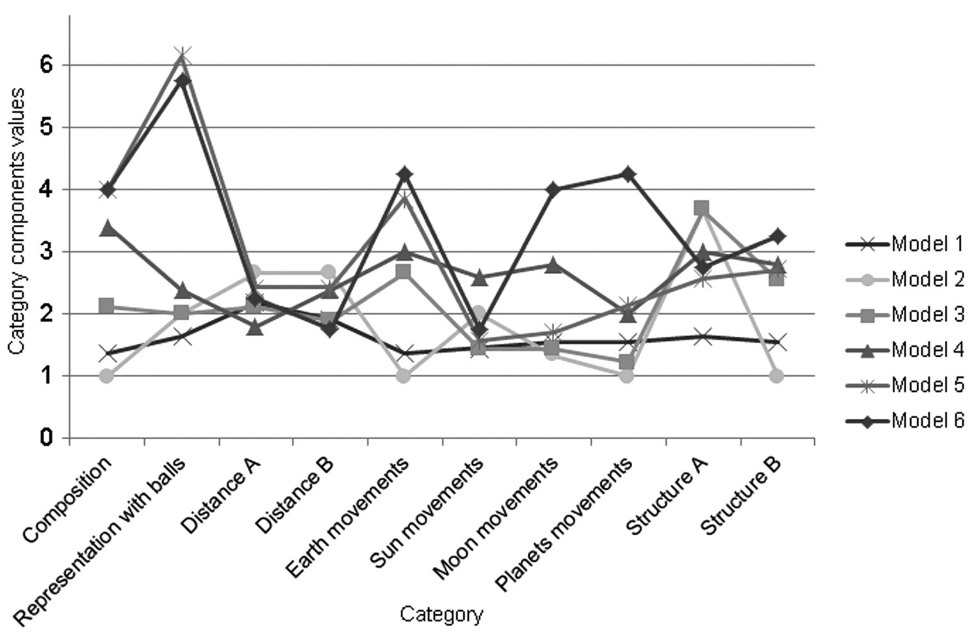

Figure 1. Average of responses grouped by model using cluster analysis

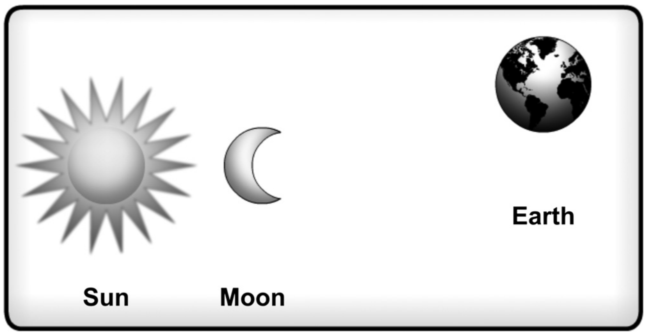

Figure 2. Model 1 includes the sun, the earth, and the moon without any movement

5.2.4. Model 3

The participants using this model (23.07%), see Figure 4, think that the solar system contains only the sun, the moon and the earth, and no other elements are taken into account. The representations with balls made by these participants include the sun, the earth to one side of the sun, and the moon on the other side of the sun. In this case, the sun and the moon are both located far from the earth.

This model is more complex because it adds rotational movement to the earth and describes the earth as moving up and down, which is how the children explain day and night. The moon and the sun may also have up and down movements, which the students provide as two possible explanations for day and night.

When the presented drawing has orbits, the students choose the acentric or the geocentric model as a representation of the solar system. However, when the drawing does not have orbits, the students select the heliocentric or acentric model.

5.2.5. Model 4

Participants using this model, see Figure 5, build a representation with balls that includes the sun, the Moon, and the earth, and in some cases one more ball is added, representing a planet. The distance between the sun and the moon with respect to the earth is not clear; sometimes it is close and sometimes it is far, but no reference is made to any type of movement. The percentage of students using this model is 12.8%

The earth has rotational movement about its own axis in this model, and the sun rotates about its own axis or moves up and down. The moon has rotational movement and the planets move up and down. The selection of a drawing with orbits corresponds to the acentric model, as does the selection of a drawing without orbits. The drawing selected may be related to elements of the solar system that they know exist from school, such as the images in textbooks representing the solar system and orbits.

