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Modeling the Round Earth through Diagrams

by **Shamin Padalkar**

Homi Bhabha Centre for Science Education, Tata Institute of Fundamental Research, India

Jayashree Ramadas

Homi Bhabha Centre for Science Education, Tata Institute of Fundamental Research, India

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Abstract

Earlier studies have found that students, including adults, have problems understanding the scientifically accepted model of the Sun-Earth-Moon system and explaining day-to-day astronomical phenomena based on it. We have been examining such problems in the context of recent research on visual-spatial reasoning. Working with middle school students in India, we have developed a pedagogical sequence to build the mental model of the Earth and tried it in three schools for socially and educationally disadvantaged students. This pedagogy was developed on the basis of (1) a reading of current research in imagery and visual-spatial reasoning and (2) students' difficulties identified during the course of pretests and interviews. Visual-spatial tools such as concrete (physical) models, gestures, and diagrams are used extensively in the teaching sequence. The building of a mental model is continually integrated with drawing inferences to understand and explain everyday phenomena. The focus of this article is inferences drawn with diagrams.

1. UNDERLYING THEORETICAL FRAMEWORK

A sound understanding of basic astronomical concepts calls for the building up of visual-spatial mental models of the Earth (and other celestial objects) and explaining everyday phenomena with reasoning based on these models. Such explanations of phenomena, such as the day-night cycle, seasons, and phases of the Moon, are fairly complex, requiring coordination of views from several points on Earth and from outside the Earth. Our interest is in studying such models and reasoning processes in middle school students.

Research in astronomy education has addressed students' understanding of concepts such as the shape of Earth and its position in the universe (Albanese, Danhoni Neves, & Vicentini 1997; Baxter 1991). Research also has identified early intuitive models consistent with local experience, such as flat Earth (Vosniadou & Brewer 1994), and models that are influenced by cultural cosmologies, such as an Earth

floating in the sea (Samarapungavan, Vosniadou, & Brewer 1996). When exposed to scientific information that the Earth is round, students typically form a synthetic model, such as an ellipsoidal Earth or hollow Earth, or a dual-Earth model that includes a flat Earth and another spherical Earth in the sky (Vosniadou & Brewer 1994). By Grade 7, most students in urban literate environments have learned that we live on a round Earth that is suspended in space. Even so, it is rare that students are able to use this model in interpreting and reasoning about everyday phenomena.

Mental models in elementary astronomy are of a visual-spatial kind. The reasoning based on these models requires abilities such as spatial visualization (the ability to imagine spatial forms and movements, including translation and rotations) and spatial orientation (perspective taking) (Hegarty & Waller 2004). In an earlier study on understanding phases of the Moon, we found that students of architecture and design who were equipped with visualization and drawing tools were able to come up with correct explanations faster and more accurately than were physics postgraduates (Padalkar & Subramaniam 2007).

It is important to distinguish between reasoning used in the process of scientific discovery and that needed during the process of learning. In scientific discovery, a model is built on the basis of observational data, along with reasoning that might be inductive, deductive, or abductive in nature. Model-based reasoning is an active area of research in science studies. The case of school learning is different. A rigorous evidence-based argument for the roundness of the Earth, requiring coordination of observations separated spatially across the globe and temporally over days and months, is far too complex for, and perhaps not accessible to, school-age students. Besides, such an argument is superfluous when most students at this level already "know" that the Earth is round and that it rotates about its axis. What is possible and meaningful for students might be a pedagogical argument developed through real-life experience and visual-spatial imagination, and reinforced through tools like concrete models, gestures, and diagrams.

2. USE OF CONCRETE MODELS, GESTURES, AND DIAGRAMS TOWARD BUILDING MENTAL MODELS

In this article, we present some observations from the first part of our study in elementary astronomy. This part concerns middle school students' understanding of the Earth as a round, unsupported object in space, rotating about its axis and attracting objects toward itself because of gravity. Of these properties, our focus here is on the roundness (sphericity) of the Earth, with the other properties dealt with peripherally at this point. For a previous effort to develop a pedagogy for the Earth, see Vijapurkar (2007).

Concrete models are often used in the initial stages of instruction in elementary astronomy. In going from qualitative descriptions to more rigorous reasoning and inference, one makes increasing use of schematic diagrams. The link between the concrete model and the diagram, however, must be maintained for one to keep testing the diagrammatic inferences against the physical situation. We found gestures to be particularly useful for this purpose.

A frequently used sequence in our pedagogy has been concrete model (or activity)-gestures-diagrams, albeit with many variations on this basic theme. Thus, typically, a subconcept—for example, roundness, horizon, or size—was introduced through concrete experiences involving activities or concrete models (or sometimes gestures followed by concrete models). The aim then was to guide students from these concrete experiences toward abstract diagrams through the intermediary use of gestures. This strategy was based on the premise that spatial reasoning is facilitated by kinesthetic experience (Tversky 2005; Klatzky & Loomis 1998). We expected that once the diagrammatic representation made sense to the students, they

would be able to draw inferences on the basis of these diagrams. We conjecture that gestures might be more abstract than concrete models, but they might be less abstract and more intuitive than diagrams. Gestures have some specific advantages over diagrams in being dynamic, three dimensional, and fluid. It has to be noted, however, that in everyday conversation, we use innumerable subtle gestures that continually fill the gap between what we speak or draw, and what we mean. It would be difficult to note all these gestures. First of all, they are so much part of the language (or the activity) that they may be used almost imperceptibly. Second, gestures may not have any meaning independent of the language or activity that they support. Third, well-developed conventions to note gestures may not exist. Adequate treatment of gestures would require a separate presentation giving due consideration to the dynamic and fluid nature of gestures. In this article, we focus on diagrams, with only brief descriptions of the gestures.

In dealing with complex visual-spatial models of the kind used in elementary astronomy, one might use drawings to reduce the working memory load while carrying out spatial visualization and spatial orientation tasks. Drawings enable us to organize information and exploit generalizations. By providing workable mental models of actual or theoretical worlds, drawings reduce the complexity of reasoning (Tversky 2005). On the other hand, if drawings are ambiguous, contain extra information, or display unfamiliar conventions, students may misinterpret them and develop alternative conceptions (Mishra 1999).

