Citation: Padalkar, S. & Ramadas, J. (2011). Using diagrams as an effective pedagogic tool in elementary astronomy. In Chunawala, S. and Kharatmal, M. (Eds.) Proceedings of epiSTEME-4 Conference, Mumbai, India, Jan 5-9, 2011, pp. 159-164.

Using Diagrams as an Effective Pedagogic Tool in Elementary Astronomy

Shamin Padalkar and Jayashree Ramadas

HBCSE (India)

shamin@hbcse.tifr.res.in, jr@hbcse.tifr.res.in

Diagrams in astronomy represent an observed phenomenon, a model, or an explanation which links a model to a phenomenon. We present results from a one-year intervention with Grade 8 students from three schools in Maharashtra, India, aimed at helping them to construct the mental model of the sun-earth-moon system and explain daily astronomical phenomena using it. The pedagogy relied on spatial tools such as concrete models, gestures, actions, and diagrams. Diagrams in it were characterized by, integration with other tools, interactivity, transformability, and inclusion of explanatory elements. These same characteristics can also be used as criteria to evaluate the diagrams of textbooks, teachers and students.

INTRODUCTION

Astronomy is one of the highly visual branches of science. Besides other physical quantities astronomical studies involve visual (colour/ brightness) and spatial (shape, position, motion) properties of celestial objects. Consequently many visual representations such as schematic diagrams, star-maps, a variety of novel graphs, charts, spectra, and simulations are used in astronomy. The main focus of elementary (school-level) astronomy, the heliocentric model, incorporates spatial information such as shapes and sizes of the bodies in the solar system and their respective distances and patterns of motion, which help to explain observable astronomical phenomena. This study is concerned with schematic diagrams for understanding the heliocentric model. The first part of this paper analyses the functions of diagrams and outlines the characteristics that make them effective as a pedagogic tool. The second part analyses students' diagrams before and after intervention to assess the effects of a diagram-centered pedagogy.

OVERVIEW OF THE STUDY

The study described here is part of larger project which began with an assessment of astronomical knowledge of students at the end of Grades 4 and 7, in relations to observations, textbook facts, indigenous information, and explanatory models. The assessment was followed by a one-year intervention for students of Grade 8, divided into 3 contact periods of 15 days each, to help them construct a mental model of the sun-earth-moon (SEM) system and to explain the phenomena on its basis. The pedagogy used concrete models, observations, gestures/actions and diagrams as spatial tools to facilitate model-based visuospatial reasoning in elementary astronomy (Padalkar and Ramadas, 2008). Post-tests were administered to the 'treatment group' and an equivalent 'comparison group' at the end of Grade 8. The sample for intervention consisted of three classes (total 80 students) from three different schools from rural, tribal and urban-slum areas in India (Padalkar and Ramadas, 2009). Data from the three schools are merged in this paper.

TYPES OF DIAGRAMS IN ASTRONOMY

We have classified diagrams in elementary astronomy into three functional types:

1. Diagrams representing a mental model of a system or of a part of system are usually drawn in an 'allocentric' or extrinsic frame of reference (the observer is not within the model). They have the following characteristics: **i.** A particular perspective (for 3d to 2d conversion) is chosen and used consistently in a projection or in a cross-sectional view. **ii**. Motion is represented through conventions, e.g. by drawing an axis, trajectories, and arrows to indicate direction. **iii.** Since distances are large in comparison with sizes of celestial bodies, these diagrams cannot be drawn to scale. Figures 1a & 1b are examples of diagrams representing a mental model of the sun-earth system from two different perspectives. They are projection views which show motion using arrows, and are not drawn to scale.

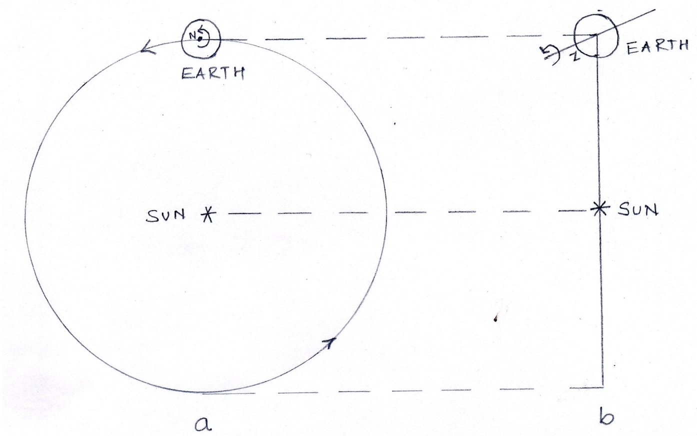


Figure 1: The sun-earth system from above the North pole (a) and from the plane of the ecliptic (b).