5.2.6. Model 5

In this model (see Figure 6), the solar system includes the sun, the moon, the earth and different planets (17.9% of students choose this model) and includes other elements such as stars and asteroids.

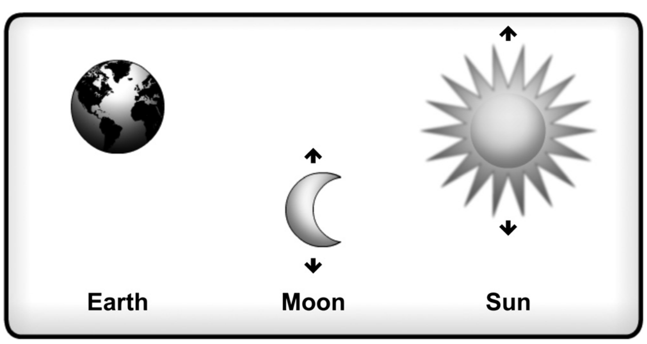

Figure 3. Model 2 includes the earth, the moon, and the sun; some movements are described

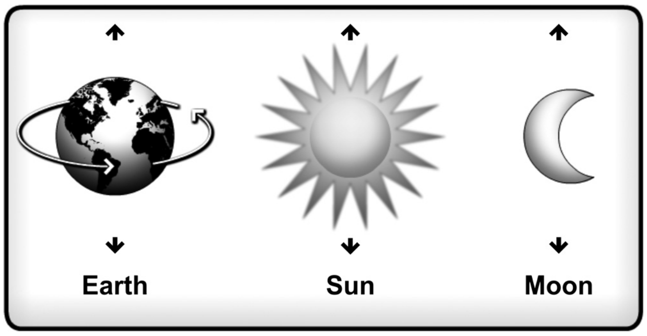

Figure 4. Model 3 includes the same elements, but the earth has two types of movement

The representation with balls constructed by participants using this model places the sun at one end and all the planets located in a straight line from the sun. The distances reported between the sun, the moon, and the earth vary; the distances are sometimes reported as far and sometimes as close.

In this model, the earth rotates around the sun. The sun and the moon do not move, or they move up and down, just like the planets. The drawings selected correspond to the heliocentric or acentric systems, both for drawings that include orbits and for those that do not.

5.2.7. Model 6

For the participants using this model (10.2%), see Figure 7, the solar system includes the sun, the earth, the moon, the planets, and some other elements such as stars or asteroids. This definition is verified by the representation created with balls. The sun is included and located at one end, and from it the planets are distributed either on a straight line or placed on a circular orbit around the sun. In all cases, the model includes the earth and the moon as part of the system. The moon and the sun are both located far away from the earth.

The earth has only one type of movement: revolution. The moon follows the earth in its movement around the sun and it moves up and down. Finally, the planets, such as the earth, revolve around the sun.

The selection of a drawing with orbits and a drawing without orbits correspond to the acentric model. However, in most cases, the students provided no explanation for this selection.

The complexity observed in the different models lies not only in a greater amount of elements, but in the dynamics, interactions and distribution of these elements. Figure 8 shows the percentages of students using each one of the models presented previously. The highest percentage of students use model 1 (28.2%), although first graders use this model the most (69.2%). In second place is model number 3 (23%), which is primarily used by third graders (53.8%), and in last place is model number 5 (17.9%), which sixth graders use the most.