Drawings have a major advantage over gestures and body movements in that they are permanent over space and time. Schematic diagrams have the further strength of analysis and abstraction, so they can be used as tools for an extended process of reasoning and inference. Two major limitations of diagrams in the astronomy context are that they are flat and static. Thus, even after schematization into diagrams, we continued to use gestures, in combination with diagrams, to make explicit the three-dimensional nature of the celestial objects, particularly the Earth. Later, in developing further the concept of rotation, we took into account the fact that static drawings have some inherent limitation for conveying motion. Motion is better internalized through concrete models, gestures, and body motion.

In the low-resource environment that prevails in these schools, concrete models, gestures, and diagrams were the best means for understanding the roundness of the Earth and deriving its consequences. We present the diagrams and some of the questions that we posed during our intervention, which required students to draw conclusions based on their own diagrams.

3. CONTEXT OF THE STUDY

The teaching was carried out in three classes of Grade 7 students in three different schools. Two are rural schools near Kolhapur, a small town, and the third is in a slum area of Mumbai. All three schools are in the state of Maharashtra in India. One of the rural schools is a local school in a farming village, and the other is a residential school in the same region that serves children from nomadic tribes. There was a total of 64 students in the three classes, 20 girls and 44 boys (see Table 1).

Table 1. Number of Students				
	Tribal	Rural	Urban	Total
Girls	4	12	4	20
Boys	13	21	10	44
Total	17	33	14	64

Small class size (compared with the lower grades) is indicative of a high dropout rate in disadvantaged populations, and the numbers show a clear gender bias regarding access to schooling. In the case of the urban sample, the class size was larger, but only a few students opted for this program. These students have little or no educational background at home. Almost all are first-generation learners. The tribal, rural, and urban students belong to a fairly low socioeconomic class. The local language, Marathi, is also their language of instruction, although the mother tongue of the tribal and rural students differs significantly from standard Marathi.

Prior to the teaching, a set of pretest questionnaires was administered to a sample of Grade 4 (end of primary school) and Grade 7 (end of middle school) students in these two rural schools. The questionnaires probed (1) the students' everyday observations, (2) their knowledge of textbook content, (3) cultural information that is part of indigenous knowledge, and (4) their explanations for everyday phenomena. The tests were followed by interviews with a small subset of students. The results (to be described in Padalkar and Ramadas, forthcoming) generally showed scanty observations, a fair knowledge of textbook content (though without significant role for reasoning), a variety of alternative conceptions, and cultural knowledge that was not integrated with school learning. On the basis of these results, we began our intervention with the students who were about to complete Grade 7 (see Table 1).

4. TEACHING CYCLE: CONTENT AND METHODOLOGY

The intervention took place through activities, classroom discussion, and Socratic questioning, which was conducted by the first author (Shamin). The aim of the first cycle of intervention was to build a robust mental model of the round, rotating Earth, unsupported in space and attracting objects toward it via "gravity." Further, students were expected to reason about some phenomena that could be explained purely on the basis of the above mental model. Apart from the main teaching sequence, which is described in Section 6, a few supporting activities—such as star gazing and a session on light and shadows—were also conducted. Collaborative learning situations had been planned, but it turned out that in the rural cultural context, continual interaction between students occurred quite naturally without special effort by the instructor (see Section 7). The total intervention was completed in around 10 hours over 7 days. The classroom interaction was videotaped.

The pedagogy, which involved both individual and group activities, can be summarized as follows:

- Night-sky observations to estimate and measure directions and elevations of stars using the hand estimation method and to keep notes of positions of the stars. Hand and body gestures were also used to mimic the shape of the constellations (details are available from the first author).
- Making an astrolabe to measure elevations of stars.
- Observation and experimentation, particularly involving light.
- Reading of interactive text material based on the history of the discovery of the shape of the Earth.
- Concrete models and photographs to help transform between egocentric (intrinsic) representation and allocentric (extrinsic) representation.
- Mimicking both structure and motion (apparent and absolute motion of celestial objects) through hand gestures and body movements, based on previous findings that the kinesthetic sense is basic to our understanding of space, including spatial properties and spatial operations (Tversky 2005).
- Diagrams from various possible viewpoints to help make the representations increasingly extrinsic, schematized, and communicable.

5. CONVENTIONAL DIAGRAMS OF THE ROUND EARTH

A common diagrammatic representation of the Earth is as a circle with a tilted axis. To indicate the sphericity of the Earth, the equator is sometimes drawn as an ellipse or a curve, while the axis of rotation is shown as before (Figure 2). Both of these diagrams create some problems. The first diagram reinforces the common intuitive notion of a flat, disk-like Earth. (Eight out of a total of 42 tribal and rural students in Grade 7 thought that the Earth is flat; none of the urban students thought so.) The second diagram is incorrect because if the axis of rotation is on the plane of the paper as indicated, the equator should project as a straight line. By showing it as a curve or an ellipse, two different points of view are confused.

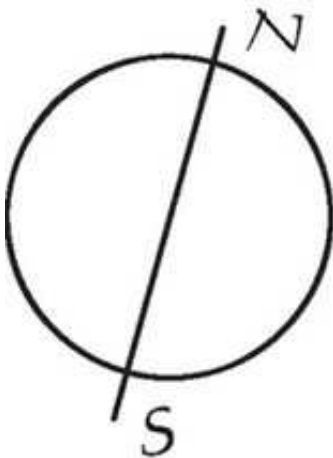


Figure 1. Is This Earth Flat?

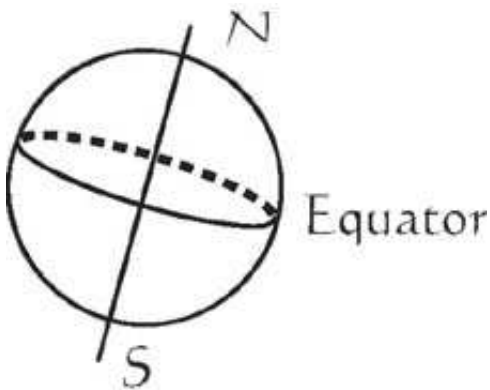


Figure 2. Mixed Perspectives in Textbook Diagram

Explicit understanding of dimensions and mapping of three dimensions on two dimensions is a prerequisite for drawing any three-dimensional object in two dimensions. Because this skill is neither taught in schools, nor are the students (particularly in low-resource environments) exposed to such drawings in print or otherwise, students have difficulty in interpreting, for example, a circle on the paper as the spherical Earth. The significant number of flat-Earth responses from rural and tribal Grade 7 students is consistent with this view. When a satellite photograph of the Earth was shown and students were asked to describe the difference between this photograph and the actual Earth, students referred to many aspects, such as size, presence of ocean, and people (and so on) on the Earth. The response that the actual Earth is a sphere whereas the photo is flat came after many hints (e.g., What is the difference between any object and its photograph?).

