Spatial Cognition and Visualization in Elementary Astronomy Education

A Thesis

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by

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DECLARATION

This thesis is a presentation of my original research work. Wherever contributions of others are involved, every effort is made to indicate this clearly, with due reference to the literature, and acknowledgement of collaborative research and discussions.

The work was done under the guidance of Professor Jayashree Ramadas, at the Tata Institute of Fundamental Research, Mumbai.

Shamin Padalkar

In my capacity as supervisor of the candidate's thesis, I certify that the above statements are true to the best of my knowledge.

Prof. Jayashree Ramadas
Thesis Supervisor
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To Kolhapur

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List of Publications

The relevant Chapter numbers in the Thesis are indicated in the brackets.

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6. Padalkar, S. and Ramadas, J. (2008). Indian students' understanding of astronomy. In *Electronic Proceedings of Conference of Asian Science Education (CASE2008)*, Kaohsiung, Taiwan, February, 2008. [Chapters 4, 6 & 7]

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Abstract

Elementary astronomy is an integral part of school science education. It is one of the subjects where elementary yet non-trivial observations are easily accessible: hence the subject has a potential to evoke students' curiosity and to empower them to pursue their questions through methods of scientific enquiry. Astronomy is also important from the scientific literacy perspective because of its connections to astrology.

Visuospatial thinking in astronomy: Elementary astronomy is known to be prone to difficulties and common alternative conceptions for students as well as adults. Although students' mental models are known to be erroneous, these models have never been studied from the perspective of visuospatial thinking and reasoning. Mental models in astronomy consist of significant amount of information about spatial quantities (shape, size, distances, patterns of motion) along with information about other physical quantities (temperature, gravitational force). Explanations of common astronomical phenomena such as day-night, seasons and phases of moon require visuo-spatial transformations such as mental simulation and perspective change.

Spatial tools: We know from the literature that although schematic diagrams are a useful spatial tool, they presents difficulties to students because of their two-dimensional, static and abstract nature. Our analysis of existing textbook diagrams and students' diagrams showed that both of them do not use the explanatory and predictive power of diagrams. Using the literature on spatial thinking and data on diagrams we developed and tried out a pedagogy for astronomy which heavily relied on spatial tools.

Research design: A ‘conjecture driven research design’ was considered suitable for this study. A conjecture is an inference based on inconclusive or incomplete evidence drawn from literature and the researcher’s experience. Conjecture based design is situated in a real classroom setting rather than in a laboratory setting and it aims to arrive at new widely applicable instructional strategies. The researchers come up with an initial conjecture, design an instructional method assuming that the conjecture is true and finally test the effectiveness of their instructional method. The planned intervention takes place over a significant period of time. As the intervention proceeds, the conjecture evolves and becomes precise and the study is usually fairly flexible to incorporate the insights gained during the intervention.

The study began with an assessment of astronomical knowledge of students at the end of Grades 4 and 7, from rural, tribal and urban-slum areas in India. This initial assessment was followed by a one-year intervention for around 80 students of Grade 8, spread over 3 contact periods of 15 days each. At the end of Grade 8 post-tests were administered to the ‘treatment group’ and an equivalent ‘comparison group’.

Assessment of astronomical knowledge: We explored Grade 4 and Grade 7 students’ understanding of astronomy in four areas: observations, textbook information, indigenous knowledge and the sun-earth model. We found that although students had observed several astronomical objects and events, they were unable to find and/or represent patterns in celestial phenomena such as path of apparent daily motion of the sun, moon and the stars. Their observations were qualitative and influenced by visual properties (colour and brightness). Although the majority of students knew standard terms such as equator, orbit, names of planets they possessed alternative models of the earth with major difficulties related to integrating gravity with spatial properties. Their explanations of simple phenomena such as day-night were erroneous or superficial and they were unable to draw ray diagrams in simple novel situations such as drawing a shadow of a stick in sunlight. Students were familiar with indigenous knowledge and cultural tools such as luni-solar calendars, but this knowledge was associated with astrology.

This assessment defined our starting point of our intervention.

Pedagogy: Helping students to construct scientifically accepted mental models, and

explaining phenomena on the basis of these mental models was the main aim of the intervention. Use of concrete models as a pedagogic tool is a well-known practice while teaching astronomy (though it is not so common in India). Advantages of concrete models are, they are three dimensional, movable and realistic, and hence they form a good starting point. However, they lack the analytical power of diagrams. From the literature we knew that gestures and actions play an important part in spatial cognition.

The following two interrelated conjectures provided the rationale for design of gestures in our pedagogy:
1. The 'phenomenon - gesture - mental model' link: distance and time scales in astronomy being beyond direct perception, actions may provide the most accessible bridge from the phenomenon to the mental model.
2. The 'concrete model - gesture - diagram' link: gestures can be used along with concrete models to make these fluid, and with diagrams to add a third dimension. Both concrete models and diagrams can be made dynamic with the use of appropriate gestures.

The pedagogic gestures and diagrams were analyzed to identify their significant characteristics. A new scheme of analysis was developed for this purpose.

Video data on student' use of gestures and diagrams was collected during classroom interaction and guided collaborative problem solving sessions. This data also served to identify students' difficulties and trace their learning trajectories. Through the course of the intervention the initial conjecture was refined and developed, with continuous inputs from both theory and data. Assessment at the end of the intervention showed that our designed pedagogy and specifically, the novel attempt of designing pedagogic gestures turned out to be useful.

Chapter 1

Introduction

This chapter begins with the importance and relevance of astronomy education, first from the broad perspective of development of scientific temper among students and then within the current social context, especially in India (Section 1.1). Conceptual difficulties in learning elementary astronomy are summarized in Section 1.2 and the possible reasons for these difficulties are discussed with reference to findings from cognitive science (Section 1.3). Keeping these difficulties in mind an analysis of the astronomy content in textbooks of Maharashtra State (Section 1.4) is presented. On this background the study is introduced (Section 1.5). The Chapter ends with the organization of the thesis (Section 1.6).

The search for explanation of natural phenomena is at the core of scientific investigation, and is often believed to form the core of good science education as well. Of the many familiar everyday natural phenomena, the motion of celestial bodies across the sky is perhaps the grandest and most significant to human life. Phenomena in the sky are easy to observe and, unlike most other everyday phenomena, their explanations do not require knowledge of advanced mathematics or complex theories of physics. Celestial phenomena therefore present a perfect context in which to introduce students to the scientific method, consisting of careful observations to generate a hypothesis, to predict its consequence, and test it against evidence. The development of astronomy since ancient times presents important and dramatic episodes in human history. Elementary astronomy has the potential to bring together several school subjects such as geometry, algebra, physics and geography, besides connecting with archeology, literature and historical research. The widespread interest of young people in popular astronomy makes it a particularly promising topic for school education.

Yet problems in students' and adults' knowledge of basic astronomy are also well documented (Bailey et al., 2004; Lelliott and Rollnick, 2009). Research shows that the heliocentric model of solar system is a difficult notion for students as well as for adults all over the world even after relevant instruction (Baxter, 1991; Raza et al., 2002). Explaining even simple daily phenomena using an appropriate part of this model can be a challenging task. Various studies report that proposing faulty explanations for occurrence of day and night, seasons, phases of moon, eclipses, etc. is common among school students and among adults (Vosniadou and Brewer, 1992; Baxter, 1991; Stahly et al., 1999).

The problem should be seen within the overall socio-cultural context where astronomical knowledge may be associated with astrology and everyday cultural practices (Section1.1). Notwithstanding its connection with superstition however indigenous knowledge in India is built on a sound basis of observation of celestial phenomena. It thus has the potential to help address the cognitive challenges of understanding basic astronomy, which are described later in this chapter (Sections 1.2, 1.3). The present astronomy curriculum in the State of Maharashtra is then described, providing the motivation for this thesis (Section 1.4).

1.1 Social context of astronomy

The level of scientific understanding of people in any society depends upon many inter-related factors such as formal education, gender, religious and cultural values present in the society, and the practices related to them. We summarize here four studies which explore public understanding and attitudes about astronomical knowledge.

Lightman and Miller (1989) documented the findings of a telephonic survey on the cosmological beliefs of the American public conducted by the Public Opinion Library at Northern Illinois University. The survey was carried out over 1111 adults aged above 18 from from 33 largest metropolitan areas and 117 counties from 42 states of USA. Some questions asked in the survey and the percentage of correct responses are as follows:

Would you say that the sun is a planet, a star or something else? (correct responses 55%)

Do you think that the universe is getting bigger in size, smaller is size, or remaining the same in size? (correct responses 24%)
Which of these statements do you agree with the most?
i. the sun will keep shining.
ii. at some point in future, the sun will stop shining and never shine again. (correct response 37%)
iii. at some time in future, the sun will stop shining, but eventually it will receive new energy and start shining again.

In the entire universe, it is likely that there are thousands of planets like our own on which life could have developed. (agree 62%)

Lightman and Miller (1989) found that the strongest predictor of cosmological understanding was formal education, followed by church membership, followed by age (the best informed were the middle aged group, who, interestingly, were beneficiaries of the so-called 'Golden age' of science education in the 15 years following Sputnik!).

In the Indian context, Raza et al. (2002) documented results from a survey of 2713 participants conducted at the *Ardh-Kumbh Mela*, a religio-cultural festival held every twelve years at Sangam, Allahabad, in India. Most of the participants (94.2%) were from Northern India (Uttar Pradesh, Bihar and Madhya Pradesh), 73% were men and 27% were women. Average age of the respondents was 39 years. The educational level and profession of the participants was also recorded. Out of a total of 26 questions on four areas of scientific enquiry (geography & climate, agriculture, and health & hygiene), 6 questions were related to astronomy and cosmology and were about shape of the earth, gravitation, occurrence of day-night, eclipses, a galaxy, and origin of human beings. An original method of data analysis was developed, in which the percentages of correct and incorrect responses were plotted simultaneously against level of education as an independent variable. The X co-ordinate of the point of intersection of two plots gave the level of schooling at which the information become part of cognitive structure to 50% of the population, and was called by the authors the 'index of democratization' on the 'cultural distance scale'.

A large percentage of participants knew the scientifically valid answer for the question 'what is the shape of the earth'. The index of democratization for this question occurred at 1 year of schooling on the cultural distance scale. The authors remarked that the concept of rotundity of the earth is not introduced at the first standard of schooling anywhere in India, and they concluded that this concept has become an integral component of the culturally tutored cognitive structure. The index of democratization for the explanation of why objects fall down was 5 years of schooling. To answer the questions 'how do day and night form' and 'why does an eclipse occur' required the rotation of the earth and the heliocentric model, and the index of democratization for these questions was 9 and 10 years of schooling respectively. Finally, the indices of democratization for the questions 'what is galaxy' and 'how did man come into being' were 15 and 21 years of schooling (Raza et al., 2002).

In all ancient cultures astronomy and astrology were not separate branches of knowledge and they were usually studied by priests and officiants. The separation between astronomy and astrology took place only after the birth of modern science (with the possible exception of some remarkable personalities and movements in history who made a distinction between the two). Literature suggests that the two branches are still fused at several places in the world, especially in societies which are less influenced by modern science.

Mohapatra (1991) investigated Indian students' conceptions of the solar eclipse. The authors remark that in the Eastern region of India, the solar eclipse is regarded as a mysterious supernatural phenomenon, when the demon *Rahu* temporaily devours the sun, either partially or wholly. During this period certain injunctions apply to daily activities, such as, one should not eat food, undertake a journey, look at the sun, start the construction of a new house and, pregnant women should not see the solar eclipse (this last ritual was not included in the study because it was thought to be socially inappropriate for school students). Other rituals, based in religious faith, are that one should not visit a temple, worship god, or solemnize a marriage during an eclipse. Furthermore, one should bathe and cleanse oneself immediately after the solar eclipse. The superstitions were however not addressed in the discussion on eclipses in the local textbooks for Grade 6.

Eighty-seven students from Grades 8, 9 and 11 from the city of Bhubaneswar participated in this study. These were more able students as determined by their academic records, came from an urbanized society and had an educated family background. The questionnaire consisted of 20 items on a three-point Likert scale. The results showed that of 12% to 19% students believed that the demon *Rahu* is the one who brings about the solar eclipse. The author concluded that these alternative conceptions are quite resistant to extinction, perhaps because students are exposed to the scientific interpretation only for limited time, but to the cultural view all through the year. Beliefs about not eating were found to be stronger than those related to undertaking a journey or starting a construction. A common reason given by students for not eating during the eclipse was that the number of germs and viruses increases during that period: an interesting instance of cultural beliefs being adapted to appear consistent with a science-based world-view (Mohapatra, 1991).

Narlikar and Rana (1997) note that there is a stark contrast between a highly "developed" society and a highly primitive one coexisting in India. On the one hand, there are important advancements in the field of astronomy and astrophysics such as, India can claim some major personalities and contributions in this field. Opportunities to learn advanced astronomy are available in about 300-350 universities and institutes. A large number of amateur astronomy clubs and astronomy popularization bodies are working for the common public, and there has been a historical tradition and heritage of astronomical knowledge for several centuries. On the other hand, there is adherence to superstitions and astrology found in the highest strata of society. On the need for astronomy education Narlikar and Rana say:

> *"In this context, there is a strong need to enhance the astronomy part in the science education curricula of Indian schools. Through astronomy*

> *one learns to appreciate the vast scope for the application of the laws of science, one realizes the smallness of the Earth in the overall scheme of the cosmos and, last but not the least, one is forced to appreciate the need to make our planet safe and habitable: for as yet it is the only known habitat for life."* (Narlikar and Rana, 1997)

Astrological beliefs are in direct conflict with astronomy, they hinder a reasoned understanding of the world, promote wrong beliefs about the nature of science, and consequently hamper the development of scientific attitude. Astrological beliefs can be even more damaging and even dangerous, since they can lead to irrational decisions in daily life. Such beliefs are transmitted in groups by passive social influence and they do not change easily or simply in response to disconfirming evidence (Farha and Steward, 2006). Thus one of the major challenges in elementary astronomy education is to replace a belief system (which might be a mixture of astronomical facts and astrological beliefs) by a reason-based astronomical knowledge. For this we need to understand the nature of the reasoning required in elementary astronomy.