The first grade groups only use the first three models, whereas there is more variety in the models used by third graders. The oldest children, the sixth graders, do not resort to simpler models, and they concentrate on

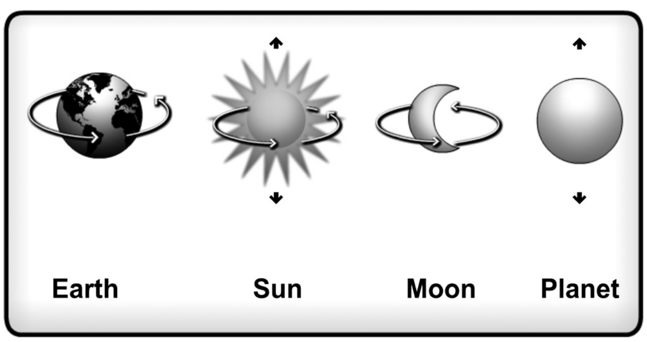

Figure 5. Model number 4 includes more types of movements and adds planets as elements

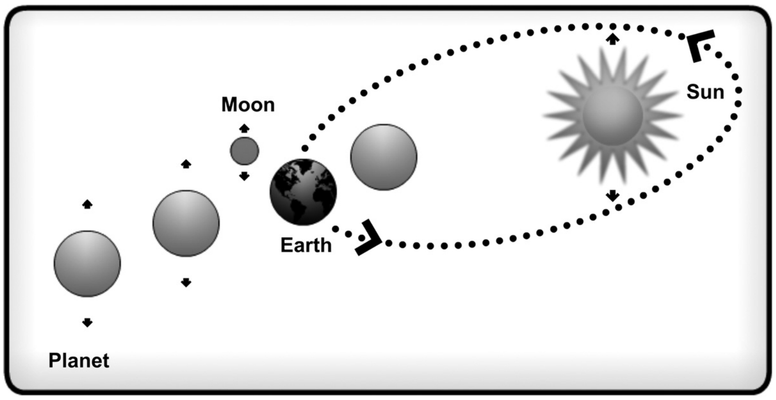

Figure 6. Model 5 is a solar system with a configuration in procession, which also attributes movements to the planets

the models that we considered more elaborate. Notably, the students are confused regarding the types of movements of the different elements, although they can mention that the earth revolves around the sun and that the moon follows the earth. Students thought that the sun had up and down movement (model 6), possibly to explain the day and night cycle. This finding shows the double construction the students make of the solar system and that the two constructions have two sources: one source is the information in their books and the information provided by their teachers, and the other source is their everyday observations. A more detailed analysis of the types of explanations children provide for different phenomena would be interesting. For example, children explain the day and night cycle through the models they create (Vosniadou, Skopeliti, and Ikospentaki 2004).

6. CONCLUSIONS

The results of this study indicate that children's ideas of the solar system appear to change as they are exposed to different information in school. In general, the data show an increase in the children's knowledge of the solar system as they age. This can be seen from the incorporation of planets and comets, and other aspects such as size and the recognition of the movements of elements. The youngest children studied (first graders) are able to identify fewer elements and build less complex models with only the sun, the moon, and the earth. The oldest children (sixth grade) make more complex models; they add more elements to their models and most of them select a heliocentric model.

The students in this study made a variety of models to represent the solar system, including the main components (sun, earth, moon, and planets), their arrangement or structure in space, and their movements. This diversity of models shows that the students were not simply reproducing the diagrams in their textbooks

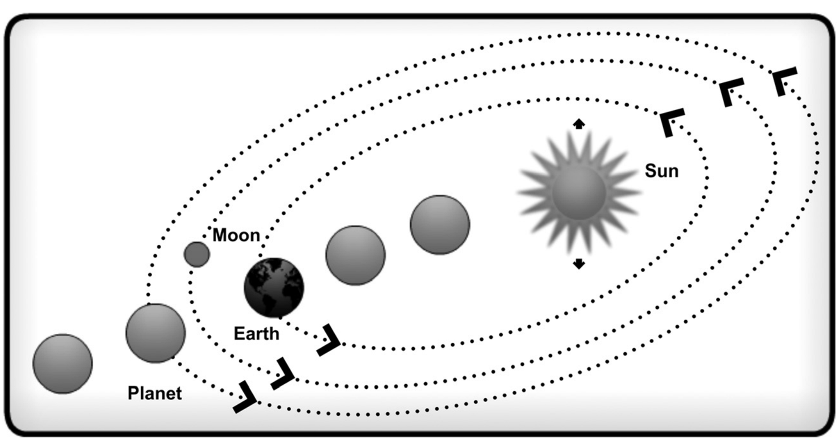

Figure 7. Model 6 represents a more complex system. It integrates more elements and most of these elements have movement