6. USING CONCRETE MODELS, GESTURES, AND DIAGRAMS TO TEACH ROUNDNESS OF THE EARTH

6.1 Representation of the Earth

Students were exposed to the globe and given ample opportunity to handle it to emphasize the three-dimensional nature of the Earth. The concept of axis of rotation was introduced through gestures—by rotating different objects, body parts, and the whole body around different possible axes—and students were asked to depict such motions by drawing. It was conveyed through this exercise that not the object itself but the motion of the object defines the axis. While rotating around themselves, students experienced how the view changes as they rotate. Appearance and disappearance of landmarks such as the door and the blackboard were linked to the rising and setting of the Sun and the stars during the day-night cycle. One friend was designated as the Sun to explain day and night in particular.

To emphasize the spherical nature of the Earth, we encouraged students to draw it from different perspectives, initially by looking at the globe from different perspectives. Because a sphere is a perfectly symmetrical shape in three dimensions, the projections are all circles—but the axis, poles, and equator could be used to characterize the different views, along with a curved arrow around the axis to show the direction of rotation.

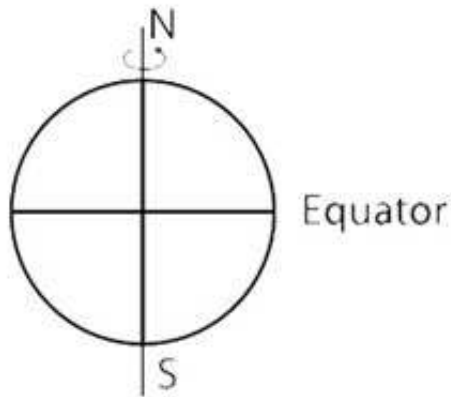


Figure 3. Side View of the Earth with Vertical Axis and Equator as a Horizontal Line (Note: A tilted axis has no significance if the ecliptic or orbit is not shown.)

The significance of a variety of diagrams is that we use different views in different situations. For instance, to depict phases of the Moon, we use a top view, and to explain seasons, we use a side view with the axis tilted. Such variations are usually done casually without explicit instructions. Therefore, from the very beginning, we tried to make students familiar with different views and aware of the relation between them so that they could call on and use the appropriate views.

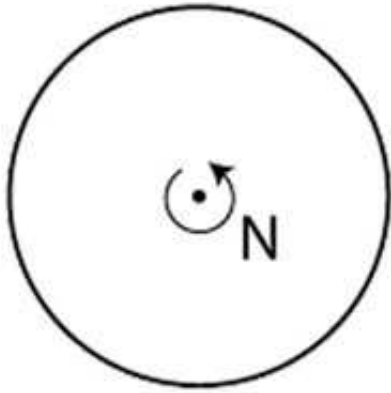


Figure 4. Top View of the Earth in Which the Axis is Shown as a Point

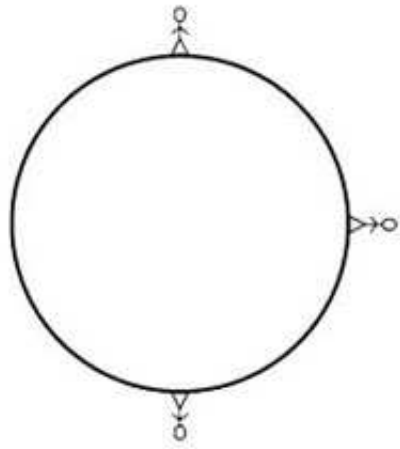
6.2 Interpretation of Up and Down

Students began by pasting toy human figures on various parts of the globe, and then, on a diagram, they drew stick figures on different points on the circumference (Figure 5a). This was followed by a discussion about why we in India do not fall off the Earth. Thus, roundness, which is a spatial property of the Earth, was integrated with gravity, a physical property. Students then indicated, using arrows, the up-down directions of each of the people shown standing on the Earth. This gave students a feel for the idea that up and down are not absolute, but vary over the surface of the Earth (Figure 5b).

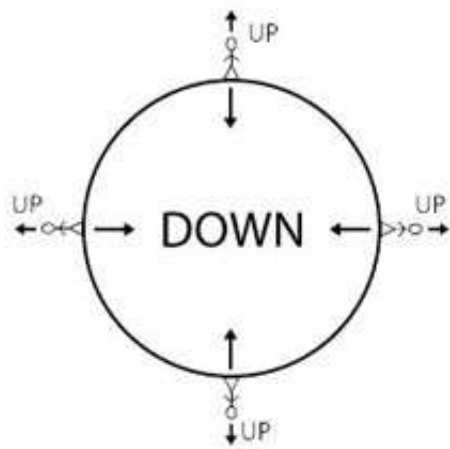
Students then were asked to determine up-down for a person in space. Through this question, it became clear that because up-down is defined with reference to the Earth, the Earth does not have an inherent up-down direction. In this way, we challenged a common misconception—that the Earth has an inherent up-down—that is probably created by conventional drawings of the Earth that show the North Pole toward the top of the paper (also matching the convention of maps in geography). We encouraged students to draw the Earth in different orientations to demonstrate that drawing the axis horizontal or the North Pole down is valid (Figure 6).

6.3 The Geosynchron

We then told the students that the axis of the Earth is aligned with the pole star, and north is defined as the direction toward the pole star (in a previous skygazing session, the students had observed the pole star, and they had been measuring its inclination every day along with that of other stars).



(a) Why don't we fall off the Earth?