1.2 Understanding astronomical space

Elementary astronomy begins from positioning oneself on the earth, positioning the earth and other prominent celestial objects in space, and positioning the planetary system in the universe. Regular and accurate naked eye observations of daily astronomical phenomena such as day-night, seasons, phases of the moon, eclipses and occultations, and changes in positions of stars and planets over the year are, we argue, not sufficient for forming a basic mental model[1] of the solar system, even minimally positioning oneself on the earth and positioning the earth, sun and the moon in space. The main reason is that the link between the observations and model is not direct but mediated by spatial transformations and abductive reasoning processes (Magnani, 2001). Even a qualitative model of the planetary system

[1]Technical terms occurring in the next two Sections, like mental models, are explained in Chapter 2 and necessary definitions are provided in Appendix G.1.

incorporates our knowledge of the relative shapes, sizes, angles, distances, speeds, and patterns of movement of the celestial bodies: details that would be difficult to deduce from earth-based astronomical observations.

Historical record shows that although fairly accurate observations and empirical rules of prediction of daily phenomena were available since ancient times in many ancient civilizations, multiple cosmologies existed at different points of time, and at different places, to explain these phenomena. When the current scientifically accepted models were proposed, they faced strong opposition. Copernicus and Galileo faced opposition on religious grounds but also, perhaps, due to the challenge of spatial thinking entailed by their theories. The long historical process of discovery of the current model of planetary motion was driven as much by careful observations of natural phenomena, i.e., the manifestations of this model, as by a series of leaps of imagination, supported by cognitive abilities such as changes in frames of reference and spatial transformations, taking account of multiple evidences, and linking observations with model through repeated corrective feedback loops.

It would be unrealistic indeed to expect to replicate this process in the classroom. Here one needs to distinguish between reasoning used in the process of scientific discovery and that needed in 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. The case of school learning is different. A rigorous evidence-based argument for the roundness of the earth, needing coordination of observations separated spatially across the globe and temporally over days and months, is far too complex and perhaps not accessible to school 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.

The model of the spherical earth and the heliocentric model of the solar system are today granted as part of our common cultural understanding. Our language no longer refers to the flat earth or the geocentric universe (with a few exceptions)! Children are formally exposed to the round moving earth as early as 7 years of age. Explaining daily astronomical phenomena on this model is part of basic scientific literacy and hence part of our school curriculum. All this exposure should lead students to believe that the earth is round, it rotates, and it revolves around the sun.

But the story is not so straightforward! To begin with, consider communities and groups of people who are not too exposed to modern science, or illiterate communities with no access to written knowledge, or inadequate access to communication media. When children from these backgrounds are introduced to the idea of a round rotating earth at a young age, it might be difficult for them to believe what they learn. Authoritative teaching practices may force them to produce expected answers, but one doubts whether those conceptual changes of great historical and scientific import might have indeed taken place.

Secondly, consider the fact that if children, even those who are exposed to the heliocentric model, try to construct a mental model based on their own experiences, it would be in conflict with the scientifically accepted model. We do observe a flat earth and all the celestial bodies moving around us. Evidence of such intuitive models as well as of models which are made by synthesis of the intuitive and scientific models has been found in young children (Vosniadou and Brewer, 1992). Other research shows that students as well as educated adults have problems in understanding the heliocentric model and cannot explain daily astronomical phenomena satisfactorily (Baxter, 1991; Trundle et al., 2007b; Subramaniam and Padalkar, 2009; Padalkar and Ramadas, 2008a).

The dilemma that students face must be resolved in a constructive way, that is, by access to evidences and arguments that support the scientifically accepted models. As did the scientists, students too need to convince themselves about the model through the observations accessible to them. So the question is, how can we help students construct the scientifically accepted mental model of the solar system and explain daily astronomical phenomena on the basis of it?

We are looking for a pedagogical argument developed through real-life experience and visual-spatial imagination. We ask first, what are the cognitive tools that are helpful in the process of spatial thinking? What are the senses and experiences which help us understand space around us?

1.3 Cognitive considerations in astronomy learning

A sound understanding of basic astronomical concepts calls for 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 like the day-night cycle, seasons, and phases of moon, are fairly complex, requiring coordination of views from several points on earth, and from outside the earth also.

The place of mental models and of visualization in scientific discovery as well as in science education is recently recognized in the literature (Nersessian, 1999; Gilbert, 2005; Ramadas, 2009). In cognitive science the study of reasoning using nonconventional resources, such as visualization, imagery and modeling, is comparatively recent in contrast to the reasoning and argumentation using conventional cognitive resources such as logic (inductive and deductive), language and numbers. Conventional reasoning could be characterized as propositional reasoning, while by nonconventional reasoning we mean imagistic reasoning, which may include transformative reasoning, reasoning by analogy, geometrical reasoning and other forms which use visual images as the basis of the reasoning, though often in combination with propositions and symbols. We consider model-based visuospatial reasoning to be a kind of nonconventional imagistic reasoning which exploits spatial properties, such as size, shape, position, motion, etc., of the mental model, and needs spatial cognitive abilities such as mental rotation and perspective taking for the process of reasoning (Nersessian, 1999; Hegarty and Waller, 2004; Ramadas, 2009).

Mental models in elementary astronomy are of a visual-spatial kind and hence the reasoning based on them needs abilities such as spatial visualization (the ability to imagine spatial forms and movements including translation and rotations) and spatial orientation (perspective taking) (Hegarty and Waller, 2004). Visuospatial abilities may affect knowledge about astronomy significantly and positively (Kikas, 1998). In a study of understanding phases of the moon (described in Section 3.2), 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 post-graduates (Subramaniam and Padalkar, 2009). From these studies, we conjecture that tools which help us understand and represent space and motion might help in understanding astronomical phenomena; and the latter might, in turn, help in developing spatial reasoning competencies. Diagrams are one of the well documented tools for representing and organizing space (Tversky, 2005). But diagrams are a static and two-dimensional representation of three-dimensional space. In addition, in scientific diagrams many visual details (eg. colour of the earth and surface topography) are removed, as are properties which may not be necessary for particular purposes (eg. existence of atmosphere or presence of the moon while explaining day and night or seasons). On the other hand, symbols and invisible aspects of the model, eg. orbit and axis of the earth, are included. These aspects remove diagrams away from reality, making them abstract and difficult to comprehend (Tversky, 2005; Mishra, 1999). Actual replicas or concrete models of the system are free from some of these distortions. So they are good for creating a mental model as a part of pedagogy, but they are often static, and more pertinently, they do not have the transformational flexibility required for reasoning. In addition, models in astronomy cannot preserve scale, due to the large range of sizes, combined with distances that are literally "astronomical" in comparison with the sizes of these objects.

In order to move flexibly between the realistic and intuitive nature of models and the analytical power of diagrams, we propose another conjecture: that gestures and actions might provide a good link between models and diagrams. The body being our prime source of understanding space and motion (Tversky, 2005; Newcombe and Learmonth, 2005), the kinesthetic feedback that one gets through small or wide gestures could be an important tool for visualizing and operating a mental model. The advantages of gestures over models and diagrams are: they are dynamic and three dimensional. Another property of gestures is that they are not permanent over space. Although this makes them inappropriate for offloading memory and for carrying out a sustained chain of reasoning, the same property makes them a powerful tool for developing individual steps of an argument: because they are less rigid, or flexible, they do not make permanent marks of specific meaning like diagrams. We suggest that, the role of gestures in the process of constructing a diagram-based argument, might be similar to that of loud thinking before giving a written argument. This argument is developed further in Section 3.3.

1.4 Astronomy education in the State of Maharashtra

Given the role of celestial phenomena in our lives, the strong connection of astronomy with astrology and superstitions, also given children's curiosity about these phenomena and their potential for illustrating the scientific method, elementary astronomy certainly should be part of school science. In India, astronomy is usually included in the "geography" curriculum and less frequently in the science curriculum and it is generally introduced at Grade 3. We next describe the curriculum of the Maharashtra State Board as seen in the textbooks which were followed by our sample. We outline the content related to astronomy in each grade, examine it with reference to the cognitive challenges discussed above, particularly in relation to visual-spatial thinking, and the possible use of visuospatial tools such as concrete models and diagrams. This description of the textbook contents is also meant to set the context of school learning within which our study was carried out. The 'diagram', 'chapter' and 'page' numbers referred to in this Section are as in the textbook. All the textbook figures are given in Appendix F and numbered as Figure F.1a, F.7i etc..

Grade 3 (Geo, 1993): The first three chapters in the Grade 3 geography textbook (pages 1-6) deal with content related to astronomy. The terms 'the sun', 'planets', 'the earth', 'satellite', 'the moon' and 'phases of the moon' are introduced in the first chapter (Stars and planets). A diagram for phases of the moon (diagram 1.1 on page no. 1; Figure F.1a) gives five snapshots of the moon shown in line. These snapshots of the phases are not shown at regular intervals; the gibbous shapes and the new moon are simply omitted. A part of the moon is shown lit (white) and the remaining part of the circle is shaded. The orientation of the phases and the light-dark shading are not true to the observed orientation of the phases from any where in India.

The terms 'day', 'month', 'week', 'year' are introduced in second chapter (Measurement of time). Diagram 2.1 (page no. 3; Figure F.1b) in the chapter explains the occurrence of day and night. A sun with divergent rays is shown and next to it parallel rays are shown near the earth. There is no scale and no apparent reason for the change in rays from divergent to parallel. The Marathi and English names of the months are also given.

Four major (North, East, West, South) and four minor (North-east, South-east, South-west, North-west) directions are introduced in the third chapter (Directions). The East is introduced in the beginning of the chapter as the direction of the sunrise and other directions are defined with respect to it. In the two diagrams for major and minor directions (diagrams 3.1 & 3.2 on page no. 5; Figures F.1c & F.1d), North is shown over the head of the person in both the diagrams. The text indicates that the boy has stretched his arms in the North-South direction, but this is not clear in the diagram due to the use of mixed perspective. No reference is made to the Up and Down directions. (We later found that confusion between North and Up, and South and Down was one of the major problems among students.) Perhaps there is no need to teach names for the minor directions (which are quite difficult in Marathi) to Grade 3 students.

In the same diagrams a full sun (not a rising sun) is shown towards East very close to the person. We found later, during classroom interaction that students associated the sun and the East so tightly (at least in a diagram context), that they labelled any direction as 'East' when they saw the sun depicted in that direction. For example, in sun-earth diagrams such as Figure 4.10 (or for a person standing on the equator (with a horizontal equator)) the direction where the sun will appear is Up, but students insisted that it is 'East'.

Grade 4 (Geo, 1992): Information about the sun, names of the planets and their shapes is provided in the first chapter (Solar system, pages: 1-4). In an accompanying diagram for the Solar system (diagram 1.1 on page no. 1; Figure F.2a), the partial sun and the nine planets are shown in a line. This is the first and only diagram representing the solar system in Grade 4. Its out of scale nature (with respect to sizes and distances) is not clarified in the text. Showing all the planets in line may give a wrong first impression.

Further, a photograph of the earth from a satellite is mentioned. A shaded (gray and white) visual representation is reproduced which may be a drawing or a low quality photograph (diagram 1.2: Our earth on page no. 2; Figure F.2b). The irregular patterns on the earth may be clouds. The spherical nature of the earth is not clear in the photograph. The word used for the shape in the textbook is 'gole/ golakar', an ambiguous word which could be translated as 'round' (shape) and may refer to a 'circular or 'spherical' shape.

The motion of the earth is explained next (rotation and revolution, and the time periods, orbit, its elliptical shape, the position of the earth in the solar system). The corresponding diagram, 'Orbit of the earth' (diagram 1.3 on page no. 3; Figure F.2c) shows two earths in an exaggerated eccentric orbit. The shape of the orbit is asymmetric (egg-shaped). The diagrams is neither technically correct nor simplified. An arrow could have been used to show the revolution of the earth instead of the earth at two positions.

Occurrence of day and night is explained with the help of a diagram 'Night-day' (diagram 1.4 on page no. 3; Figure F.2d). This diagram is on the same page as the previous one which shows the sun with divergent rays, whereas this one depicts parallel rays from a partially drawn sun. No explanation for this inconsistency is given in the text.