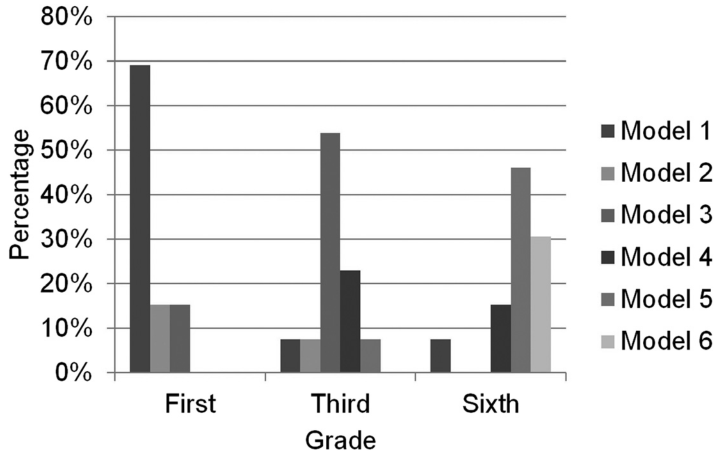

Figure 8. Percentage of model users by school year

or the diagrams they have had access to in their environment, although the oldest children's models are gradually approaching those diagrams in complexity. Movements up and down are still present in the majority of the children's explanations for their models. In studies such as Sharp and Kuerbis's (2005), similar results are presented: children use a variety of models, with a gradation of complexity. Based on our results, third graders build the widest variety of models. While most astronomy topics are introduced formally in fourth grade, children in lower grades develop a variety of astronomical models. This can be explained, as mentioned by Vosniadou and Brewer (1992, 1994), by the idea that children are creating synthetic models. In other words, they are trying to relate the information they receive in school to the information they had previously constructed through observation.

The models constructed do not specifically correlate to school years. Their use is distributed throughout the different grades in elementary school (Figure 8). Thus, it could be said that first graders know fewer components of the solar system, and their incorporation of everyday observations, such as the rising and setting of the sun, is more obvious. The knowledge of sixth graders is more closely related to what they learn in school, yet explanations about the movement of the sun, the moon, and planets observed in the first models that children build persist in later models. Although the youngest children studied have not received formal instruction in astronomy, they do have information (perhaps generated by their cultural or educational context) that allows them to build a representation of the solar system.

The representation children use to explain day and night, with the up and down movements of the sun and the moon, persists in all the models seen in this study, regardless of the incorporation of new elements (planets), and regardless of the assignment of movements, such as rotation and revolution. This finding contrasts with other studies (Sharp and Kuerbis 2005) but agrees with the conclusion of Vosniadou (2010); external representations, such as the solar system diagrams presented to children in school, are interpreted alongside previously learned elements or internal representations that are based on observations.

In models 1 through 4, which generally correspond to the youngest students, the moon, the sun and the earth do not have a structural association, and it is not until models 5 and 6 that the moon appears associated with the earth, although the moon's movement continues to be up and down. This is an indication of the difficulty that children have in establishing correspondence relations between the movements of objects and their relation with a third element, such as the sun. When students observe heavenly bodies, they cannot establish the proximity or remoteness of the moon or the sun with respect to the earth. Though sixth graders appear to introduce this association more frequently, further research is necessary to discover whether this is an association determined only in diagrams, or if it is indeed a construction of a sun-earth-moon dynamic process.

Children behave differently when they select a representation of the solar system that has orbits and when they select one that does not have orbits. Although there appears to be no distinction between the selection of the heliocentric and the acentric representations, when the drawing has orbits the selection of the geocentric diagram increases. Unfortunately, the interviews did not allow us to analyze this situation. This line of research would be interesting to follow.