2. Diagrams representing a phenomenon or patterns in the phenomenon (over time) show a view as seen by an observer (usually) on the earth, and record either observed position or shape. Such diagrams may be drawn over 12 hours (eg. to identify the pattern of motion of the sun, moon or stars over a day or night), or 30 days (eg. to identify the pattern of phases of the moon and its apparent position) or 1 year (to identify patterns in the changes in path of the sun). Phenomena such as phases of the moon are perceived in two dimensions and can be represented relatively easily on paper. Others such as path of the sun need to be represented as projections of three dimensions on to two dimensions (Figure 2).

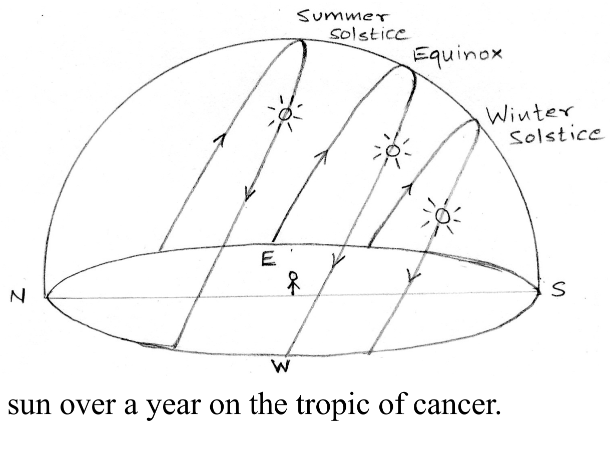


Figure 2: Changes in the path of the sun over a year on the tropic of cancer.

3. Diagrams providing explanations or predictions include an argument, and generally require a change of reference frame from allocentric to egocentric. Such diagrams are drawn from an allocentric frame of reference yet try to either predict or explain what an observer at particular position observes. Explanatory diagrams are distinct from diagrams representing a model. Explanatory diagrams require selection of a preferred point of view, inclusion of only relevant parts and elements of the model and also additional elements or transformations. Identification of the relevant elements of a model and choosing a suitable point of view may make explanatory diagrams difficult to construct (Figure 3).

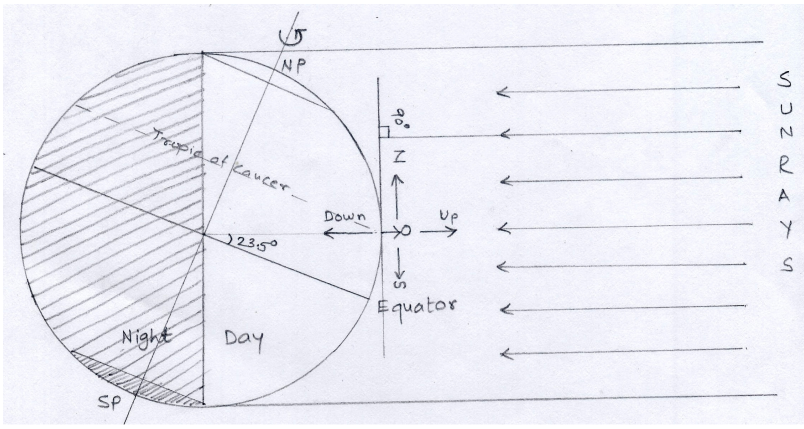


Figure 3: Apparent position of the sun for a person on the tropic of cancer on the day of summer solstice.

CHARACTERISTICS OF PEDAGOGIC DIAGRAMS

Diagrams were central to our pedagogy and used extensively for both communication and reasoning. The conversation in the class and the textual material provided to students were designed around diagrams which had the following four distinguishing characteristics:

1. Integration with other spatial tools: Diagrams represent a three dimensional, dynamic reality in two dimensional static fashion. Schematic diagrams exclude many realistic details and include temporal and conceptual elements such as trajectories and functions. We addressed these difficulties by supporting diagrams with other spatial representations such as concrete models, gestures and action, spatial tools which were expected to help students construct a mental model and meaningful diagrammatic representations.