Grade 5 (Geo, 2006a): In the first chapter in Grade 5 (The shape of the earth, page nos. 1-2), three evidences for the spherical shape of the earth are given: **i.** the photographs of the earth from space, which is already introduced in Grade 4 (a good quality photograph occurs on the cover page of this book). **ii.** the shape of the shadow of the earth in the solar eclipse. Students are asked to observe shadows of a disk and an orange cast at different angles to discover and their diagrams are provided in diagram 1.1 (Shadow of a disk and an orange on the shapes of the shadows on page no. 1; Figure F.3a), **iii.** going away from the coast in a ship or a ship approaching a coast. In the accompanying diagram (diagram 1.2: A ship approaching an observer page no. 2; Figure F.3b) the word 'line of sight' is used but not explained in the text. Line of horizon would have been more appropriate, since the line of sight is not a fixed line for any observer. Students are asked to perform this exercise with a small paper boat on a large ball or on a large inverted *kadhai* (hemispherical vessel or wok). Both of these activities are simple and appropriate.

Diagram 1.3 (page no. 2; Figure F.3c) shows the axial and equatorial 'diameters of the earth' and informs us about the bulge at the equator. The words '*Uttar Dhruva* (North Pole) '*Dakshin Dhruva*' (South Pole), and '*Vishuvavrutta*' (Equator) are used in the text as well as in diagrams. These terms are explained in the next chapter. Unfortunately the term 'pole' is introduced in Grade 5 geography whereas 'axis of rotation' (a prerequisite concept) is introduced in Grade 6 (in both geography and science textbooks). The meaning of terms such as 'equatorial diameter' and 'polar diameter' is left to the students' intuition.

Chapter 2 (Determining location on the earth, page nos. 3-5): A simplified example of a Cartesian graph is introduced with diagram 2.1 (page no. 3). The concepts of latitudes (diagram 2.2: Drawing latitudes on a globe on page no. 3; Figure F.3d), longitudes (diagram 2.3: Drawing longitudes on a globe on page no. 4; Figure F.3e), and how to determine the coordinates of a location on the earth (diagram 2.4 : Latitudes and longitudes on page no. 4; Figure F.3f) are introduced with some activities with a ball or a globe. It is also stated that the length of a great circle is equal to circumference of the earth. The concept of 'terminator' is introduced using a ray-diagram (diagram 2.5: The terminator '*Prakashvrutta*' on page no. 5; Figure F.3g) and it is told that the terminator is also a great circle. That the terminator actually divides the earth in two parts could have been demonstrated using a model.

Chapter 3 (Local time and standard time, page nos. 6-7): This chapter gives information about the motion of the earth (rotation around axis/ axial motion, revolution/ orbital motion) and relates the local time (noon, day, night) with rotation. A diagram from an observer centric perspective is provided and the shadows are drawn using parallel rays from the sun (diagram 3.1: Positions of the shadows and noon on page no. 6; Figure F.3h). The terms local time and standard time are explained and the examples of each are provided (difference of 1 hour 56 minutes in the Easternmost and Westernmost parts of India; Five and half hour difference between Indian Standard Time and Greenwich Mean Time).

Concrete models are suggested for the first time in the Grade 5 geography textbook although the earth and day-night are explained in Grades 3 and 4.

Grade 6 (Geography) (Geo, 2006b): The first chapter in the geography book (Solar system, page nos. 1-3) starts with information about stars and planets, solar system, the sun, planets, satellites. A schematic diagram of the solar system (diagram 1.1; Figure F.4a) is provided, which contains the sun on the extreme left side and planets and their partial orbits. It is difficult to determine the perspective of this diagram. The orbits of the inner planets are almost circular and those of outer planets are shown more elliptical. The rings of Saturn, Jupiter are shown from an oblique view. Axial motion and the direction of orbital motion is not shown. A straight line trajectory of a comet is shown. The terms 'asteroids', 'dwarf planet', 'comet', 'meteoroid', 'inner and outer planets', 'galaxy', 'artificial satellite' and 'space ships' are introduced. The characteristics of planets, and tables for their relative sizes, distance from the sun, number of moons, inclination of axis, period of rotation and period of revolution are given at the end. Students are asked to use the data to draw a picture or diagram of the solar system.

Chapter 2 (Motions of the earth and their consequences, page nos. 4-5): Axis and orbital motion of the earth is described along with observational consequences of each. The diagram of an exaggerated ellipse (diagram 2.1: Apogee and Perigee positions, Figure F.4b) is a standard textbook diagram which however leads to the widespread misconception about seasons, that the earth is closer to the sun in summer and farther in winter. The diagram uses mixed perspective (orbit from above and the axis from side). An activity using a bangle and a matchstick is suggested to show that the inclination of the axis remains the same around the orbit. An activity of drawing an ellipse using two pins and a thread is also given. (The word '*kendrasthan*' is a rather non-standard translation of 'focus'?).

Chapter 3 (Seasons, page nos. 6-8): The apparent changes in the rising position of the sun are described along with the Marathi terms for them (*Uttarayan* & *Dakshinayan* which means 'going towards the North' and 'going towards the South'). The situation at the equinox (diagram 3.1, Figure F.4c) and the two solstices (diagrams 3.2 and 3.3, Figure F.4d & F.4e) is explained using diagrams. Diagram 3.4 (Figure F.4f) shows an oblique view of the earth's orbit with the sun at the center. Although different perspectives are used in different diagrams this is in general not specified in any of the diagrams.

Chapter 4 (Local time and international date line, page nos. 9-11): The time difference on different longitudes is explained and the Coordinated Universal Time ('International Standard Time' if translated back from Marathi) is introduced. The discontinuity in the time at the 180° longitude is explained using a game and the international date line is introduced.

One of the initial pages includes four figures of the earth with map showing the continents and oceans on it, one from above the North pole (Northern hemisphere), one from above the South Pole (Southern hemisphere) and two from within the plane of equator (Eastern and Western hemispheres). Overall the Grades 5 and 6 Geography textbooks have several diagrams that are pedagogically appropriate and they also suggest interesting activities to students. Their main problem may be an overload of facts and a lot of often redundant terminology.

Grade 6 (Science) (Sci, 2007a): The content on the first two pages of chapter 12 (page nos. 109-118) in Grade 6 science textbook deals with why the earth is hospitable to life, going on to the axial and orbital motion of the earth. A photograph (or a picture) of the earth (Figure F.5a), and a schematic diagram of the solar system (the sun, the planets and their orbits, with no arrows to show direction of motion; Figure F.5b) are given on the first page of the chapter (page no. 109). In another diagram (Figure F.5c on page no. 110), the rotational motion of the earth is shown by a tilted axis and two dotted curved arrows near the middle of the earth. The significance of another thick curved line through the Indian ocean remains unknown. None of the diagrams carry a caption.

Grade 7 (Geo, 1995a): The first chapter in the geography textbook (Revolution of the earth, page nos. 2-5) explains the revolution of the earth. The terms, diagrams and overall content a similar to but more detailed than chapter 3 in the Grade 6 geography textbook (diagram 1.1: Summer solstice - position on 21^{st} June; Figure F.6a, diagram 1.2: Winter solstice - position on 22^{nd} December; Figure F.6b, diagram 1.3: Position on 21^{st} March and 22^{nd} September; Figure F.6c, diagram 1.4: Revolution of the earth and seasons; Figure F.6d). One diagram explaining that the intensity of light depends upon the angle of incidence of parallel sun-rays (diagram 1.5: Perpendicular and oblique sun-rays; Figure F.6e) and another showing the corresponding temperature belts on the earth (diagram 1.6: Temperature belts on the earth; Figure F.6f) are newly introduced in Grade 7.

In chapter 4 (pages 13-14) there is a two page discussion about the tides which contains three diagrams: two of them have the moon and the sun on the same side of the earth and in the remaining one, the angle between the sun and the moon is 90° (tides were not dealt with in our intervention).

Grade 8 (Geo, 1996): The first three chapters on the Grade 8 geography textbook are: The universe (page nos. 2-3), The moon and phases of the moon (page nos. 4-6) and eclipses (page no. 7-9). In the first chapter schematic diagrams of two orthogonal views of our galaxy are shown (diagram 1.1: Galaxy (if seen from front) & diagram 1.2: Galaxy (if seen from side) both on page no. 2; Figures F.7a & F.7b). Information about its size, stars, the number of stars in the galaxy, position of the sun in the galaxy etc. is provided. A diagram of the Great Bear and the Pole Star (diagram 1.3: *Saptarshi* and *Dhuvatara* on page no. 3; Figure F.7c) is one of the few diagrams which represent observations. The chapter gives information about other celestial objects such as the sun (its distance from the earth, temperature, the sun-spots), asteroids, satellites, and comets. The term 'Light Year' is explained at the end of the chapter.

The second chapter provides information about the moon (shape, gravitation, density, origin, motion and its consequences). Diagram 2.1 (on page no. 4; Figures F.7d) shows the 'Apogee and Perigee positions of the moon'. The phases of the moon are explained using a schematic diagram (diagram 2.2: Phases of the moon on page no. 5; Figures F.7e) which uses the parallel rays (drawn in a small portion) and the top view of the orbit. The arrow for direction of revolution of the moon is shown and waxing and waning phases are specified. Only three Marathi names of the phases (for the full, new and the half moon) are used. The observable phases are drawn outside the orbit. These could have been drawn more accurately using a projection technique.

A section on artificial satellites and spaceships gives uses of these devices, a mention of space science in India along with a map of locations of space research centers in India (diagram 2.3 on page no. 6).

Chapter 3 on eclipses begins with the explanation of the lunar eclipse with the help of an explanatory diagram (diagram 3.1 on page no. 7; Figures F.7f). The orbit of the moon and the direction of revolution of the moon is shown in the diagram. However, without any introduction to shadows the diagram of the lunar eclipse is introduced with the sun as an extended source. There is no addressing of the inconsistency that the sun was treated as a source of parallel rays until this point. No arrow-heads are shown on the light rays. Eclipses could have been explained more simply though less accurately using parallel sun rays. Prior exposure and training in drawing ray diagrams would have helped greatly.

The total and partial solar eclipse is explained using diagram 3.2 (on page no. 8; Figures F.7g) and the annular solar eclipse is explained using diagram 3.3: Solar eclipse (on page no. 8; Figures F.7h). The figures are similar to the diagram for the lunar eclipse. Diagram 3.4 (on page no. 9; Figures F.7i) shows the observable views of solar eclipses (partial, total, annular). The characteristics of both lunar and solar eclipse are listed and it is also noted in the beginning of the chapter that the eclipses have nothing auspicious or inauspicious about them.

The back of the cover page of the Grade 8 geography textbook includes two colour photographs of the total solar eclipse (one shows the corona and the other shows the diamond ring) and one photograph of a comet. The captions are given on the contents page.

The Grade 8 Science textbook (Sci, 1996) mentions gravitational force in relation to projectile motion. The Grade 9 Science (Part I) textbook (Sci, 2006) has a section on 'Gravitational force' in the Chapter 'Classification of Forces', which includes Newton's law of gravitation, gravitational force of the earth (Diagram 8.2 on page no. 93; Figure F.8) and acceleration due to gravity. Science textbooks of Grades 8, 9 (Part I) and 10 (Part I) ((Sci, 1996, 2006) & (Sci, 2007b)) include a chapter on 'Light' each dealing with different aspects of geometrical optics (shadows, reflection, refraction). Concepts from both gravitation and optics are of vital to astronomy. Some geometrical concepts, which are useful in astronomy, are introduced in the higher grades (Grade 9, 10). For example, two dimensional Cartesian geometry is introduced in Grade 8 (Mathematics) (Mat, 1996). The geometry textbook of Grade 9 (Geo, 2006d) contains a chapter on 'Point, line and plane', where the plane gets introduced for the first time. Three dimensional shapes are introduced in the Geometry textbook of Grade 10 (Geo, 2006c) in the context of volume. However, this content in the Science and Geometry textbooks is introduced after the dependent concepts in astronomy are learnt (up to Grade 8) and it remains unconnected to the astronomy part in the Geography textbook.

Geography textbooks of Grades 9 & 10 (Geo) & (Geo, 1995b) do not include any content related to astronomy (Notably, last chapter of older Science textbook (Part II) (Sci, 1995) was 'Space Research' (page nos. 147-158) which was removed in the revised textbook.

Overall, in the current Maharashtra State Textbooks, there is very limited use (or suggestions for use) of concrete models (most such suggestions are in the geography textbook of Grades 5 and 6). Some of the diagrams in the textbooks may communicate incorrect information, are open to misinterpretation or may create misconceptions in students. The views (perspectives) are not specified nor used consistently. No effort has been made in general to sensitize students to the scale (sizes and distances) and assumptions in the diagrams. Whether the diagram represents an observable phenomenon or a model, or is an explanatory diagram, is not clear from many diagrams, and is not specified in any of them. Most of the diagrams (especially the explanatory ones which are difficult to comprehend) are not well connected to the text. The content is presented more in an informative fashion rather than as reasoned arguments. The information about the motion of the earth is repeated in all the Grades and the use of terms across the Grades is not consistent (eg. as many as three terms, '*pariwalan*', '*akshiy gati*' and '*dainic gati*' for axial motion and '*paribhraman*', '*kakshiya gati*' and '*varshik gati*' for revolution). The occurrence of day-night is explained in Grades 3, 4 and 5 and occurrence of the seasons is explained in Grades 6 and 7, almost identically. Revolution of the earth is introduced in Grade 3 but its observational consequence in the night sky is never mentioned. In fact, the changes in the night sky could have been introduced first and then the reason could have been told (an order similar to the historical development). In practice teaching is driven by the limited expectations from students in examinations, in which neither is knowledge probed in detail nor are any problems posed, that could be based on new or hypothetical situations. Consequently even the diagrams are rote-learned and reproduced in examinations. This is the situation that we are trying to address.