(b) Up and down are not absolute

Figure 5. Up-Down on the Earth

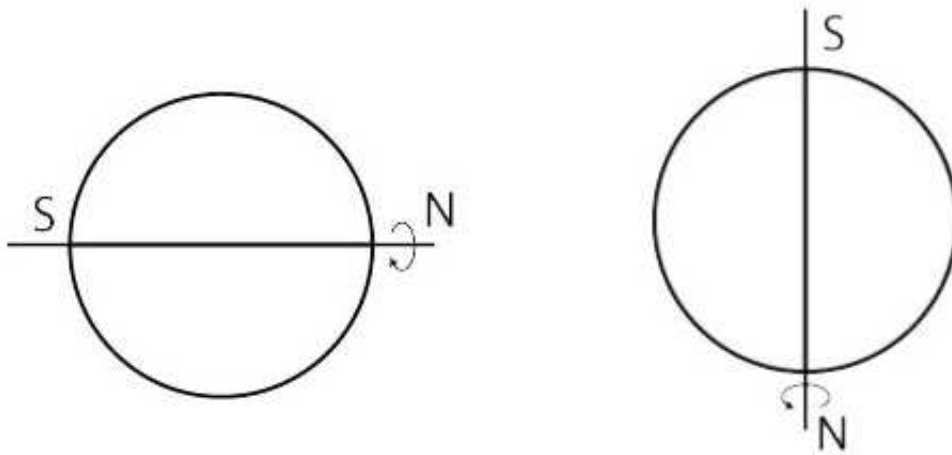


Figure 6. Does the Earth Have a Natural Up-Down?

The globe was hung on a stand in such a way that the axis of its rotation pointed toward the pole star. In other words, the axis of this globe was parallel to the axis of the Earth. This particular model is sometimes referred to as "rectified Earth," but we prefer the term "geosynchron" or *Samantar Prithvi* coined by an Indian nongovernmental organization (NGO) concerned with popularization of astronomy (Monteiro 2006). Many concepts and phenomena, such as day-night, directions, orientations, and shadows, can be demonstrated on the geosynchron and immediately correlated with the phenomena on the Earth. Most of the diagrams in this teaching sequence were used in coordination with parallel situations on the globe or the geosynchron.

6.4 Directions—Local and Global

First, all eight directions were drawn in the conventional way on the blackboard (Figure 7a). Next, a discussion of local directions, which had been initiated in the previous outdoor stargazing session, was continued indoors (Where is north? Which is the north end of the classroom? If you walk farther north, which places will you pass . . . in the district, state, and so on, until you get to the North Pole? Which places are toward a particular direction from some other place?). Gestures and body movements were used to determine all eight directions (which are given distinct names in Marathi).

The local directions were then redrawn on the blackboard, matching the directions in the classroom. The natural "straight ahead" direction determined by the classroom seating arrangement could be signified by "up" on the blackboard (Figure 7b).

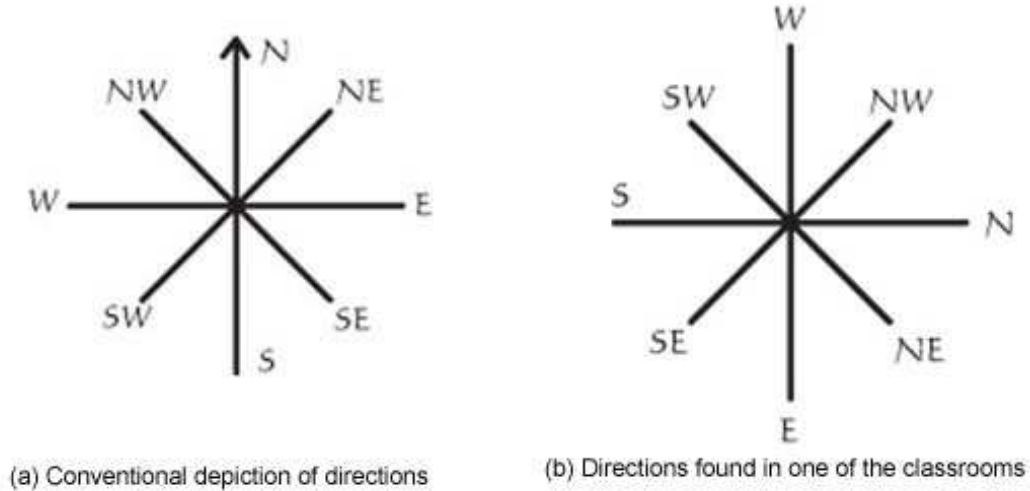


Figure 7. Directions

A concrete model of three orthogonal axes made up of three sticks was used to show the six major directions and give students a feel for three dimensions. Students know how a point on a paper can be identified by using two axes, X and Y. We introduced a third axis, Z, and showed that solid things such as the Earth, whose exact shape cannot be depicted on a piece of paper, are three dimensional. Similarly, space around us can be marked using two sides of each of these three axes: up and down, north and south, and east and west.

These directions were determined for a person on the globe. The concrete model of axes was used wherever necessary. It then became clear that directions are not absolute: they change as one's location on the Earth changes. Next, the students collaborated in constructing a diagram on the blackboard to depict all these directions at a few points on a circle representing the globe (Figure 8a). Here gestures served to emphasize directions going into and out of the blackboard. In one class, we tried curved arrows to show directions in and out of the board but found that students were confused by this convention. Using another view was found to be a better option (Figure 8b). In this way, like the up and down directions, all other directions were also shown to depend on one's location on the Earth.