External representations such as drawings, diagrams or scale models (such as those that the children constructed using balls) support the development of conceptual constructions such as the models shown in this study. These external representations can also support the construction of arguments (Schoultz, Säljo, and Wyndhamn 2001), but although students were asked to provide further explanations for their actions and the selections they made, such arguments were not abundant in this study. Constructions such as the models presented here, while supported by external representations, require other factors such as the children's development and their ability to interpret external representations, at least on a structural level (Schnotz and Bannert 2003). The representations of the solar system that are available to elementary school children do not provide much more than the composition of the system, with no support for the development of its dynamics; they do not provide enough elements to establish new constructions and reasoning.

The solar system representations and models that children can develop are, of course, limited by factors such as the lack of a perceivable phenomenological process, and the necessity of complex abstraction that implies size, location in space, and complex and related movements. Therefore, the students' only referents and the constructions they make are limited to the descriptions and diagrams presented in educational material (illustrations, diagrams, and scale models) that provide a limited and static representation of the solar system. It is, therefore, not surprising that children create static representations of the solar system in which the sizes and movements of elements and the distances between elements are unclear.

The results of this study also show that, regardless of the external representations presented, the youngest children studied do not incorporate these representations into their own representations, as shown by models 1 through 4, which include no planets, specific locations, or trajectories.

The solar system is a complex topic presented in basic education. It is necessary to reconsider the expected learning of elementary school children, as well as to investigate students' conceptions about the different components of the solar system and the representations that students can create when supported by other representation systems such as computer simulations.

Appendix: Topics related to astronomy in new curriculum

2009 Curriculum	Natural sciences	Geography
	Second grade Description of the apparent movement of the sun. *Third grade* The phases of the moon. Measuring time based on the phases of the moon. *Fourth grade* Eclipse formations. Day and night sequence from the movements of the earth and the moon. Change in the explanations of the earth's movements with respect to the sun throughout history. *Fifth grade* The solar system: The planets' characteristics and movements. Location of the earth in the solar system. Space exploration. Mars. *Sixth grade* The Universe's basic components and its characteristics. Contribution of technology and scientific procedures to our knowledge of the Universe.	*Fifth grade* Shape and inclination of the earth, its rotations and revolutions, their connection with the seasons.

References

Afonso López, R., Bazo González, C., López Hernández, M., Macau Fabrega, M. D., and Rodríguez Palmero, M. L. 1995, "Una aproximación a las representaciones del alumnado sobre el universo," *Enseñanza de las Ciencias*, 13, 327.

Baxter, J. 1989, "Children's Understanding of Familiar Astronomical Events," *International Journal of Science Education*, 11, 502.

Baxter, J. 1995, "Children's understanding of astronomy and the earth sciences," in *Learning Science in the Schools: Research Reforming Practice*, ed. S. Glynn and R. Duit, Hillsdale, N. J: Erlbaum, 155.

Calderón, C. E., Flores, C. F., Gallegos, C. L., and Palafox, P. G. 2006, "Ideas Infantiles Sobre el Sistema Solar," *Ethos Educativo*, 35, 41.

Candela, A. 1991, "Argumentación y conocimiento científico escolar," *Infancia y Aprendizaje*, 55, 13.

Candela, A. 2001, "Earthly Talk," *Human Development*, 44, 119.

De Manuel, B. 1995, "¿Por qué hay veranos e inviernos? Representaciones de estudiantes (12–14) y de futuros maestros sobre algunos aspectos del modelo Sol-Tierra," *Enseñanza de las Ciencias*, 13, 227.

Kikas, E. 1998, "The Impact of Teaching on Students' Definitions and Explanations of Astronomical Phenomena," *Learning and Instruction*, 8, 439.

Klein, A. 1982, "Children's concepts of the earth and the sun: A cross cultural study," *Science Education*, 66(1), 95.

Kuhn, T. S. 1957, *The Copernican revolution: Planetary astronomy in the development of Western thought*, Cambridge, Massachusetts: Harvard University Press.

Lelliot, A., and Rollnick, M. 2010, "Big Ideas: A Review of Astronomy Education Research 1974–2008," *International Journal of Science Education*, 32, 1771.