1.5 This study

The study consists of three parts: **1.** investigation of students' initial knowledge, **2.** exposing students at the end of Grade 7 to various problem situations over one year, requiring them to explain or predict some daily astronomical phenomena with the help of tools for visuospatial reasoning such as concrete models, gestures and diagrams and **3.** assessment of their progress at the end of Grade 8. At the heart of the thesis are the rationale and specific features of the pedagogical sequence that we developed with the aim to help students use visuospatial reasoning to explain daily astronomical phenomena, and analysis of the spatial tools used in this pedagogy.

1.6 Organization of the thesis

The motivation and significance of this study and current state of astronomy education in general and in the State of Maharashtra has been provided in this Chapter. Results from literature on astronomy education and some findings from cognitive psychology which are crucial to this study are summarized in Chapter 2. Chapter 3 describes the research design and the characteristics of our student samples. The pedagogic sequence in our intervention is described in Chapter 4 and analysis of the spatial tools used in the pedagogy is presented in Chapter 5. Chapters 6 and 7 provide a detailed analysis of data from the pre-intervention and post-intervention tests. Results from earlier chapters and insights gained during intervention are summarized in Chapter 8. The original tests and the material used during the intervention are given in the Appendices.

Chapter 2

Literature Review

This chapter begins with a review of literature in astronomy education (Section 2.1). Next we review four main issues from cognitive science that have a bearing on learning of astronomy, namely, conceptual change (Section 2.3), mental models (Section 2.4), visualization (Section 2.5) and spatial cognition (Section 2.6). Important terms in cognitive science are explained in Appendix G.1. It turns out that studies of astronomy learning have considered conceptual knowledge frameworks and in some cases mental models but research on visualization and spatial cognition has been largely overlooked so far. The Chapter ends with a review of literature on spatial tools, specifically gestures and actions (Section 2.7) and diagrams (Section 2.8) which are of particular importance for our study.

2.1 Astronomy education

A report on research in astronomy education by Bailey et al. (2004) reviews the literature from 1973 to 2004. Bailey et al. mention an earlier review by Charles Wall (1973), according to which 58 studies were carried out in astronomy education between 1922 and 1972. Subjects of these studies include: students' conception about moon, the day/night cycle and gravity. Wall classified these studies in two ways: by school level and by type of research. He found 21 studies at elementary level, 19 at secondary level, and 18 at college level. Based on type of research Wall found 12 descriptions of the field of astronomy education, 31 studies on achievement, and 15 on curriculum development. This distribution shows that more than half the studies in this period (1922-72) were on achievement and the studies were distributed almost equally over all the levels from elementary to college. Bailey et al.'s review from 1973 to 2004 found a few research studies on student understanding in astronomy covering several topics such as lunar phases, the shape of earth and related issues, diurnal motion, cosmology and astrobiology, planetary motion, definitions of terms like equator, axis and orbit, explanation of seasons and beliefs about astronomy as a subject. Research on instructional methods included studies on teaching for conceptual understanding, collaborative learning in astronomy, and specific curriculum interventions. Bailey points out that research in astronomy education is a relatively new field. The first dedicated journal in this field, "Astronomy Education Review", started in 2002, is an electronic journal (Bailey et al., 2004).

Deustua et al. (2009) submitted an article in support of astronomy education research to a subcommittee on the status of the profession. These authors proposed that the research in astronomy will be useful for **i.** Professionals who want to assess the knowledge and skills of astronomy students, **ii.** Elementary and secondary school administrators and educators, and **iii.** Research scientists who work at the interface between astronomy and learning.

A more recent review by Lelliott and Rollnick (2009) selected 103 articles based on the following criteria:

i. Only peer-reviewed print-based journal articles published between the years 1974 and 2008 in which astronomy is the focus of the study, based on the big ideas described below.

ii. Studies conducted in primary and secondary classrooms, during visits to museums and science centres, and among pre- and in- service teachers. Post-secondary courses (e.g. university level courses) are not included, with the exception of teacher education.

iii. Empirical studies, conceptual pieces, and reviews from the full range of research methodologies, but excluding historical analyses, practitioner, and opinion pieces.

The review is structured around eight 'big ideas' (important topics or key concepts as identified by the American Association for the Advancement of Science's

Project 2061) in astronomy. Four of these topics (gravity, the solar system, stars, and the concepts of size and distance) are regarded as fundamental to astronomy. The other four big ideas (earth's shape, the day/night cycle, the seasons, and the earth-sun-moon system) represent topics commonly taught at school level, and intensively researched over the past 30 years. Several researchers found that primary teachers had similar misconceptions as their students across a range of big ideas, which suggests the need for improved training at this level particularly teachers' pedagogical content knowledge.

There has been considerable increase in peer-reviewed journal articles on astronomy education since the early 1990s. The number of intervention (as reported detailed description of interventions) increased after 1990, and especially after 1997 (prior to 1997 there were only two).

Most authors did not specify the theoretical basis of their research. In a quarter of the articles more than one theoretical framework was evident, and Lelliott and Rollnick identified four principal frameworks across the field. They are:
i. Conceptions held by study participants, normally associated with individual or personal constructivism and in some cases relating to Piaget's developmental theories
ii. Mental models or frameworks of conceptions held by participants
iii. Studies of conceptual change and knowledge acquisition
iv. Cultural, cross-cultural, and worldview studies

The most commonly identified theoretical framework used by researchers was that of 'conceptions'. The earlier studies (1970s and 1980s) mainly consisted of researchers attempting to identify students' misconceptions, and (to a lesser extent) comparing these across cultures. By the 1990s, the research was becoming more theorized, with interest shifting to Vosniadou's mental model theories, often coupled with how students were able or struggled to change their non-scientific conceptions. Cross-cultural, mental model, and conceptual change theories have dominated research articles since the turn of the century.

Less frequently occurring frameworks included sociocultural theories and attitudes. However it is important to note that studies related to attitude found that astronomy scored highest when compared with the other sciences (in a survey of about 3000 15-year-olds in the UK as they entered key stage 4, and again at the end of the year). During subsequent interviews with a sample of the pupils, the researchers cited by Lelliott and Rollnick found that the ‘remoteness’, ‘unknownness’, and excitement of discovery all contributed to the level of interest, and they concluded that “there seems to be something inherent in the subject of astronomy itself which appeals to many of our young people”.

Some potential problems and solutions suggested by the authors are: relatively few researchers identified language as being a barrier to understanding concepts in astronomy, but it is likely to be important, especially for second-language learners. The authors suggest that future researchers promote the manipulation of physical models while subjects are being questioned, either by written or interview methods, so that a more accurate estimation of their knowledge can be obtained. We further suggest that a full description of the models be provided, so that subsequent research can build on the findings established.

At the school level there has been little discussion on what are the most appropriate topics to cover. Lelliott and Rollnick suggest that research into the most relevant big ideas in astronomy in relation to countries’ curricula would benefit their schooling systems. Part of the problem may be due to the subject of astronomy falling across the disciplines of physics, geography, astronomy, and earth science, resulting in under-educated teachers teaching it to students. It is vital that each disciplinary constituency becomes familiar with the teaching methods and research carried out in the others. There has been a tendency for research into astronomy education to be reported in separate disciplines, and for the field to flourish there needs to be a greater emphasis on inter-disciplinary cooperation. Similarly, astronomy education researchers need to find innovative ways in which to disseminate their findings to teachers (Lelliott and Rollnick, 2009).

Next we will summarize results from diagnostic research in the area of elementary astronomy and then describe some of the important efforts of material development.

2.1.1 Alternative conceptions in astronomy

The earliest influential diagnostic work done was by Nussbaum and Novak (1976) on young American students' concept of the earth. This paper demonstrates that students as young as Grade 2 construct their own notions depending upon their experiences and exposure. The method of testing was structured interviews, based on Piaget's clinical interview method[1] In order to identify the intuitive notions, Nussbaum and Novak interviewed half the students prior to instruction and the remaining half after instruction. Six audio-tutorial lessons of 15 to 25 minutes duration were the mode of instruction (there was no intervention from teachers). The lessons dealt with the concepts of the earth and some relevant prerequisites such as distance, space, force, gravity and modeling. The study revealed five different notions of the earth:

I The earth we live on is flat and not round like a ball. There are four versions of this notion, out of which first two focus on local roundness on the earth:

- **a** The earth's roundness is just the road's curves.
- **b** The earth's roundness is just the mountain's shape.
- **c** The globe represents some other planet in the sky.
- **d** The earth's ballness is just the shape of the sky.

II Students who held Notion II believe that the earth is like a ball, and could suggest some proofs for the spherical shape, but lack the notion of unlimited space. These students believe that a ground limits the space below, and the sky limits the space above the earth.

III Students who held Notion III had some idea of unlimited space, but still hold a frame of absolute up-down directions.

IV Students who held Notion IV do relate up-down directions to the earth; but up-down are directed only in the vertical direction instead of away or towards the center of the earth.

[1] Subsequently the clinical method was extensively used in the area of astronomy education, sometimes along with the written questionnaire. Brewer (2007) has argued in support of this methodology, especially over close ended questionnaires.

V Notion V is the scientific notion where students held the notion of a spherical planet surrounded by space and things falling to its center.

Nussbaum and Novak found students at each of these levels and claimed that students go through an intellectual progression while undergoing conceptual change. Thus learning the concept is accomplished in a series of identifiable steps rather than as a single "conceptual leap". Also, the study revealed that the given instruction did not result in significant advances in students' concepts of the earth, which showed that the intuitive notions are robust and need a powerful instructional strategy to attain the correct notions (Nussbaum and Novak, 1976).

Mali and Howe (1979) investigated 8, 10 and 12 year old Nepali students' concepts of the earth and gravity using tasks similar to those used by Nussbaum and Novak (1976) and the same schemes of five notions for analysis of students' responses. The authors note that Nepali people had no formal schooling nor exposure to media that could introduce modern scientific ideas to them. This study found that all five of Nussbaum and Novak's notions were present in Nepali students, with a large number of students holding Notion I. Their versions of Notion I were slightly different from those in Nussbaum and Novak (1976) and are as follows:

a No concept of the earth and gravity (child has never heard this word before)

b1 Flat earth like a disk (either empty space or rocks, soil, water below)

b2 Flat earth like a disk (endless layers of such worlds)

c The dome of the sky and possibly one such below for a spherical earth, and we live on a flat surface cutting through the center of it.

Note that the notion of 'earth is another planet in the sky' in the original scheme (Nussbaum and Novak, 1976) was absent in this scheme. The authors concluded that:

• Nepali students were slower in changing their notions in comparison with American students.

• The frequency of higher level notions increased with age which supported the hypothesis of serial progression of a concept by Nussbaum.

• The authors also administered a set of Piagetian tasks of conservation, seriation and classification and found the intertask correlations moderate but statistically significant. From frequency distributions, high scores on conservation were found to be a necessary but not sufficient condition for a higher level notion of the earth concept.
• The authors found that notions of the earth depend upon cognitive development as well as on access to sources of information (Mali and Howe, 1979).

Another cross-cultural study in the same line by Klein (1982) compared concepts of earth in 7 and 8 year old Mexican-American and Anglo-American students. This study focused on a group of 8 concepts related to the round rotating earth, which students had already learnt in the school. The method of investigation was again interviews. This study concluded that
• Majority of students from both the groups had alternative notions regarding the earth, hence additional research was needed to determine whether the age at which these concept are introduced and current instructional are appropriate.
• Mexican-American students gave fewer answers that demonstrated understanding than Anglo-American students for six of the eight concepts, and for the other two concepts, there were no significant differences. Mexican-American students gave more answers which demonstrated pre-causal thinking. According to the author, there might be two reasons for this: firstly, although Mexican-American students were bilingual and had no apparent difficulty in understanding everyday English, the language in the classroom might have posed a difficulty. Secondly, self-image could have played significant (negative) part in their learning.
• There were no apparent sex differences in understanding in either group (Klein, 1982).

Sneider and Pulos (1983) conducted a larger cross-sectional study to identify students' 'alternative frameworks' with 159 students from Grade 3 to Grade 8. The method of testing was again structured interviews, which included 6 items (3 on shape of the earth and 3 on gravity) modified from Nussbaum and Novak (1976). Students were divided into 3 levels based on a "gravity scale" (absolute 'Down'; 'Down' towards surface of the earth; and 'Down' towards center of the earth) and into four levels based on the "earth's shape scale" (flat earth; partially flat from upper side; ball shaped earth, but people live only on the top of the earth; and spherical earth with people living all around it). (Out of 5 notions identified by Nussbaum and Novak (1976), the first three correspond to the first three levels of the shape of the earth scale and first level of the gravity scale. Notion IV correspond to Level 4 in shape scale and level 2 in gravity scale and Notion V corresponds to level 4 on the shape scale and level 3 on the gravity scale.) There was a strong positive relationship between the two scales and the data fit well with the model predicted by Nussbaum in 1979. If another Notion (level 3 on the shape scale and level 2 on gravity scale) is introduced between Notion III and Notion IV, the model fit even better. Students at this level understood that objects fall towards the surface of the earth, but failed to grasp that people live "under our feet" on the other side of the world.

Sneider and Pulos also carried out a multiple regression analysis using as independent variables the students' performance on tests of these cognitive abilities: 'Verbal Opposite test', 'Spatial Reference system' and 'Field Independence/ Dependence' and on a fourth test of students' interest in geography and science. Two further independent variables were age and gender. The only significant predictors of understanding of earth and gravity concepts were found to be verbal ability, spatial reference frame and gender. Verbal ability made a significant contribution at all levels, spatial reference frame contributed to the attainment of Notions IV, V and VI while gender contributed only to the advancement from Notion V to VI. These gender differences were attributed to the possibility of difference in astronomy-related experiences of girls and boys.