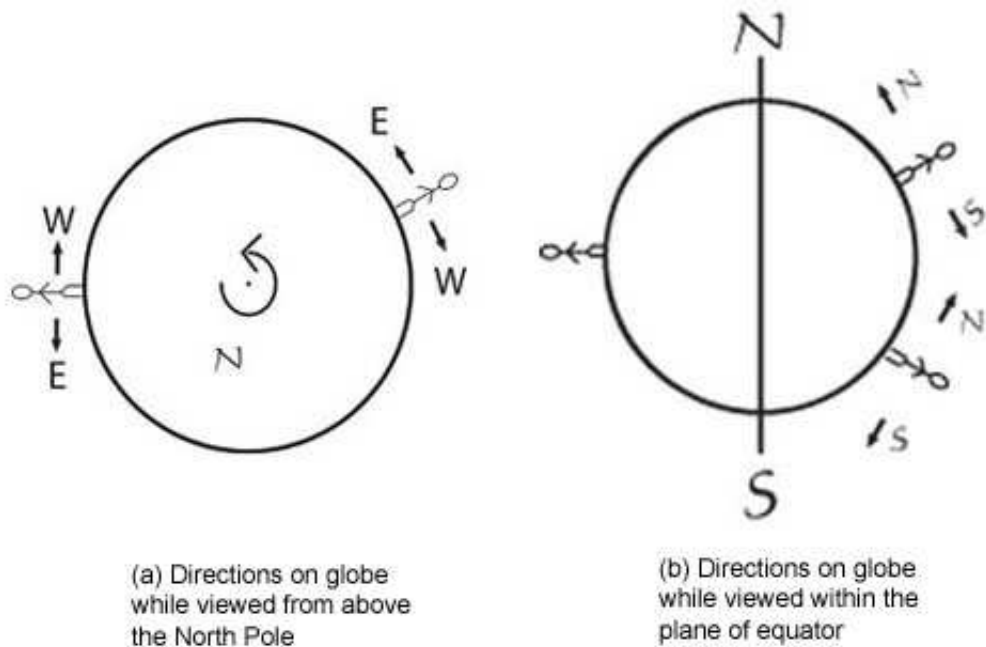


Figure 8. Directions Depend on Location on the Globe

6.5 Horizon and Related Consequences

The horizon is a very useful concept in observational astronomy and for the process of drawing inferences from diagrams. The Marathi equivalent *kshitij* is mostly used in literary contexts in the sense of "far away," and most students were not aware of its precise observational meaning. During the night-sky observations, students were shown and explicitly told the meaning of *kshitij*. Students then used the horizon as reference while determining the position of some stars by measuring its vertical inclination with respect to the line of the horizon. The other position coordinate in this rough and intuitive procedure was provided by one of the eight directions.

The apparent flatness of the Earth was first addressed with the help of gestures. Students were asked to imagine a small ping-pong ball and shape their hand to hold it. Then the size of the ball was increased to a cricket ball (about the size of a baseball), then to a football (soccer ball), then to a room-size big ball (as seen in a circus), and ultimately, we reached the largest ball that students knew. Through these gestures, the hands and arms became less and less curved, and ultimately flat. The largest ball that one can hold is the Earth, for which one needs to fall down on the Earth with stretched arms. These gestures demonstrated how curvature decreases as the size (radius) of the sphere increases. In continuation with this activity, the students were asked to draw concentric circles of increasing radii (Figure 9) in their interactive reading material, and these questions were asked: What happens to the curvature as the radius continues to increase? What will a circle of infinite radius look like?

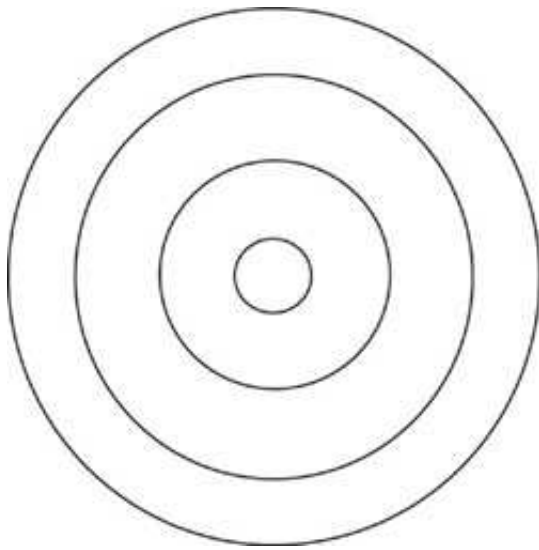


Figure 9. Curvature Decreases as the Radius Increases.

In the classroom session, students were first asked to draw how much of the curved surface of the Earth a person might see when he or she is standing on that surface. Students intuitively drew tangents from the person's eye level to his or her side. Then, considering the large size of the Earth compared with our own size, the height of the person was reduced and the tangents were redrawn. Finally, with negligible height of the person, a single tangent was drawn at the point where the person was standing, which was said to represent the horizon (Figure 10).

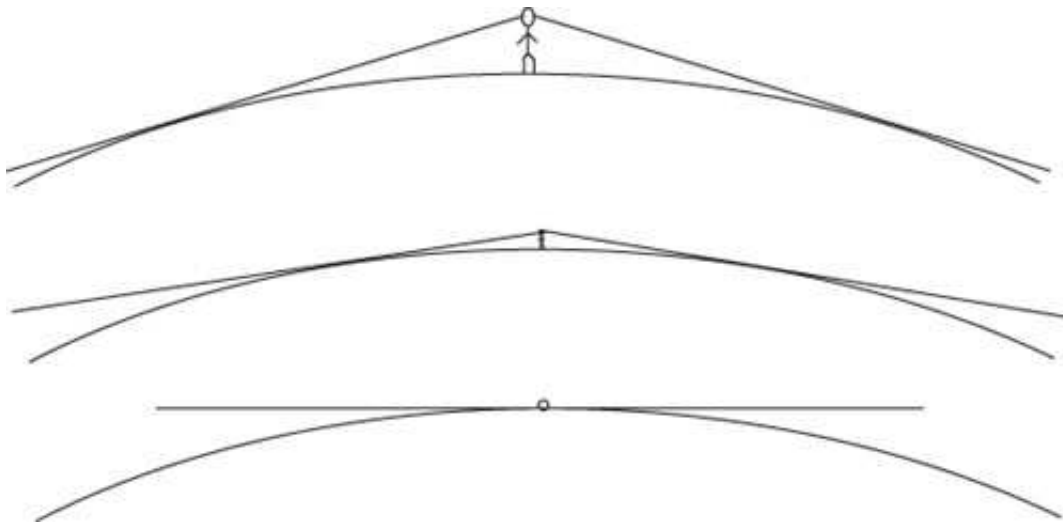
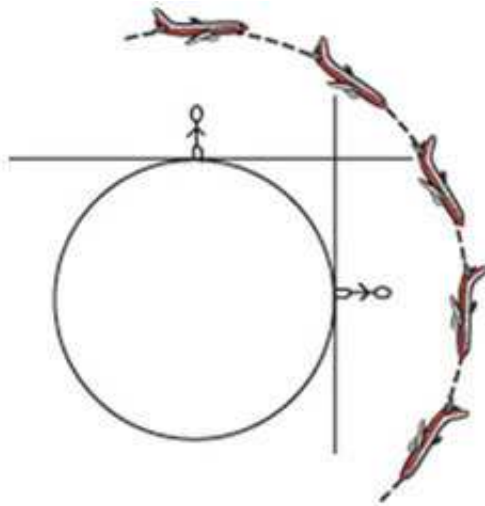
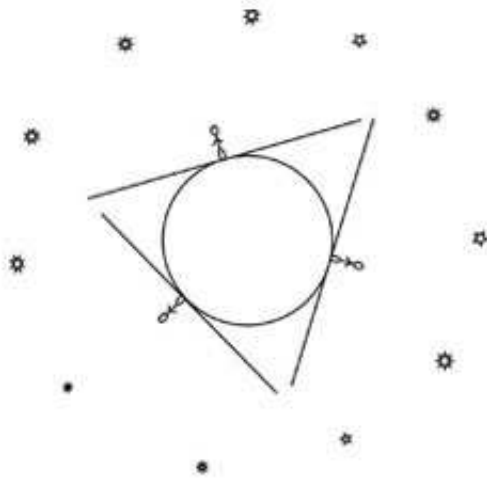