The dynamic nature of a system can be indicated by a gesture added to a diagram. Gestures which point towards a real or imagined entity are called 'deictic gestures' (Goldin-Meadow, 2006; Roth, 2000). We found deictic gestures useful not only in referring to an object in a diagram, but also to convey spatial properties such as length, orientation, direction or trajectory of dynamic objects such as a ray of light or a celestial body. We encouraged such gestures in the classroom and students used them spontaneously during sessions of guided collaborative problem solving (Padalkar and Ramadas, in press).

2. Interactivity: During pre-intervention testing, we found students unable to draw a schematic diagram on their own. They needed continuous scaffolding to achieve mastery over both the subject matter as well as the diagrammatic medium. In place of giving a readymade diagram we had it evolve through a dialogue. The transformable nature of diagrams (described next) could also get manifested during the process. Skeletal diagrams and step-wise instructions were used in guided collaborative problem solving with students working in groups of three, to solve a graded sequence of problem tasks.

3. Transformability: Diagrams have an advantage over other spatial representations in that they allow spatial transformations and enable transformational reasoning, making them flexible and closer to mental models (Ramadas, 2009). The following properties and elements in diagrams help in carrying out transformational reasoning:

i. Representation of motion: Information about the motion of the system in the diagram provides a hint to transform it in order to represent the system after a lapse of a given time, and thus to draw an inference.

ii. Using multiple perspectives: Use of more than one perspective brings out the three dimensional nature of the system under consideration, a practice common in architecture and engineering. We have observed architects using it to solve problem of the moon's phases (Subramaniam and Padalkar 2009). In Figure 1, the top view (Figure 1a) represents the directions of the earth's rotation and revolution and the correct shape of its orbit, whereas the side view (Figure 1b) shows that the orbit is planar and the axis makes an angle of 23.5° with the ecliptic. Using multiple perspectives in case of the earth and the system involving the earth is a way of challenging the common notion of absolute directions in space (Nussbaum and Novak, 1976). We deliberately used representations such as the earth with the South pole on the top, or with the earth's axis horizontal, or perpendicular to the plane of the paper.

4. Inclusion of explanatory elements: While explaining phenomena we found that certain elements help to build an argument through explanatory diagrams. These 'explanatory elements' are usually not present in the other two types of diagrams i.e. those representing mental models or phenomena. The following are some examples:

i. Elements which help define the local environment of an observer: Drawing the *horizon* and determining *local directions* help to transform an allocentric frame to an observer-centric frame. Both these concepts (horizon and local directions) are missing in textbooks.

ii. Rays: Drawing rays from a celestial object helps to determine a observational aspects, for example the terminator (boundary between day and night), shadows and occultations, and the angle of a celestial body above the horizon. Extending the rays until they touch the surface allows one to see a consequence (eg. a terminator) through construction of the diagram. A geometrical argument can be built using such diagrams, leading to inferences like, an angle at which the sun will be seen from a particular position (Figure 3). Ray diagrams are already used in the textbooks to explain lunar and solar eclipses. Eratosthenes's method of measuring the radius of the earth is a classic example of using light rays to build a geometrical argument.

Explanations involve assumptions or simplifications, which usually get reflected in diagrams. In Figure 3 for example, we have assumed that the sun-rays are parallel, the horizon is tangential to the surface of the earth and atmospheric effects are neglected. In pedagogy, it is important to state the assumptions explicitly and to justify them.

ASSESSMENT OF STUDENTS' DIAGRAMS

Of the four characteristics discussed above, the first two, 'integration with other spatial tools' and 'interactivity' have to do with classroom interactions. The second two, 'transformability' and 'presence of explanatory elements', can be seen directly in diagrams (of textbooks, teachers or students). We assess these two characteristics in diagrams drawn by students from four groups (see 'Overview of Study'): Grade 4 (Gr4), Grade 7 before intervention (Gr7), Grade 8 after intervention (Gr8t), and Grade 8 without intervention (Gr8c).

All percentages are calculated out of number of possible students' diagrams where that component could have been shown. A * next to any value in the Tables indicates a significant difference (by pair-wise z test, $p \leq 0.05$) between that value and the one in the next row (in Tables 1-3) or column in Tables (4 & 5).