Interestingly, Sneider and Pulos's study integrated the earlier three studies (Nussbaum and Novak, 1976; Mali and Howe, 1979; Klein, 1982) to find a pattern of development in the concepts related to the earth and gravity. The analysis of 741 students from all four samples suggested that:

- Most students through age 10 held Notions I, II and III.
- The widest spread of these notions was among the 11 and 12 year olds.
- Most students aged 13-14 held Notions IV and V.
- There was considerable variation in concept attainment within each group and between groups of approximately the same age.

• There were no major differences in frequency profiles of students from different cultures (Sneider and Pulos, 1983).

A study by Jones and Lynch (1987) was the first one to investigate a broader content related to the sun-earth-moon system. Nine to twelve year old Tasmanian students (from Grades 3 to 6) were interviewed about shape, size and motion of the earth, sun and the moon. The authors were motivated to challenge then existing astronomy teaching as "diluted descriptive" in which "students are 'told the facts' rather than be confronted with the original evidence and arguments" and argued for a return to the "qualitative and quantitative sharpness recommended in early science texts". The authors argue that the rise of heuristic science teaching with its emphasis on direct experience may be a factor in the decline of astronomy education. Incidentally, the observations of a fact-based rather than evidence-based approach is similar to what we have found in India, as described in Chapter 1.

Jones and Lynch is probably the first published study which used concrete objects and asked students to choose those which resemble the shapes of celestial objects and manipulate them to show the motion of these bodies. All earlier documented studies used drawings as far as this literature survey can determine.

The students' cosmographies found in this study fell under five distinct spatial models. Three of them were earth-centered: **1.** a "magic model" in which the sun and the moon move close to earth and far away which results in change in intensity of the light and in day and night; **2.** a spinning earth model with the sun and moon at fixed positions on opposite sides; and **3.** an orbiting sun and/or moon model, in which the earth is fixed. Models 4 and 5 were heliocentric: both earth and moon orbit around the sun in the Model 4, and Model 5 was the accepted scientific model, in which the earth rotates and revolves around the sun and the moon does so around the earth.

Note that except Model 1, which reflects a 'primitive' notion of the system, all the others were logically workable models to explain day and night. Students who held the last two models could correctly explain the occurrence of day and night. Most of the students (even those who held Model 5), did not know the details such as rotation times and whether the moon rotates.

The responses regarding shape were of 3 kinds: at least one of the three shapes two-dimensional, all three shapes 3 dimensional but not all spheres, and finally, all the shapes chosen to be spheres. Further the sizes and order of the sizes of the sun, earth and moon were also recorded.

Jones and Lynch found a positive relationship between grade level and selection of spatial model. Older students (Grade 6) chose a sun-centered model more often than an earth-centered model. There was significant relationship between grade level and choice of shape, but the relationship between choice of shape and gender was not significant. There was no evidence for relationship between grade level and knowledge of relative sizes, but there was evidence of relationship between gender and knowledge of relative sizes. Fewer girls than boys selected the correct relative sizes.

Jones and Lynch see a similarity between the hierarchy in students' responses and the historical development of understanding of the earth-sun-moon system. They consider it unlikely that students would observe astronomical phenomena and understand the possible discrepancy between their perception and reality. Rather the development of correct notions of relative sizes must arise from direct communication through textbooks, media, formal teaching and family discussion. Models 2, 3 and 4 of students' cosmographies are unlikely to come through school, media and books, they may be a result of interaction between students' knowledge derived from the perception of natural phenomena and current science knowledge presented by teachers, textbooks and media. This hypothesis was based on Ausubel's model that the child assimilates new information into an existing cognitive structure but in the process of assimilation, components of intended meaning may become distorted. This theory, which leads to the notion of alternative frameworks, has sustained one of the important streams of research in the area of astronomy education (Jones and Lynch, 1987).

For example the study by Baxter (1989) investigated students' alternative theories about daily astronomical phenomena and drew parallels between students' theories and historical theories in the Middle edges. This study addressed two additional notions, namely, 'phases of the moon' and 'seasons' along with the notions of 'earth and gavitation' and 'day-night' which were already studied earlier. Twenty students from UK between the ages 9 to 16 years were first interviewed to construct an astronomy conceptual survey instrument. This multiple choice instrument was administered to 100 students from a similar background and age-groups.

Regarding the planet earth in space and gravitational field Baxter found four notions (similar to Nussbaum (1979)). The most popular notion, which gained support with age was ‘round earth but with absolute vertical up-down’. The notion of the ‘flat earth’ and ‘round earth with people living only on the upper part’ declined with age. A few students, only in the older age groups, agreed with scientifically accepted notion.

On day and night the younger students gave more occultation based explanations (the sun goes behind the hill or it gets covered by clouds or by the moon) while the older students gave more explanations involving the movement of astronomical objects. Explanation involving the sun orbiting around the earth and the earth orbiting around the sun once a day were consistent with cosmographical Models 4 and 5 identified by Jones and Lynch (1987). The percentage of students who held the scientifically accepted notion increased at age 13 but inexplicably decreased at age 14.

Regarding phases of moon only the younger students held that they occur because the moon gets covered by clouds (Notion 1). According to Notions 2, 3 and 4 the shadow of some object (a planet, or the sun or the earth respectively) cast on the moon causes the phases. Notions 2 and 3 were not very prevalent but Notion 4, which happens to be the correct explanation for the lunar eclipse was the most popular explanation found in the study and in most later studies as well. The fifth, scientifically accepted notion was held by students from all age groups, but again, the percentage was surprisingly least for the oldest age-group.

Out of six notions to explain the seasons found by Baxter, the first two were rare and based on occultation (planet takes heat from the sun and the winter cloud stops the heat from the sun). The third, according to which the sun was the further away in winter, is most popular explanation. This result too has been confirmed in many later studies. Notion 4 (the sun moves to the other side of the earth to give them their summer) and Notion 5 (changes in plants cause the seasons) were again not very popular and are found only in two younger groups. The scientifically accepted sixth Notion citing the earth's axis "at an angle to the sun" was found in all age-groups but was more popular in oldest age-group.

The trend found by Baxter was that early notions were based on observable features, intermediate notions involved motions of astronomical bodies which at the end were (not always) replaced by scientifically accepted notions. Significantly, some students proposed two explanations at a time, reflecting an unresolved dilemma between the notions they been introduced to through schooling and their own physical observations. The study thus signifies the importance of initial conceptions that students bring with them before they are exposed to accepted notions and the intermediate notions they hold as they undergo conceptual change. The author suggests that younger students may be encouraged to observe as many of the astronomical events as possible but it may not be appropriate to expect understanding of scientifically accepted notions before early adolescence. Also, the presentation of ideas held in the past could be used to point out incorrect notions, to make students comfortable that their ideas although incorrect, were once popular views and importantly, to demonstrate the tentative nature of science (Baxter, 1989).

In a subsequent paper Baxter (1991) proposed 2 levels at which the Alternative Conception Movement could influence and enhance classroom practice:
Level 1: By developing teachers' awareness of the commonly occurring alternative frameworks.
Level 2: By having students identify their own particular explanation, put the notion to the test (the challenge may come from peers or by the teacher) and discover if it holds good.
This paper demonstrates the Level 2 approach for a group of third year students in England (Baxter, 1991).

In a large scale study by Schoon (1992) a multiple choice questionnaire was administered to 1,213 American students from elementary, secondary and college levels. The sample was drawn from both inner-city and suburban schools and was a mixture of students from white (63%) black (16%) and Hispanic (17.5%) groups. The questionnaire consisted of 20 questions based on 20 common alternative conceptions, out of which 2 were related to day-night, 4 were related to the moon and 2 were related to phases of the moon, 4 were related to seasons and path of the sun, 2 were related to observations of planets. The remaining 6 were related with geology and natural history, which we will not discuss here. For 6 of the questions, which all happened to be from astronomy, the alternative option was chosen more often than scientifically accepted conception, and these were called ‘Primary alternative conceptions’. The primary alternative conceptions (along with the percentage of participants which held it in brackets) were the following:

1. At 12:00 noon, the sun is directly overhead. (82.4%)

2. Summer is warmer then winter because the earth is nearer the sun. (77.6%, also found in (Baxter, 1989))

3. In May, June and July, the sun sets in the West. (58.6%)

4. When we have a full moon, people that same night in Australia will have a different phase of the moon. (52.9%)

5. The different phases of the moon are caused by the shadow of the earth falling on the moon. (48.1%, also found in (Baxter, 1989))

6. In each day during summer the amount of daylight is more than the day before. (32.4%)

For thirteen questions, alternative options were chosen less often than scientifically accepted conception, but twice as often as the least chosen distractors. They were called ‘Secondary alternative conceptions’. The secondary alternative conceptions related to astronomy are as follows:

1. We can often see planets at night but only with a telescope or a pair of binoculars. (41.5%)

2. It takes one day for the moon to go around the earth. (35.9%)

3. Day and night occur because the earth goes around the sun. (19.6%, also found in (Jones and Lynch, 1987; Baxter, 1989))

4. It takes one year for the moon to go around the earth. (19.5%)

5. The moon shines because it is like a star, just bigger. (15.7%)

6. The moon shines because it makes light like the sun. (9.5%)

7. We can often see planets because every night they are in the same place in the sky. (9.1%)

8. Day and night occur because the sun goes around the earth. (8.8%, also found in (Jones and Lynch, 1987; Baxter, 1989))

The alternative conception that ‘The direction North is straight up.’ (chosen by 4.7% participants) could interfere with one’s ability to function in society and was called a ‘Functional alternative conception’. This conception was more common among younger, urban, and minority students and according to the author, this may be (in terms of consequences) the most important of the alternative conceptions.

The alternative conceptions were prevalent in all age and racial groups, in both genders and among urban and suburban students. The prevalence of alternative conception decreased with age and educational level. The understanding of students who had taken earth science class was not always better than those who did not. Males held significantly fewer alternative conceptions than females, with the exception that black males held more alternative conceptions than black females. Urban residents held significantly more alternative conceptions than suburbanites. The possible reasons were attributed to the predominance of the minority groups in the urban sample and school system and curricula involved.

The author suggested that direct observations may help overcome many alternative conceptions. Making students reflect on their own conceptions and their limitations were pointed out to be important. Other ways suggested to facilitate conceptual change were, proposed as posing a problems which force students to make connections between concepts, discussion of history, and emphasizing relationship between the natural sciences and other disciplines. Importantly, the author suggests that manipulation of physical material will be useful and all the senses should be used when learning about the natural world (Schoon, 1992).

In 1992 Vonsniadou and Brewer published a paper on children’s mental models of the earth (Vosniadou and Brewer, 1992). The motivation of the study was to propose a framework for conceptual change and to place students’ mental models of the earth in this framework as an example. This and the subsequent series of papers by Vosniadou and her colleagues is discussed in the Section 2.4.

Bisard et al. (1994) compared 708 students’ conceptions through a questionnaire consisting of 11 questions about seasons, phases of the moon, tides, advanced astronomy, earth science and other physics concepts. The sample comprised of 180 middle school students, 157 high school students, 236 university freshman and sophomores, 56 university juniors and seniors in upper division science classes, 52 science majors in teaching methods classes and 27 in general education methods classes. The correct response rate steadily increased from middle school to introductory college students, then slightly decreased for science majors in teacher education classes and it was much lower for general education majors. Interestingly, the correct response rate for general education majors was approximately equivalent to middle school students, which indicates that the misconceptions might be getting fed back to students through their teachers forming a 'misconception cycle'.

No significant gender differences were observed at the middle school level, but became they noticeable at high-school with males scoring significantly better than females on many of the questions. Females scored significantly better only on the question on tides (Bisard et al., 1994).

Kikas (1998) tested Estonian students' ability to define and explain astronomical concepts (equator, axis, orbit, day-night cycle and seasonal changes). Twenty students were interviewed twice: 2 months after having gone through relevant instructions (in Grade 5) and then 4 years after that (in Grade 9). The teaching was done by a regular school teacher and when analyzed, was found to be formal, traditional, teacher centered. The teacher gave information for most of the time and students recorded it passively (unfortunately the picture is not very different in Indian schools). On this background, Kikas found that students remembered the definitions and explanations reasonably well (in the sense that their wording matched to that in textbook, but was not connected to their personal experience) two months after studying them. However, after four years, they had forgotten the scientific definitions, explanations, and facts and they used their everyday knowledge. Thus, ninth-grade students' explanations were similar to younger children's explanations (mainly synthetic answers) and they gave fewer scientific answers than the fifth graders (Kikas, 1998).

Ricardo Trumper published two consecutive papers in 2000 and 2001. The study (Trumper, 2000) was carried out on 76 Israeli university students from different disciplines to identify their conception of basic astronomy. There were 19 questions on day-night (time-zones), phases of the moon, distances and dimensions (absolute and relative), seasons (tilt in the earth's axis, position of the sun at noon), solar eclipse, motion of the moon (rotation and revolution) and nature of the universe. The same questionnaire was given to 433 students (351 females) of preservice training for future high-school teachers (both science and non-science majors from year one to four) in (Trumper, 2001). Forty seven percent were science majors and only 16% had studied physics course in high-school. Misconceptions were found to be common among university students and future high-school teachers. Table 2.1.1 shows the percentages of correct responses to each question from both the samples.