Figure 10. Developing the Concept of "Horizon"

Students were then asked to draw the horizon for people at different locations on the Earth. This exercise demonstrated that inclination of the horizon changes as one's location on the Earth changes; as a result, the visible part of the sky must also change (Figure 11a). Visibility and apparent position of distant ships and airplanes were discussed. Then the students were given interactive reading material about the history of the discovery of the shape of the Earth. They were given a diagram (Figure 11b) with people on the globe and projections of distant stars, and they were asked which of the stars each of them could see by drawing a line of horizon for the respective people.



(a) Visible part of the sky changes because of change in inclination of horizon.



(b) Positions of still objects change as the position on the globe changes.

Figure 11. Horizon at Different Locations

This led the students to conjecture that inclination of any fixed object in the sky would change with our position on Earth—because of change in inclination of the horizon. Even the Sun, at its topmost point (highest inclination), would not be overhead at all places on the Earth. Felicitously, the day of this lesson was March 21, the spring equinox. The Sun was drawn along the line of the equator, and students were asked where it would appear to people at the same longitude (where it was noon), but at a different latitude. From this, students could derive that even at noon, the Sun was overhead only on the equator. From all other places at that longitude, it appeared to be toward north or south (Figure 12).

Variation in the Sun's position during the year was not discussed at this point because the revolution of the Earth and angle between axis and the ecliptic was not yet introduced. The conjecture about the shortest shadow not being zero was verified by observation of the gnomon and other southward shadows when the Sun was at its highest inclination, which indicated that the Sun was not at the zenith but a little toward north. The path of the Sun over the day was traced from east to west by moving an extended arm. This was an instance of an exercise combining observation and gestures, linking up with the mental model and diagram.

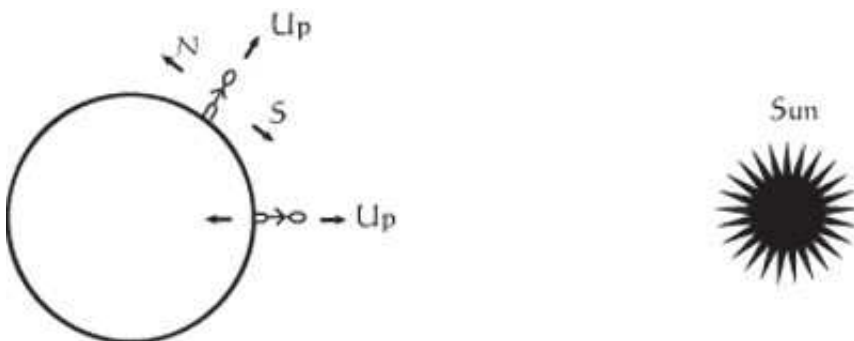


Figure 12. Is the Sun Overhead at Noon?

6.6 Parallel Ray Approximation and Related Consequences

As an object goes farther from a viewer, the angle subtended by it at the viewer's eye becomes smaller. This activity was conducted during an outdoor session. In a sequence of diagrams (Figure 13) approaching the limiting case, the two lines defining this angle become parallel.

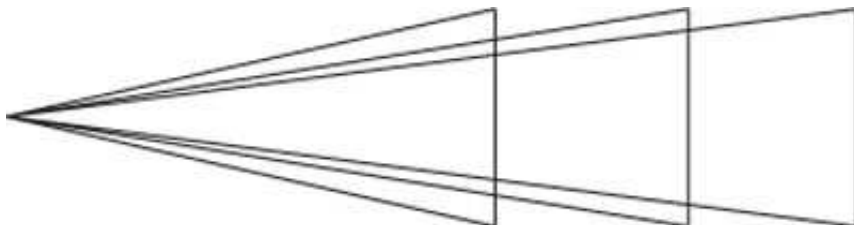


Figure 13. Distant Object Subtends a Smaller Angle

The Sun rays reaching the surface of Earth are similarly approximated to be parallel because the diameter of the Earth is very small in comparison with the distance between the Sun and the Earth.

Another sequence of diagrams, linked with outdoor activities, was used to derive the shadows due to light from parallel-ray, point, and extended sources. The experiences of our own shadow at different times and points were recollected and done on the spot if necessary. This was followed by a sequence of shadow activities to demonstrate that the Sun's rays are parallel. Thus, a picture of the Sun could be substituted by parallel rays coming (on March 21) from a direction normal to the axis of the Earth. With this assumption, students drew the shadow of a vertical stick at different latitudes on the surface of the Earth (Figure 14), leading to the conclusion that the length of the shadow increases as we go away from the equator. This diagrammatic result was linked with the observed or visualized inclination of the Sun at noon at different latitudes.