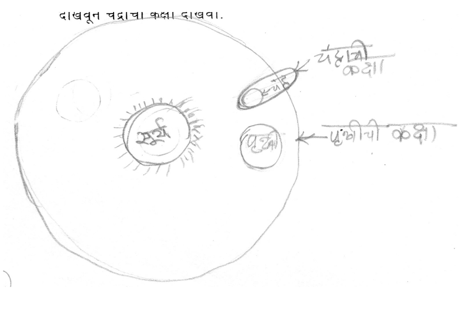
General considerations regarding students' diagrams: We expected an overall increase in the proportion of diagrammatic responses from Grade 4 to Grade 7 to Grade 8 and a further difference between the treatment and comparison groups in Grade 8. We also expected that students in the higher grades and in the treatment group would show less not-explanatory contextual details and artistic embellishments in their drawings. Table 1 shows that the percentage of diagrammatic responses increased from Grade 4 to Grade 7, and from Grade 7 to Grade 8, but there was no significant difference between the treatment and the comparison group. The percentage of incorrect diagrams increased over Grades, but was lower in the treatment group than the comparison group. The number of realistic details was not significantly different between Grades 4 and 7 but it decreased sharply after intervention and was lower in the treatment group than the comparison group.

Grade	N	Percentage of diagrammatic responses	N	Percentage of incorrect diagrams	N	Percentage of diagrams with unnecessary elements
Gr4	352	76*	352	2.84*	264	38.64
Gr7	451	88*	494	13.16*	177	46.33*
Gr8t	650	92	703	24.89*	220	12.73*
Gr8c	932	91	1012	33.1	304	24.01

Table 1: Percentages of total diagrams, irrelevant diagrams and diagrams which contain realistic details out of total number of diagrams.

Remarkably an assessment of drawing proficiency (based on size, sharpness, smoothness, neatness and planning of drawing) showed that Grade 4 students had the highest average drawing proficiency, followed by Grade 8 students in the treatment group.

Transformability of diagrams: Transformability of diagrams could be brought about by two means- representing motion and using multiple perspectives. In using multiple perspectives one has to ensure the multiple elements (rotational axis, poles, equator, orbits, and celestial bodies) are represented in a coherent and consistent way. Thus we consider 3 criteria related to transformability of diagrams. **i.** Coherency: the relation between different elements (rotational axis, poles, equator, orbits) of the system (whether the axis is perpendicular to equator, whether the sun is inside the earth's orbit). An example of an incoherent diagram is Figure 4 where both the earth and the moon are not in their orbits. **ii.** Perspective consistency: all the elements of the system consistently represented from that same perspective (either from above the North pole, from within the plane of equator or making a certain angle with ecliptic). For example in Figure 5 the equator is drawn from the plane of ecliptic and the axis is drawn from above the North pole. Figure 4 also happens to illustrate perspective inconsistency between the orbits of the earth and moon. **iii.** Representation of motion: the axis, trajectory and direction of motion of celestial objects.



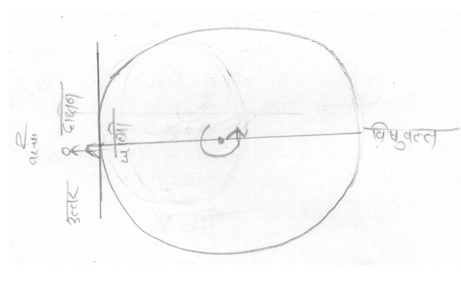


Figure 4: Student's diagram of the sun-earth-moon system shows incoherency in elements.

Figure 5: Student's diagram of the earth from 'within the plane of the ecliptic' shows inconsistent perspective.

The percentage of diagrams showing coherency and perspective consistency are shown in Table 2. If a diagram contained only a single element or no element, then neither coherency nor perspective consistency could be determined hence these diagrams are omitted from Table 2.

Grade	N	% Coherent diagrams	% Incoherent diagrams	% Consistent perspective	% Inconsistent perspective
Gr4	352	0*	0.85	0*	0
Gr7	536	5.08*	1.27*	4.24*	0.85*
Gr8t	650	15.97*	11.17*	23.12*	15.58*
Gr8c	932	2.44	1.69	2.63	0.38

Table 2: Percentage of coherent and incoherent diagrams and diagrams with consistent and inconsistent perspectives.

Table 2 shows that the percentage of coherent diagrams and perspective consistency was significantly less in Grade 4 than in Grade 7, and increased post-intervention. Both coherency and perspective consistency were higher in the treatment group than in the comparison group. However, the percentage of both incoherent diagrams and perspective inconsistency also increased post-intervention and was higher in the treatment group than in the comparison group. This apparently surprising result follows from the fact that diagrams with 'indeterminate model coherency' and 'indeterminate perspective' decreased after the intervention, i.e. more students drew more than one parts of the model in their diagrams, leading to increase in coherency and consistency as well as incoherency and perspective inconsistency.