The analysis showed no significant difference through the years (Trumper, 2001). Males scored significantly better (57% & 45.6%) than females (43.2% & 36.8%) in both (Trumper, 2000) and (Trumper, 2001) respectively. Science major performed significantly better (43.7%) than their non-science colleagues (34.5%) (Trumper, 2001).

Stanton (2007) speculated on difficulties of South African teachers and students in astronomy education, especially because of a change in the underlying philosophy of teaching (valuing of indigenous knowledge systems), in the method of delivery (away from formal didactic teaching and rote learning) and in the curriculum (modern, relevant and utilitarian). Stanton felt that teachers were not ready to meet these challenges. Elementary astronomy was shifted from geography to science and science teachers were not competent with the content, nor with relevance of indigenous knowledge. Students continued to learn the explanations by rote because of their pre-existing frameworks, difficulty in visualization of three-dimentional spatial relationships and motions, and lack of visual literacy or difficulty in interpreting diagrams. The author recommended research on efficacy and limitations of textbook diagrams, use of models and development of spatial abilities in students (Stanton, 2007).

2.1.2 Alternative conceptions about the moon

Although study of alternative conceptions about the moon was part of most of the studies summarized so far, there are several recent studies have have focused exclusively on the moon. Most of these studies include both the implementation of instructional material and studying of students' conceptions. We summarize find-

Table 2.1: Summary of data from (Trumper, 2000) and (Trumper, 2001)

Question on	% Correct responses (Trumper, 2000)	% Correct responses (Trumper, 2001)	Major alternative conception
Reason of day-night	62	52	The earth moves around the sun
Time-zones	49	39	Latitude difference results in a greater time difference
Phases of the moon	51.3	48	The earth's shadow on the moon
Distance between the sun and the earth	35.5	36	Underestimation
Distance between the sun and a close star	19.7	22	Underestimation
Earth's diameter	31.6	18	Overestimation
Angular size of the sun as seen from saturn	39.5	40	
Relative distances from the earth (Moon - Pluto - Star)	50	39	Pluto behind stars
Reason behind seasons	67.1	63	Earth closer to the sun in summer
Longest daylight period in Australia	65	46	
Position of the setting sun after autumn equinox	27.6	28	
Position of the rising sun on summer solstice	17.1	19	Sun rises directly at the East
Position of the sun at noon	32.9	26	overhead
Time period of revolution of the moon around the earth	60.5	56	
Time period of revolution of the moon around the sun	68.4	56	Moon does not revolve around S
Time period moon's rotation	22.4	23	Moon does not rotate
Phase of the moon on the day of solar eclipse	22.4	19	Full moon
Centre of the universe	73.7	50	Sun is at center of universe
Overall correct response rate	48.5	38.4	

ings from these studies and also the pedagogic methods. We appropriated some of the activities developed in these studies to fit them into our approach of constructing mental models and using them for visuospatial reasoning, as explained further in Chapter 4.

The early and much cited study by Stahly et al. (1999) investigated third grade students alternative conceptions about phases of the moon. Stahly et al. noted that the alternative conceptions about the phases of the moon already documented in the literature were that, clouds cover the moon or that a planet or the sun or the earth casts its shadow on the moon. The most frequent alternative explanation of the phases of the moon was that the earth casts its shadow of the moon (which happens to be correct explanation for the lunar eclipse) proposed by 37% to 70% people in different studies.

Stahly et al. carried out pre and post-instructional interviews of four students (2 girls and 2 boys) of different abilities. They were asked to draw pictures of their explanations and create three-dimentional models to accompany their verbal responses. Pre-instructional explanations included cloud coverage and 'rotation of the earth' (earth's journey around the sun) and one's vantage point on earth (2 students). Post-instructional interviews showed awareness of the role of the sun in lighting up the moon and movement of the moon around the earth in the post-instructional interviews. Yet students maintained some aspects of their original conceptions even after instruction. Opportunity to manipulate models of the sun-earth-moon system to explain phases of moon was helpful in creating conceptual conflict, which in tern helped the conceptual change (Stahly et al., 1999).

Abell et al. (2002) designed their elementary science course for preservice teachers which followed the sequence: **a.** observe others teach, **b.** reflect on their own teaching, **c.** read and discuss expert theories, and **d.** examine themselves as a science learner. A 6-week study of phases of the moon included a number of activities aimed at helping students understand phases of the moon and reflect on their own science learning, enhancing their understanding of the nature of science and challenging students' existing theories about science teaching and learning and modifying them.

• Individual activity: Students were asked to observe the moon every day for a month and maintain a notebook to note day, time, shape and notes on weather conditions, viewing location and position of the moon in the sky These notes were discussed in the class and students were encouraged to reflect upon class discussions in writing. After two week, students recognized the pattern and began to generate predictions, questions and explanations.

Note here that observing the moon and finding a pattern in its shape and position (time of rise and set) needs some initiation into methods of data collection and data display. Time, training and maturity are needed. One cannot expect uninitiated school students to observe the phenomenon carefully enough to notice the pattern. Building an explanation to support the observations still remains a distant goal.

• Large group activities: Students would share and compare observations and explain their developing theories. A *KWL* chart with three columns (*K*now, *W*ant to know, *L*earned) was used to organize students' knowledge and a class moon calendar was used to record sightings during two class meetings. The moon calendar was useful in understanding techniques and difficulties in data collection.

• Small group activities: Following large group discussion, students discussed data or solved problems in small groups. This allowed students to voice their theories and ideas, listen to their teammates' ideas and develop models. Moon puzzlers were designed to scaffold students' knowledge construction and they were presented in the form of a controversy to be resolved, or a student's response or question which was to be addressed by a science teacher or using information from various sources such as children's literature, newspaper, television, or internet sources. The advantage of small group discussions was that many students were more comfortable sharing their ideas with familiar classmates than in the whole class.

• Models and simulations: Students were encouraged to construct models to help visualize celestial bodies and manipulate them. Initially they were asked to produce simple (two dimensional) diagrams, then they were asked to construct tactile three dimensional models using balls (or other available spherical objects) and light sources such as an overhead projector, lamps, flashlights etc. At the end, students themselves represented the earth, moon and the sun and acted out their positions and motions. Computer animations of the SEM system were also shared. Some students found these simulations helpful in consolidating their ideas. In general, students recognized the use of these models as cognitive tools and they claimed that the timing of these modeling activities is crucial to their success. The use of models, gestures (actions) and diagrams is elaborated in a systematic way in our study (Section 3.3).

• Science stories: Different kinds of stories were used to make the moon investigation more personal and meaningful experience. Students were encouraged to write their own science stories, in various forms of prose, poetry or in the form of conversation with the moon. Stories from children's literature and history of science (from different cultures such as Egypt, India, China and Greece) provided critical conceptual understanding.

Abell et al. used students' notebooks as an assessment tool and evaluated frequency of observations, the use of class data, the development of patterns and predictions, and the thoughtfulness of their reflections about teaching and learning science (not the accuracy of the scientific ideas). The authors claim that the project was successful in developing accurate concepts about lunar phases, boosting students' confidence in learning science and changing their model of science teaching from 'transmission of knowledge' to 'meaning making process' (Abell et al., 2002).

Hermann and Lewis (2003) came up with a rather simple three-step teaching strategy to address misconceptions about the phases of the moon: identify misconceptions, overturn it and replace it with a scientific conception. A limited set of three multiple choice and two short response questions were prepared based on earlier misconceptions research. After an intervention consisting of four lessons students' conceptions about the moon were assessed and the frequency of the correct responses was found to have increased from 21.4% in the pre-test to 52.9% in the post-test.

Trundle, Atwood and Christopher came up with series of four papers during 2002 to 2007. Three of these reported preservice teachers' (mostly Caucasian American females) conceptions and the last reported fourth grade students' conceptions about phases of the moon. ‘Physics by Inquiry’ by McDermott (1996) was used as instructional material in all these studies. Instruction included systematic observations of the moon (time, date, shape, orientation to the horizon, cardinal direction of position of the moon, approximate angle made by the sun, observer and moon) for 2 months. Students shared observations once in a week. After this, students looked for patterns in appearance of the moon and in the moon-observer-sun angle. This was followed by a modeling activity, in which the sun was replaced by a bulb, the moon was replaced by a white ball and observer on the earth was the student carrying out the activity herself.

Trundle et al. (2002) begins with a table of common alternative conceptions with their percentages found in earlier studies. Sixty-three preservice elementary teachers enrolled for the physics course went through instruction. They were divided into 3 groups of 21 students each in which the pre-instructional interviews were conducted using either physical models, or drawings or there was no pre-instructional interview. The post-instructional interviews contained physical models which were not the same as the model used in the instruction. Fifteen students from a method course (who did not go through instruction) formed a control group.

Students’ explanations were coded in 11 categories, four of which represented partially or fully correct responses: ‘The moon orbits earth’, ‘Half of moon (facing the sun) is illuminated’, ‘The part of illuminated half we see determines the phase’, ‘Relative positions of the earth, sun and moon determines the phase’. Three of the alternative responses were: ‘Shadow of the earth falling on the moon’, ‘Earth’s rotation about its axis’, and ‘Clouds or weather conditions’. Overall the responses were categorized as: Scientific, Scientific with alternative fragments, Scientific fragments, Alternative (eclipse, earth’s rotation, cloud, or other), or Alternative fragments.

In the pre-instructional interviews 90.5% in physics group had alternative conceptions or alternative fragments. Proposed explanations of moon phases before instruction were: shadow of the earth falling on the moon, earth’s rotation about its axis, vantage point on the earth, clouds, planet casting shadow, and sun’s shadow on moon. Besides these there were explanations involving sun’s orbit of earth and moon, varying light from sun to moon, how directly the sun shines on the earth, varying distance between sun and the moon (moon near sun = full moon), varying distance between earth and the moon (closer moon = full moon).

Most Physics group students and almost all Method group students held alternative conceptual understanding or alternative fragments. Sixty-one percent of students interviewed before instruction did not understand that the moon orbits the earth. Ninety-three percent of students interviewed before instruction did not understand that half of the moon is always illuminated by the sun.

Post-instruction students' conceptual understanding was changed to 'scientific', 'scientific with alternative fragments' and 'scientific fragments' after instruction. In the method group no participant showed scientific/ scientific alternative / scientific fragmented conception.

Using three-dimensional models on both pre and post assessment had no instructional value. Although no significant difference between use of physical models and drawings was seen, models were found easy, convenient for participants and for the researchers to code. Interviews using models took half an hour, whereas, interviews using drawings took an hour (Trundle et al., 2002).

Trundle et al. (2006) also investigated 52 preservice elementary teachers conceptions about the moon before and after instruction, but this time the focus was on observation of the phases rather than their cause. The US National Educational Research Standards (US-Standards, 1995) expects grades K-4 students to observe the phases and come up with the pattern, and grade 5-8 students to explain them, assuming that observations are easier than explanations. This assumption is questioned by the study of Trundle et al. In this study the focus was on the observations of the phases of the moon and students were asked to draw (without naming) the sequence of phases and also predict the expected sequence.

In the pre-assessment, few students drew most of the eight commonly named phases, while post-assessment, most students drew them. In pre-test responses, drawings for the waning moon were more common (104) as compared to the waxing moon (58). While in the post-test, all 53 participants attempted to draw both a waxing and waning sequence.

Nonscientific shapes such as over or under-circulating crescents and false gibbous (more than half moon similar to partial lunar eclipse) were common in the pre-test (about 25%). About 92% students drew all the phases correctly in the post-test. Only 3.8% students could draw scientific moon phase sequence prior to instruction, which increased to 75% after instruction. The authors note that learning to draw the observable phase sequence is conceptually more challenging than merely drawing the observable phases. They point out the influence of popular media for example, the waning crescent and false gibbous were common responses often found in newspaper and other media (Trundle et al., 2006).

The third study in the series (Trundle et al., 2007b) focused on only 12 female elementary preservice teachers' conceptual understanding and the issue of investigation was durability of conceptual change. Therefore the participants were interviewed before, three weeks after and 6 to 13 months after instruction (eight participants 6 months after and remaining four participants 13 months after instruction). In the interview participants were asked to explain the phases of the moon, and then to demonstrate phases using three-dimensional models.

Participants who consistently held a single coherent alternative explanatory framework on the pre-assessment were more likely to change to a scientific conception than were those who initially held multiple, alternative frameworks. The former were better able to engage in a comparison of a crucial elements of their initial framework and the scientific explanatory framework. Thus, holding only one alternative framework may be evidence of better metacognitive ability which may lead to intentional learning. Therefore, encouraging metacognitive awareness might be particularly helpful (Trundle et al., 2007b).

Trundle et al. (2007a) investigated 48 fourth-grade American students' conceptions of observable lunar phases before and after instruction. The sample included 54.2% females and most of the students were Caucasian. Since the focus was again on observations, the tasks were the same as (Trundle et al., 2006), except that students were not asked to estimate the moon-earth-sun angle as part of their observations. In addition to assessment through the drawing tasks, 10 students were interviewed after instruction on their explanations of the phases of the moon.

The waning crescent was the most commonly drawn shape before instruction, a result consistent with (Trundle et al., 2006). About 57% of the responses for the shapes were non-scientific and about 81% responses for the gibbous shape were of false gibbous, i.e. explanations based on earth's shadow falling on the moon. In the post-test, more than 77% students attempted to draw each of the expected phases and more than 93% responses were of scientific shapes. There was improvement also in the sequence of phases.