Mali, G. B., and Howe, A. 1979, "Development of earth and gravity concepts among Nepali children," *Science Education*, 63, 685.

National Curriculum in England. New Zealand Curriculum. Resource document. http://nzcurriculum.tki.org.nz/Curriculum-documents/The-New-Zealand-Curriculum/Learning-areas/Science

Nussbaum, J. 1979, "Children's Conceptions of the Earth as a Cosmic Body: A Cross Age Study," *Science Education*, 63, 83.

Piaget, J. 1929/1984, *La Representación del mundo en el niño*, Madrid: Morata.

Samarapungavan, A., Vosniadou, S., and Brewer, W. F. 1996, "Mental Models of the Earth Sun and Moon: Indian Children's Cosmologies," *Cognitive Development*, 11, 491.

Secretaría de Educación Pública. 1993, *Plan y Programa de estudios*, México: SEP.

Secretaría de Educación Pública. 2009, *Plan y Programa de estudios*, México: SEP.

Schoultz, J., Säljo, R., and Wyndhamn, J. 2001, "Heavenly Talk: Discourse, Artifacts and Children's Understanding of Elementary Astronomy," *Human Development*, 44, 103.

Schnotz, W., and Bannert, M. 2003, "Construction and Interference in Learning from Multiple Representations," *Learning and Instruction*, 13, 141.

Sharp, J. 1995, "Children's Astronomy: Implications for Curriculum Developments at Key Stage 1 and the Future of Infant Science in England and Wales," *International Journal of Early Years Education*, 3, 17.

Sharp, J. 1996, “Children’s Astronomical Beliefs: A Preliminary Study of Year 6 Children in South-West England,” *International Journal of Science Education*, 18, 685.

Sharp, J., and Kuerbis, P. 2005, “Children’s Ideas About the Solar System and the Chaos in Learning Science,” *International Journal of Science Education*, 90, 124.

Sharp, J., and Sharp, J. 2007, “Beyond Shape and Gravity: Children’s Ideas About the Earth in Space Reconsidered,” *Research Papers in Education*, 22, 363.

Sneider, C., and Pulos, S. 1983, “Children’s Cosmographies: Understanding the Earth’s Shape and Gravity,” *Science Education*, 67, 265.

Valanides, N., Gritsi, F., Kampeza, M., and Ravanis, K. 2000, “Changing Pre-School Children’s Conceptions of the Day/Night Cycle,” *International Journal of Early Years Education*, 8, 27.

Vosniadou, S. 1991, “Designing Curricula for Conceptual Restructuring: Lessons From the Study of Knowledge Acquisition in Astronomy,” *Journal of Curriculum Studies*, 23, 219.

Vosniadou, S. 1994a, “Universal and Culture-Specific Properties of Children’s Mental Models of the earth,” *in Mapping the mind: Domain specificity in cognition and culture*, ed. L. A. Hirschfeld and S. A. Gelman, New York: Cambridge University Press, 412.

Vosniadou, S. 1994b, “Capturing and Modeling the Process of Conceptual Change,” *Learning and Instruction*, 4, 45.

Vosniadou, S. 2010, “Instructional Considerations in the Use of External Representations,” *in Use of Representations in Reasoning and Problem Solving*, ed. L. Verschaffel, E. De Corte, T. de Jong, and J. Elen, London, UK: Routlege, 36.

Vosniadou, S., and Brewer, W. F. 1987, “Theories of Knowledge Restructuring in Development,” *Review of Educational Research*, 57, 51.

Vosniadou, S., and Brewer, W. F. 1992, “Mental Models of the Earth. A Study of Conceptual Change in Childhood,” *Cognitive Psychology*, 24, 535.

Vosniadou, S., and Brewer, W. F. 1994, “Mental Models of the Day/Night Cycle,” *Cognitive Science*, 18, 123.

Vosniadou, S., Skopeliti, I., and Ikospentaki, K. 2004, “Modes of Knowing and Ways of Reasoning in Elementary Astronomy,” *Cognitive Development*, 19, 203.

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