An important feature of mental models is that they are dynamic and can be simulated or 'run' to draw inferences (Hegarty, 1992). Representing motion in diagrams is a means of rending them dynamic and thus 'transformable'. Table 3 summarizes the percentages of diagrams which (**a**) did not represent motion, (**b**) represented axial motion of the earth correctly, (**c**) represented orbital motion of the earth correctly, and (**d**) represented orbital motion of the earth where it was not required (explaining apparent motion of the moon and day and night)

Grade	No. of students	N	No motion (**a**)	Axial motion (**b**)	N (orbital motion)	Orbital motion (**c**)	Unnecessary orbital motion (**d**)
Gr4	88	616	41.88	0.65	176	-	0
Gr7	59	413	36.56*	0.73*	118	0*	0*
Gr8t	55	385	27.79*	34.29*	110	15.45*	13.64
Gr8c	76	532	46.05	3.2	152	0.66	9.21

Table 3: Percentage of diagrams in which Axial and Orbital motion was shown.

Table 3 shows that the percentage of diagrams showing motion, either axial or orbital, was not significantly different in Grades 4 and 7. However Grade 8 students in the treatment group significantly improved in representing both axial and orbital motion and were significantly better than the comparison group also. Only 4 and 3 students respectively represented the rotation of the earth in Grade 4 and Grade 7. Axial motion was represented in various ways: **i.** Only axis of rotation (textbook notation). **ii.** Only arrow (signifying motion, but no specific axis of rotation). **iii. Axis + curved arrow to show direction of rotation (notation used in the intervention)** . **iv.** Other (e.g. ring). Students from the Grade 4, Grade 7 and the Grade 8-comparison group did not used 'Axis + curved arrow' notation while most of the students in Gr8t used it.

Table 3 shows that none of the Grade 7 students attempted to draw the orbital motion of the earth. Significantly higher number of students showed it in post-intervention test. Only one student in the comparison group drew orbital motion. Many Grade 8 students from both the treatment and the comparison groups unnecessarily drew orbital motion in response to two questions regarding apparent motion of the sun and occurrence of day-night. This might be because they erroneously explained the occurrence of day-night on the basis of the revolution rather than rotation. None of the Grade 4 and Grade 7 students made this mistake. Surprisingly, one tribal student from the treatment group drew the sun moving around the earth to explain occurrence of day-night.

Inclusion of explanatory elements: Three elements were identified as those which help explanations (see Characteristics of Our Pedagogic Diagrams): horizon, local directions and parallel rays. Students were required to draw horizon and local directions in three diagrams. The results are in Table 4. In Question 1 in Table 4, students had to draw the earth, human beings on it, and the horizon and local directions for two of those human beings. Since none of the students from Grade 4 and Grade 7 drew the 'horizon' and 'local directions', their percentages are not listed. In Question 2, students were asked to draw the earth from specific perspective (within the plane of equator), a person on the equator, and horizon and local directions for that person. In Question 3, a diagram of the earth from the plane of equator (vertical axis aligned towards the Pole star) and a person standing on latitude 20° North was provided and students were asked to predict the apparent position of the Pole star for that person. Questions 2 and 3 were asked only to Grade 8 students.

About 80% students from the treatment group correctly drew the 'horizon' and 'local directions' when explicitly asked in Question 1. Percentage of students who correctly drew the horizon decreased to 55% and those who correctly determined local directions also decreased and ranged from 33% to 69%, when the diagrams was required to be drawn from a specific perspective.

No.	Question	Horizon		Local directions		
		Gr8t (N=55)	Gr8c (N=76)		Gr8t (N=55)	Gr8c (N=76)
1	Earth and human beings (draw horizon and Up-Down)	85*	0	Up	78*	0
				Down	75*	0
		80*	0	North	80*	0
				South	73*	0
2	Position of the Pole star for person on equator (draw horizon and local directions)	55*	1	Up	67*	0
				Down	69*	0
				North	35*	3
				South	33*	3
3	Position of the Pole star for person on 20° latitude	40*	1		0	0

	Average over questions	65	0.5		63.75	0.75

Table 4: Percentage of students who drew the 'horizon' and 'local directions'

In Questions 3 students were not explicitly asked to draw the horizon and local directions, but they needed to determine horizon and the local directions so as to answer the question. The percentage of students who drew the horizon further dropped to 40%. None of the students drew local directions for the person although about 35% students from both the group correctly answered that the Pole star would be seen at North. Only 1 student from the comparison group drew the horizon and 3% students drew North-South directions.