Eight out of 10 students who were interviewed gave the scientific explanation (half the moon is always lit, the moon orbits the earth and hence the illumination relationship changes) and the remaining two gave scientific fragmented (but not alternative) explanation, of phases of the moon. The fourth grade students' success was roughly comparable with that of elementary pre-service teachers in Trundle et al. (2002), although the students did not estimate the moon-earth-sun angle as teachers did. Therefore, the moon-earth-sun angle does not seem to be a prerequisite for qualitative understanding of cause of the phases of the moon (Trundle et al., 2007a).

Ogan-Bekiroglu (2007) reported a two-fold research study which investigated **a.** 36 Turkish pre-service physics teachers' conceptions of the moon, moon's phases and other lunar phenomena, and **b.** effects of model-based teaching. The study was based on the theoretical framework of mental models which is discussed in detail in the Section 2.4. It investigated a number of aspects of knowledge about the moon including observations about rising and setting, phases, eclipses, facts about rotation and revolution of the moon, and explanations of phases, lunar eclipse and tides.

Four different questionnaires including 22 factual, explanatory and generative questions were given at four different points of time through the study, out of which first three probed pre-instructional knowledge of the participants. Some prominent alternative conceptions were:
1. Moon rises and sets every day at the same time.
2. We do not always see the same face of the moon
3. Shape of the Moon's orbit is circular
4. Tides are caused due to only moon's gravitational force

Participants' mental models from their responses in the tests were classified as 'Correct', 'Complete', 'Incomplete', 'Flawed', 'Incoherent', and 'None'. Against the background of coherent verses fragmented representation of knowledge (described in Section 2.3) this study supports the presence of incoherent models.

The instruction in this study included observations, sharing of data, discussions, construction and presentation of models. Out of 6 physical models (as distinct from 'mental models' inferred from responses) generated by different groups, one was in the form of a diagram and the remaining 5 were concrete models, either manipulated by participants or mounted on a panel. The authors also mention 'gestural models' but these are not described in any detail. Models have limitations because of their assumptions and approximations. The participants were asked to express the limitations of their models during their oral model presentations.

Construction of concrete models and use of them in explanations enabled pre-service teachers' to shift from flawed, incoherent, or incomplete mental models to correct mental models of the moon and lunar phenomena with the facilitation of model-based teaching. The most positive effects of model-based teaching were found on the relationship between tidal effect on the earth and the appearance of the moon, and seeing the same phase of the moon all over the world at the same time. On the other hand, the pre-service physics teachers were not able to explain the reason for the daily time difference in moonrise in their models.

As mentioned in the beginning of this subsection, many of the recent studies were focused on the phenomena and their explanations related to the moon, as opposed to the earlier studies which probed alternative conceptions on several astronomical phenomena. This might be because of recognition of the complexity of the phenomena related to the moon. Consequently, these recent studies use the framework of mental models and probe for explanations in detail rather than relying on simple multiple choice questionnaires. Importantly, although the focus of these studies is on students' understanding, most of them also include instruction, (which is not common in the earlier studies). This might be because researchers have become more interested in ways of bringing about change in students' understanding, which might not be possible without specially designed intervention (Ogan-Bekiroglu, 2007).

2.1.3 Instructional material in astronomy

Based on the results from diagnostic research, several innovative instructional methods have been proposed. This concern with preparing instructional materials to address students' alternative conceptions and difficulties is in line with current curricular concerns (US-Standards, 1995; NCF, 2005).

'Physics by Inquiry' by McDermott (1996) is a classic example of instruction at elementary level with major emphasis on activities, observations and key questions through which to develop conceptual understanding. One section in Volume I (Astronomy by Sight: the sun, moon, and stars) contains activities such as plotting graph of shadows using a gnomon, observing daily motion of the sun, measuring size and shape of the earth using Eratosthenes's (276-194 B.C.) method, keeping notes of phases of the moon to find a pattern, modeling the phases in a dark room, night sky observations, describing locations on the earth using latitudes and longitudes, and preparing celestial clocks and calendars. Another section in Volume II (Astronomy by Sight: the earth and the solar system) builds on the observations taken in Volume I and develops the model of the earth and solar system to explain the annual motion of the sun, stars and the planets.

Michael Zeilik and his colleagues wrote two papers on conceptual astronomy at the undergraduate level. Zeilik et al. (1997) first identified 120 most essential (core) astronomical concepts and their interrelationships, and sorted them into four concept clusters ('cosmic distances', 'heavenly motions', 'celestial light and spectra', and 'scientific models'). Then they assessed students' prior experience and knowledge using a 19-item test. Based on these two, a teaching sequence for a full semester astronomy course for undergraduate level was developed and implemented. Although the majority of participants were white (60%), the class had Hispanic American (20%), African American (4%), Native American (5%), and other students and only about 50% students had a background in physics or maths.

The pedagogy included instructional concept maps, small discussion groups, hands-on learning activities, and quiz which enabled students to learn through visual, kinesthetic, aural and social modalities. The assessment system included tests, quiz, group activities, and homework. Students' mean scores were found to be significantly increased on a "misconception measure" and "connected understanding measure", but their attitudes towards science and astronomy slightly deteriorated over the semester (Zeilik et al., 1997).

This same course was implemented over three semesters and the gain for 400 students was calculated (Zeilik et al., 1999).

$$< g >= \frac{post\% - pre\%}{100 - pre\%}$$

Zero <g> indicates no gain and <g> = 1 indicates maximum possible gain.
Over each of the three semesters, large gains (<g> = 0.45 to 0.54) were found in conceptual understanding. Large gains (<g> = 0.49) were found using the 'multiple choice item format' based on misconception research. Gains using 'select and fill in conceptual map', were smaller but were still large (<g> = 0.33). Surprisingly, self-reported prior course work in physical science or math had no relationship with achievement in astronomy.

The first two out of four parts of Zeilik's book on undergraduate astronomy (Zeilik, 2000) are devoted to elementary astronomy. They reflect the current understanding of research in astronomy education and contain new, useful visuals.

There have been several articles which report innovative methods to teach some small aspect, or a unit in elementary astronomy. We summarize three recent representative cases from three different sources which dealt with the content relevant to our study:

Astronomical sizes and distances are beyond perception, which is one major source of difficulties among students. Yet, knowing rough sizes and ratios is basic requirement in elementary astronomy. Moldwin (2000) documented an activity to scale down the sun earth model. He first asked students to estimate the ratio of the size of the earth to the sun, and then showed a drawing with the correct ratio (about 100 times). The problem was phrased in various contexts such as driving around the earth and the sun (circumference), how many earths would fit into the sun (volume) and finally calculating the ratios of diameters of the sun and the earth, and the distance between them using powers of 10, to place a 'baseball sun' and a 'pin earth' at 9 meters distance.

Variation in the apparent path of the sun across the sky is one of the challenging phenomena to understand. The prevalence of incorrect responses to questions based on the position of the sun at rising, setting and noon are documented in Subsection 2.1.1. Rowlands (2005) gives a detailed description of the sun's path at different latitudes in different seasons using series of simple but conceptually useful drawings. A software called 'SunPath' has also been documented to be useful.

ScienceScope published a series of articles related to astronomy in 2007 which included activities to create scaled down model of solar system (Seidel, 2007), and presenting a scaled-down model of the solar system on a map available on *Google Earth* (http://earth.google.com/). The advantage of using *Google Earth* is its provision of zooming out to see a map of a successively larger area and finally to map planets at far away distances (Schneider and Davis, 2007).

Brunsell and Marcks (2007) presented results from a survey to probe students' common misconceptions related to phases of the moon and supplemented these with a modeling activity of moving a ball (moon) around oneself to see the phases as lit by a bright light source (sun).

Nock (2007) provided a discussion method to teach changes due to seasons. He proposed plotting graphs (on computer) of hours of daylight versus time over the year (data available on website) in selected cities (at different latitudes) and comparing them. The effect of change in angle of incident rays on intensity of light could also be discussed in the classroom.

Stein (2007) reported results form a four-item-survey (available online) carried out over 3,200 people. Results on common misconceptions: 56% people agreed that phases of the moon occur due to the earth's shadow cast on the moon, 53% agreed that the moon's phase seen at the same time from two different locations on the earth is different, 53% did not know that the sun never comes overhead in continental United States and 52% agreed that the earth is closer to the sun in summer.

Omitting Pluto from the list of planets in our solar system was one popular piece of news in 2007 and students were curious to know the reasons. The classification system for celestial bodes was explained through an activity of dividing a 1.3 Kg lump of modeling dough into 10 parts to represent celestial bodies in the solar system, while conserving the ratios of their sizes (Hurst and Gurton, 2007).

Ristvey et al. (2007) introduced NASA's Dawn mission to explain IAU's (International Astronomical Union) new system of classification of the celestial bodies and categorizing Pluto as a 'dwarf planet'.

'Astronomy Education Review' an electronic journal has been publishing 2 issues per year, since 2002. Although often based on some theoretical framework, the research reports in this journal mainly address practical issues such as innovative pedagogic practices, assessment tools, etc.. Because of free internet access, this journal provides good guiding material for teachers and new researchers. Some freely available tests such as Astronomy Diagnostic Test (ADT) and Lunar Phases Concept Inventory (LPCI) have been developed to diagnose students' alternative conceptions. Several websites are developed to address common alternative conceptions in astronomy. Here are some examples: Popular Misconceptions in Astronomy (Mis), Skyscript (Sky), Bad Astronomy (bad, a), Bad Moon Rising (bad, b) from Paper Plate Education.

In India, there are a number of local groups of amateur astronomers (e.g. *Navnirmiti* and *Khagol Mandal*, Mumbai), and non-governmental organizations (such as *Bharat Gyan Vigyan Samiti*) working for lay-people. Some of these groups bring out their own publications. Though not necessarily based on the research in the area of astronomy education, the authors of these publications are often aware of common alternative conceptions. There are about 14 planetariums spread all over the country. Science popularization bodies in India such as *Vigyan-Prasar* and science popularization departments of various universities and national institutes such as the Inter University Center for Astronomy and Astrophysics have contributed to newspaper and magazine articles, through pamphlets of various astronomical events, diaries, calendars, booklets on experiments and activities and books in local languages and through public lectures, exhibition, science parks etc. Astronomy has been a part of various science education activities of the Homi Bhabha Centre for Science Education (TIFR). Picture based pamphlets on day and night, phases of the moon etc. for young students, tests and programs developed for the Bombay Association for Science Education (BASE) teachers since 1999 and the Homi Bhabha Curriculum for Primary Science (Ramadas, 2001b,a; Vijapurkar, 2003, 2006) are some of the examples.

2.2 Need for a theoretical framework

Empirical studies in astronomy education carried out till date (summarized in Section 2.1) have established the presence of alternative conceptions in astronomy. They have provided us a catalogue of alternative conceptions along with their relative prevalence. These studies could be said to have been influenced, implicitly if not explicitly, by the 'conceptual change' framework (Lelliott and Rollnick, 2009) which is discussed in Section 2.3. Going beyond documentation of students' conceptions, elementary concepts such as shape of the earth have been probed using the mental model approach which we describe later (Subsection 2.4.1). On the other hand we have seen already, in complex problems such as phases of the moon, the documentation of alternative conceptions has been followed up by studies of the reasoning process from observation to explanation, observed with or without scaffolding (Subsection 2.1.2).

Both mental models as well as reasoning processes involve aspects of visuospatial thinking and representations, which have thus far remained neglected in the literature on astronomy education. Therefore in Sections 2.5, 2.6, 2.7 and 2.8 we have gone on to review the literature on visuospatial cognition and on specific cognitive tools such as diagrams and gestures, which has informed our research.

2.3 Conceptual change

Research in science education established the prevalence of alternative conceptions among students. These studies inspired the 'conceptual change' framework of learning, which has been arguably the most influential framework from late 70's to early 90's in the field of science education and in developmental psychology too (diSessa, 2006). In Subsection 2.3.1 we shall summarize characteristics and limitations of this framework and then summarize the newer frameworks which turned out to be fruitful for research in astronomy education.

The question ‘What is a concept?’ traditionally falls under the purview of epistemology. Rationalist philosophers of science (Plato, Kant, Fodor) believe that concepts originate in the mind, either innately or through reason, and the human mind processes these a priori concepts to draw inferences. On the other hand, empiricists such as Locke, Hume and Mill believed that concepts are formed post-priori, through a process of abstracting common characteristics from several particular instances acquired through perception (Thagard, 1996). In both cases ‘concepts’ are of importance to all these frameworks and they are useful in explaining a large part of human cognition.

In the ‘Artificial Intelligence’ tradition of the 1980s and 1990s conceptual structures were seen as a kind of mental representation (other such mental representations are: logic, rules, analogies, images and connections) (Thagard, 1996). ‘Mental processes’ can be carried out on ‘mental representations’ to draw inferences. Concept based structures are *hierarchical* in nature i.e. properties of a concept are shared by all its instances as well as by concepts in the sub-categories which fall under that concept. This is referred to as the property of *inheritance*, which comes in useful in drawing inferences and providing explanations (Chi, 2008). This static characterization of conceptual structure is however insufficient in the context of developmental psychology (and also for learning theory).