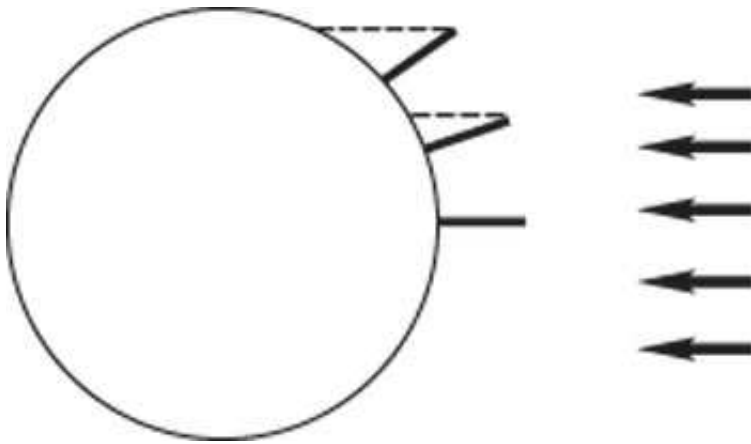


Figure 14. Parallel Rays and Shadow Lengths at Different Latitudes

A similar exercise was carried out to show that the inclination of any star (in particular, the pole star) changes along with the inclination of the horizon—assuming, of course, its rays to be parallel as seen from any point on the Earth (Figure 15). However, the parallel ray approximation was one of the more difficult concepts to digest. Most of the students agreed that Sun rays must be parallel, after we actually checked it in sunlight by measuring the shadow area while changing distance of the object from the ground. Students found out that the size of the shadow does not change, which is possible only if the rays from the Sun are parallel. But it was hard for them to accept that rays from stars were parallel because the appearance of a star was like a point source. From this diagram onward, wherever the parallel ray approximation was involved, students showed less certainty in their responses.

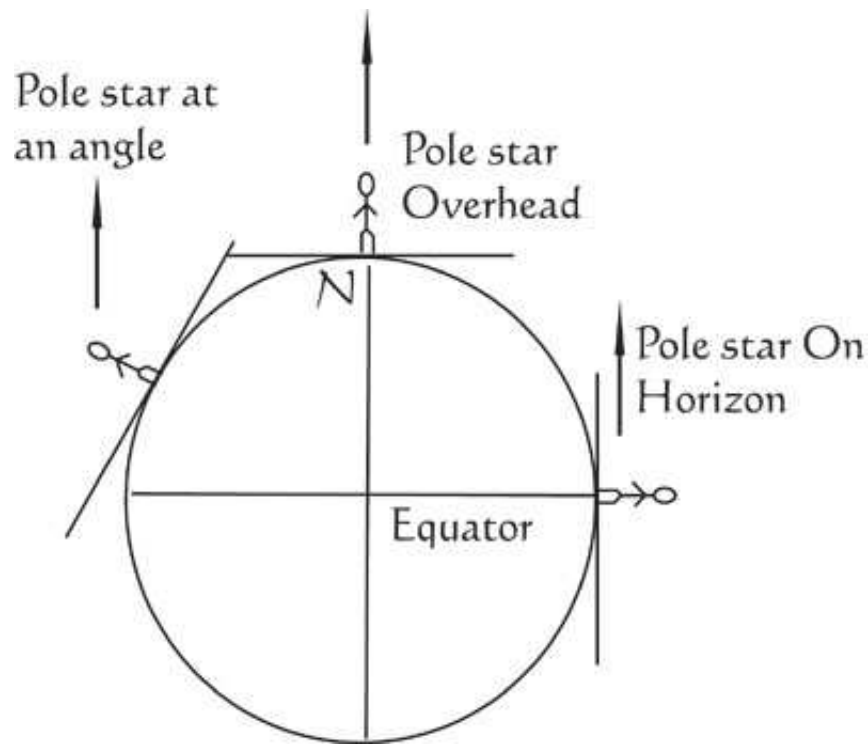


Figure 15. Inclination of Pole Star from Different Locations

From the shadow of a stick at two different locations on the Earth and some additional data (in this case, the distance between the two locations), the radius of the Earth can be determined. This method was first used by the Greek astronomer Eratosthenes (276 B.C. – 194 BC.). A simple diagram to explain the situation was drawn (Figure 16), along with a geometrical diagram to find the formula for the radius of the Earth (Figure 17). It was expected that this part would be difficult to understand for middle school students because it needs a geometrical formulation that they are not familiar with. However, we went ahead with the lesson, assuming that exposure to a historically significant event would be motivating and might give them a sense of the size of the Earth. Their reading material described how Eratosthenes determined the radius by a much simpler method than actually measuring the circumference of the Earth. The new formulas were introduced in the class, and the radius of the Earth was calculated on the blackboard. We hoped that this exposure would motivate students to keep a record of shadows of their own gnomon.

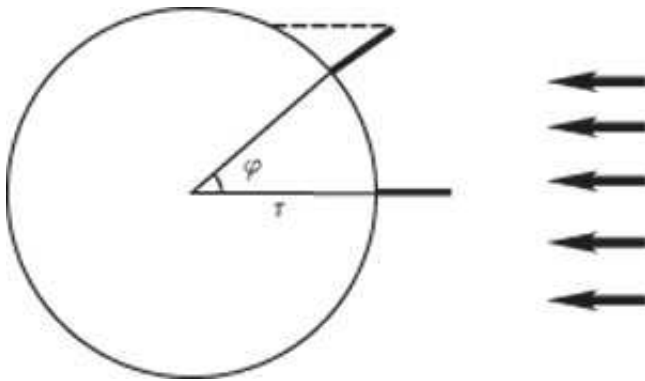


Figure 16. Eratosthenes' Determination of the Radius of the Earth

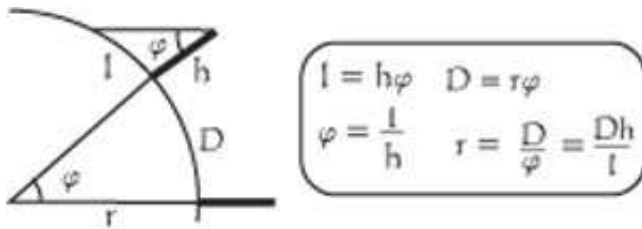


Figure 17. Eratosthenes' Determination of the Radius of the Earth (approximate geometrical proof)

7. DISCUSSION

Further data and analysis will help us decide whether this teaching sequence was successful in helping students to develop at least partially correct working mental models of the Earth. The teaching is to be followed up by more drawing exercises to reinforce the mental model of the round, rotating Earth. At this point, however, we can make a few observations on the basis of students' responses during teaching.