Parallel rays: Students were required to draw parallel rays in 3 questions (Table 5). Two of these questions (Questions 2 & 3) were not given to Grades 4 and 7 students. In Question 1 students were asked to explain the occurrence of day-night, where the terminator was to be determined with the help of parallel sun rays. In Question 2, students were required to draw parallel rays from the Pole star to determine its angle above the horizon for a person standing on latitude 20° N. In Question 3, to explain the seasons, students were required to draw parallel sun-rays to determine both the terminator and the angle of the sun above the horizon.

No.	Question	Gr4 (N=88)	Gr7 (N=59)	Gr8t (N=55)	Gr8c (N=76)
1	Sun rays to explain occurrence of day-night	24	20	36*	16
2	Rays from Pole star to determine its position for person on 20° N latitude.	-	-	2	0
3	Sun rays to explain occurrence of seasons	-	-	24*	0
	Average over questions	24	20	20.67	5.33

Table 5: Percentage of students who drew 'parallel rays'

From Table 5 we see that percentage of students who drew parallel rays for Questions 1 and 3 is significantly higher in the treatment group than in the comparison group. Although the average percentage of students who drew parallel rays is similar in Grades 4 and 7 is apparently comparable to the Grade 8-treatment group, this may be because the textbooks contain diagrams for this particular situation, and these diagrams contain parallel rays. Only the Grade 8 students were given problem situation in which they were required to draw parallel rays from the Pole star and to explain seasons (Question 2 and 3). Percentage of students who drew parallel rays to explain seasons (Question 3) was significantly higher in the treatment group than in the comparison group. However, only one student from the treatment group and none from the comparison group drew parallel rays from the Pole star, demonstrating the difficulty in learning to use the parallel ray approximation in the case of stars.

SUMMARY AND CONCLUSIONS

Diagrams in elementary astronomy represent either models, or phenomena, or explanations which relate models and phenomena, and each of these kinds of diagrams have certain distinct properties. When diagrams are used in combination with other spatial tools such as concrete models and gestures, then they are interactive, and contain transformable and explanatory elements, then they serve as effective pedagogic tools.

After an intervention using a specially designed diagram-centered pedagogy, students started to draw more schematized diagrams in place of realistic picture-like representations. Students in the treatment group included more parts of the model in their drawings but, as a result, percentage of coherent as well as incoherent diagrams increased and percentage of diagrams with consistent perspective as well as inconsistent perspective increased. It appears that they were taking more risks in expressing ideas in drawings, and often the results were positive, but there was also an increase in errors. Further practice with diagrams may have addressed this problem. After intervention students started to use more scientific conventions (for axis, orbit, & motion) and also more specific explanatory elements in their diagrams.

Diagram-centered pedagogy is quite possible to integrate into a normal classroom without requirement of any special equipment. Blackboards, wall charts, workbooks with skeletal diagrams for problem solving and tabular formats for recording observations, are all easily provided, once diagrams are seen as an essential learning tool. Simple models and gestures, to complement the diagrams, are also possible to integrate into classroom discourse. These measures will help bring visual and spatial thinking back into the science classroom.

REFERENCES

Gardner, H. (1980). The reach toward realism. *Artful Scribbles* (pp. 18-37). Basic Books.

Goldin-Meadow, S. (2006). Nonverbal communication: The hand's role in talking and thinking. In W. Damon & R. M. Lerner (Eds.) Handbook of Child Psychology, volume 2, 6th edition (pp. 336-369). John Wiley.

Hegarty, M. (1992). Mental Animation: Inferring motion from static displays of mechanical systems. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 18 (5), 1084-1102.

Nussbaum, J. and Novak, J. D. (1976). An assessment of children's concepts of the earth utilizing structured interviews. *Science Education*, 60(4), 535-550.

Padalkar, S. and Ramadas, J. (2008). Modeling the round earth through diagrams. *Astronomy Education Review*, 6 (2), 54-74.

Padalkar, S. & Ramadas, J. (in press). Designed and spontaneous gestures in elementary astronomy education. Accepted for publication in the *International Journal of Science Education*.

Ramadas, J. (2009). Visual and spatial modes in science learning. *International Journal of Science Education (Special Issue on "Visual and Spatial Modes in Science Learning")* , 31(3), 301-318.

Roth, W.-M. (2000). From gestures to scientific language. *Journal of Pragmatics*, 32, 1683-1714.

Subramaniam, K. and Padalkar, S. (2009). Visualisation and reasoning in explaining the phases of the moon. *International Journal of Science Education*, 31(3), 395-417.