Regular school experiences in India provides little opportunity for students to develop their diagrammatic skills. Our teaching and examination pattern emphasizes neat and stereotyped diagrams that are merely copied from textbooks in a rote manner. Away from urban areas, out-of-school exposure to diagrams is also missing. Initially we found that students were reluctant to draw, especially when they were asked to construct their own diagrams. They would spend an excessive amount of time preparing their supplies: sharpening pencils, cleaning erasers, fussing with the ruler and compass. We found it necessary to break the barrier of this so-called neatness, toward making students self-reliant in drawing. Students were therefore encouraged to draw profusely in freehand, on the blackboard as well as on paper. At the end of the sessions, almost all students were able to draw circles, lines, and arrows with confidence and fluency. It appeared to be a transition similar to that in reading, when students start to read words or sentences as a whole instead of letter by letter.

In the final teaching session, as revision, each student was asked to either tell or draw and explain any point that he or she had appreciated during the course. Approximately 70% students preferred to draw and explain, and further, most of their diagrams were correct and mature.



Figure 18. A Student at the Blackboard

One student who had, prior to the course, proposed a flat Earth model and explained day-night in terms of movement of the Sun, drew a "top view" of the Earth in his postcourse interview. On it he was able to show directions for people standing at different locations on the Earth and to explain how day and night occur because of the rotation of the Earth. The parallel ray approximation was, however, not understood well by this student (Figure 19). In general, the latter has been seen as a difficult concept (Feigenberg, Lavrik, & Shunyakov 2002), and we too observed the same.

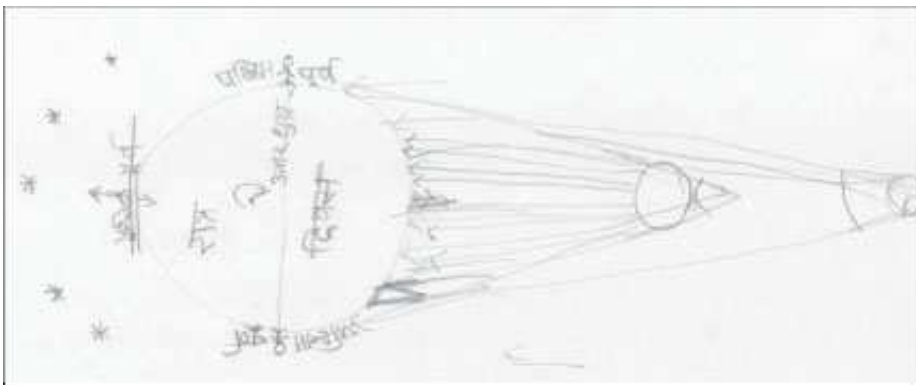


Figure 19. A Student's Response in Postteaching Interview

We found that students handled the diagrams quite confidently up to a certain point in the sequence of teaching. However, the diagrams shown in Figures 15, 16, and 17 posed obvious problems for them. It remains to be seen whether further work with the parallel ray approximation and practice with more precise and quantitative diagrams will reduce some of these difficulties.

An interesting aspect of the classroom interaction was the natural collaboration and consultation that occurred among groups of students, and often in the class as a whole. In response to any challenging question, students would go into a huddle, discuss the question intently for a few minutes, and finally come up with a consensus response. This seems to us to be reflective of a consultative process that is common in rural and tribal society. In groups of urban, and particularly elite, students, we have not noticed such a tendency. The dynamics of this interaction and its effect on individual learning outcomes should form the subject matter of an independent study. We, however, hope to use this interaction fruitfully in designing specific collaborative learning situations for astronomy.

Elementary astronomy is a challenging area in scientific education largely because of the spatial visualization and vast scales of time and distances involved in it. We are exploring how research in visual and spatial reasoning can contribute to developing a pedagogy for astronomy systematically. We have built the pedagogy around activities, concrete models, gestures, and diagrams. At the same time, we expect that elementary astronomy would prove to be a useful vehicle for helping students understand, make, and interpret diagrams, a skill that is of broad application. Further, we hope that research in astronomy education will suggest new problems to cognitive science and will eventually enrich our understanding of visual and spatial reasoning.

References

Albanese, A., Danhoni Neves, M. C., & Vicentini, M. 1997, "Models in Science and in Education: A Critical Review of Research on Students' Ideas about the Earth and its Place in the Universe," *Science Education*, 6, 573.

Baxter, J. 1991, "A Constructivist Approach to Astronomy in the National Curriculum," *Physics Education*, 26, 38.

Feigenberg, J., Lavrik, L. V., & Shunyakov, V. 2002, "Space Scale: Models in the History of Science and Students' Mental Models," *Science and Education*, 11, 377.

Hegarty, M., & Waller, D. 2004, "A Dissociation between Mental Rotation and Perspective-Taking Spatial Abilities," *Intelligence*, 32, 175.

Klatzky R. L., & Loomis J. M. 1998, "Spatial Updating of Self-Position and Orientation during Real, Imagined, and Virtual Locomotion," *Psychological Science*, 9, 293.

Mishra, P. 1999, "The Role of Abstraction in Scientific Illustration: Implications for Pedagogy," *Journal of Visual Literacy*, 19(2), 139.

Monteiro, V. 2006, "How to Make a Geosynchron?",
http://hsb.iitm.ac.in/~jm/ARCHIVES/Jan-Feb06/article_files/discover_it_4.html.

Padalkar, S., & Ramadas, J. forthcoming, "Indian Students' Understanding of Astronomy," paper to appear in *Proceedings of the Conference on Asian Science Education*, Kaohsiung, Taiwan, February 20-23, 2008.

Padalkar, S., & Subramaniam, K. 2007, "Reasoning Processes Underlying the Explanation of the Phases of the Moon," In *Proceedings of epiSTEME-2: International Conference to Review Research on Science, Technology and Mathematics Education, Mumbai, India, February 12-15, 2007*, C. Natarjan & B. Choksi (Editors), New Delhi: Macmillan India, 121.

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

Tversky, B. 2005, "Visuospatial Reasoning," in *The Cambridge Handbook of Thinking and Reasoning*, K. Holyoak & R. Morrison (Editors), Cambridge, UK: Cambridge University Press, 209.

Vijapurkar, J. 2007, *Small Science, Class 5 Text Book, Work Book, and Teacher's Book*, New Delhi, India: Oxford University Press.

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

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