In their book ‘Cognitive Development’, Flavell et al. (1977) argued that defining a ‘concept’ is a difficult task, but they roughly characterize it as: “A mental grouping of different entities into a single category on the basis of some underlying similarity- some way in which all the entities are alike, some common core that makes them all, in some sense, the same thing” (Flavell et al., 1977). Children’s conceptions (which were found to be different from those of adults) were identified in various areas of natural and behavioral sciences. Another major finding was that these alternative conceptions were found difficult to change. Hence it became of prime importance to understand ‘how are alternative conceptions formed?’ and ‘how can they be replaced by accepted scientific conceptions?’

In contrast to the AI perspective in which mental representations are static structures, Flavell’s definition from developmental psychology used the word ‘grouping’ which is a *verb*, which indicates the dynamic and flexible aspects of conceptual structures. From both education and developmental psychology there was an interest in ‘conceptual change’ rather than in merely identifying alternative conceptions, indicating an interest in the dynamic process rather than in static representations. This interest resulted in the transition of focus of research in cognitive psychology, as well as in science education, from static mental representation such as conceptual structures to more dynamic and flexible mental representations such as mental models (See also Section 2.4).

Conceptual change research was influenced by Piaget’s theory of constructivism in the field of cognitive developmental psychology and Kuhn’s work on ‘change of scientific theory’ in the field of history and philosophy of science (diSessa, 2006). The history of astronomy contains dramatic turns which were instrumental in the rise of modern science, therefore the history of science approach has been particularly influential in astronomy education. Researchers have shown the parallels between development of students’ notions and notions in history, and have advocated the use of historical development of the heliocentric model in instruction (Albanese et al., 1997).

One prominent framework from a learning theory perspective to explain alternative conceptions and the robustness of these conceptions is given by Michelene T. H. Chi. Chi (2008) starts with three hypothetical situations about students’ prior knowledge (before instruction):

- No prior knowledge or some related prior knowledge. In this case, learning consists of ‘adding new knowledge’.
- Incomplete prior knowledge; learning can be considered as ‘gap filling’.
- Acquired ideas, either in school or through everyday experiences, which is ‘in conflict with’ the to-be-learned concepts.

Conceptual change is necessary in the last case. According to Chi, knowledge can be misconceived at three grain sizes, or levels: individual beliefs, categories, and mental models. An individual false belief is of the grain size of a single idea. A misconception, such as “Pole Star is the brightest star in the sky”, is a false belief and can be easily corrected by showing the Pole Star to a child. Some false beliefs are stable, are manifested consistently in students’ responses, and they do not get revised even while learning new information simply because they are not explicitly refuted.

Category mistakes: As said above, a category-based conceptual structure can be used for inference or explanation, since conceptual structures are hierarchical and assume the property of inheritance. A conceptual structure may be imagined as a hierarchical tree structure with branches standing for categories with mutually exclusive properties. When properties of categories are mutually exclusive, they are called categories of different "kind". On the other hand, categories on different branches are "lateral" categories. Lateral categories which occur at about the same level within a tree are called "parallel". A property of a category can be applied to a member of that category or its subcategories, whether or not it holds true, whereas it cannot be applied to member of a lateral category.

Ideally, if a learner has no obvious category for a new concept or phenomenon, s/he should assign it to the highest level of category that is appropriate. But instead of assigning it more generally to a higher-level category, s/he may instead assign it to a lateral category, or to a category in a different (ontological) tree altogether. These 'category mistakes' are one of the main source of robust misconceptions. Several examples from physics and other areas are produced in support of this claim in (Chi, 2008). For example, students often treat concepts such as force, heat, electricity, and light as *entities* instead of *processes*. Conceptual change requires a shift across lateral or ontological categories.

Continuing with Chi's proposal of the three grain sizes, in our view the most appropriate characterization of students' alternative conceptions in astronomy is in terms of flawed mental models. According to Gentner and Stevens (1983) and Chi (2008) an organized collection of individual beliefs forms a mental model. A mental model is an internal representation of a concept (e.g. the earth), or an inter-related system of concepts (e.g. the solar system) that corresponds in some way to the external structure that it represents. The model can be "run" mentally, much like animated simulation, to depict changes and generate predictions and outcomes. An incomplete or non-existing mental model may be so sparse and disconnected that its structure is not possible to capture. In that case we could not even say for certain that this mental model is in conflict with the correct scientific model (Chi, 2008).

Children's mental models could be coherent but incorrect, i.e. made up of a number of false individual beliefs. If very few of these beliefs are revised, the complete mental model will not get revised. Also, knowing or learning many correct beliefs does not guarantee successful transformation of a flawed mental model. Some critical or important beliefs serve to discriminate a flawed model from the correct model.

Chi (2008), also note that a holistic confrontation (using a visual depiction such as a diagram of a flawed mental model, and then contrasting it with the diagram of correct model) may induce successful transformation, but they are not aware of any instruction offering this kind of holistic confrontation. Thus, designing an instructional sequence for change in mental model is one of the immediate challenges in educational research, one that is addressed in our study.

In a somewhat different account, Andrea diSessa argues that children's knowledge is not coherent but in pieces. According to diSessa (2006), intuitive physics' consisted largely of hundreds or thousands of elements, called p-prims (phenomenological primitives). P-prims are explanatory primitives, provide people with their sense of which events are natural, and which are surprising. P-prims are many, loosely organized and sometimes highly contextual, so that the word 'theory' is highly inappropriate for them. DiSessa proposes a rough spectrum of constructs, from low to higher level as: 'p-prims', 'normal facts', 'narratives', 'mental models' and 'coordination classes'. The highest structure (coordination classes) stands for an explicit model of a certain kind of concept/ complex systems than includes many coordinated parts, including p-prims. Conceptual change requires students to adopt a new targeted system, with an additional criteria of internal consistency, which diSessa describes as a shift from "the mere collection to coordination of a large set of elements into a newly organized system". Our findings about internal consistency of students' mental models are presented in Section 5.3.

2.3.1 Critique of the conceptual change framework

Mental representation of conceptual structure, as described by Chi (2008) is hierarchical and allows for only subordinate/ superordinate relations. However, all knowledge cannot be represented in this form. Sometimes elements relate to each other with different kinds of relations which exist simultaneously and are not possible to represent in a hierarchical relationship. To take a simple example, the earth simultaneously rotates on its axis and revolves around the sun. These relationships are not of categorical kind and hence they cannot be described as a tree structure with inheritance of properties; rather such relations need to be placed together into mental model. In a tree structure where concepts inherit the properties of categories to which they belong, the reasoning involved in drawing inferences is propositional. In a mental model on the other hand, the relations among different elements are present simultaneously, and can be, and are often described through spatial metaphors. Visuospatial reasoning thus becomes a part of processing with mental models. Further, the relations among different elements in a mental model being more complex than in a conceptual structure, these elements are more vulnerable to fragmentation and frequent inconsistency. From this perspective we feel that diSessa's description of children's knowledge structures fits better with the mental model perspective and we have tried to verify this aspect (Subsection 5.3.3). Neither Chi not diSessa address the visuospatial aspects of mental models which are of prime concern in our studies.

Finally, Mental models include dynamic elements and they are flexible, in the sense that a part of a mental model can be chosen to be transformed in the process of reasoning. This factor has influenced the methodologies of recent research in astronomy education. Most of the earlier studies reviewed in Subsection 2.1.1, which fall in the conceptual change paradigm, are cross-sectional in nature. They provide snap-shots of conceptual structures at different Grade levels or ages. But to study mental models, it is important to see how they develop over time and how they are transformed to draw inferences. Thus longitudinal studies (e.g. Trundle et al. (2007b)) may suit better the research on explanations based on mental models. Some studies based explicitly on mental models in astronomy and cognitive science are described in the next section.

2.4 Mental models

According to Gilbert and Boulter (1998) a model can be defined as a representation of an idea, an object, an event, a process or a system. 'Models', being more perceptually accessible than theories, play a key role in the conduct of scientific enquiry. They more readily permit the consequences of theories to be deduced and tested by experiment. A model of a target system, in their view, is produced from a source by the use of metaphor in which the target is seen, if only initially for the sake of argument, and for a short time, as being very close to the source. Gilbert and Boulter (1998) cite Nagel's analysis of three components of a theory: **i.** a logical skeleton of the explanatory system, **ii.** a set of rules that in effect assign an empirical content to the skeleton, and **iii.** an interpretation or model to suggest that models can be viewed as an intermediary between the abstractions of theory and the concrete actions of experiment. According to Gilbert (2005) to simplify a complex phenomenon and represent it so that it becomes accessible to human senses is 'model'.

Gilbert and Boulter (1998) consider not just mental models, which are personal or private representations of a target, but also models expressed through discourse, written material (text and visuals) and actions (physical models and gestures). The latter lead to the creation of a consensus model, i.e. an expressed model which has been subject to testing by a social group and which has been agreed by some as having some merit. Finally, they consider teaching models, which are specially constructed to aid understanding of a consensus model. A good teaching model contains major features which approximately match in number those in the consensus model, with a high degree of similarity existing between the two so that equivalence of meaning can be perceived readily. A teaching model serves as an introduction to the consensus model, and it is built up through the classroom discourse, preferably using hands-on, experiential means. The teaching model is kind of expressed model which uses tools like oral discourse, writing, drawings, physical models and gestures. Also the capacity of students to form and express mental models could be enhanced if they are provided with explicit opportunities to become aware of their mental models and are given opportunities to express those models. Gilbert and Boulter's paper is important because it places mental models into a pedagogic perspective. It views the process of ‘learning a model’ as one of enculturation or participation in socially organized practices. This perspective is useful when we come to the description of pedagogy (Chapter 4). In this Section however we consider mental models from a mainly cognitive perspective.

Norman (1983) made the following observations about the mental models:
1. Mental models are incomplete.
2. People’s ability to ‘run’ their models are severely limited.
3. Mental models are unstable: People forget the details of the system they are using, especially when those details (or the whole system) have not been used for some period.
4. Mental models do not have firm boundaries: similar devices and operations get confused with one another.
5. Mental models are ‘unscientific’: People maintain ‘superstitious’ behavior patterns even when they know they are unneeded because they cost little in physical effort and save mental effort.
6. Mental models are parsimonious: Often people do extra physical operations rather than the mental planning that would allow them to avoid those actions (Norman, 1983).

2.4.1 Mental models in astronomy

Vosniadou and her colleagues were the first to study mental models in context of elementary astronomy through a series of papers. The first study (Vosniadou and Brewer, 1992) focused on children’s Mental models of earth. It was carried on 20 first graders (age: 6;9), 20 third graders (age: 9;9), 20 fifth graders (age: 11 years). Approximately half of the students were girls, and half were boys. They were interviewed based on a 48 item questionnaire, for between 30 to 45 minutes. The following five mental models of the earth were identified:
1. Flat earth (square/ disk), **2.** Dual earth (one is flat on which we live, one is a sphere in the sky), **3.** Hollow earth (we live inside a hollow sphere), **4.** Flattened earth and **5.** Spherical earth (scientifically accepted model).

Vosniadou and Brewer proposed that children form ‘intuitive’ or ‘initial models' which exclusively rely on interpretations of experience derived from everyday observations. When exposed to scientifically accepted information, children try to assimilate the information that the earth is a sphere with their preexisting knowledge structures, in a way that allows them to retain as many of their presuppositions as possible. The two main pre-suppositions in case of the earth come from properties of physical objects namely 'flatness' (ground is flat) and 'support' (unsupported things fall). When one of the presuppositions of their earlier models get replaced but others do not, the resultant mental models are combinations of intuitive and scientific models. These models are called 'synthetic models' and Models 2, 3 and 4 in the above list are of this kind. In these models, the earth is considered as a physical object rather than an astronomical one (i.e. flatness and support are applied to the earth also). The study showed that children shift from intuitive to synthetic to scientific models as they grew up.

In terms of conceptual structures and conceptual change discussed in Section 2.3, Vosniadou and Brewer point out that changes in students' mental models of the earth come about, not through restructuring of hierarchical conceptual structures, but through changes in an explanatory framework. Regarding the issue of coherence versus fragmentation, they claim that a great majority of the children were consistent in their use of a well-defined mental model, although it may not have been always the same as the culturally accepted model. They also claim that some stable understanding of conceptual structures (from long term memory in contrast to 'on the spot thinking') constrains the range of possible mental models that children can form.

Another article by Vosniadou and Brewer (1994) based on the same study identified students' mental models of the day and night cycle. Eight distinct alternative explanations of the day-night cycle found in this study were divided into intuitive, synthetic and scientific models. The numbers in the bracket represent the number of students who held each of these models in Grade 1, 3 and 5 respectively.

- Initial models constrained by the model of a flat and stationary earth:

1. The sun is occluded by clouds or darkness (2, 1, 1)

2. The sun moves out into space (1, 1, 0)

3. The sun and the moon move up/down on the ground (7, 0, 0)

• Synthetic models: the presupposition about the shape of the earth is correct in Models 4 and 5 and the presupposition that the earth is static is corrected in Models 6 and 7.

4. The sun and the moon move up/down to the other side of the earth (2, 0, 0)

5. The sun and the moon revolve around the earth once every day (0, 1, 0)

6. The earth and the moon revolve around the sun every 24 hours (0, 1, 0)

7. The earth rotates up/down or west/east. The sun and moon are fixed at opposite sides or the sun is fixed but the moon moves (1, 4, 10)

• Scientific model: 8. the earth spins (1, 3, 1); Mixed models (2, 7, 7); Undetermined (1, 2, 0)

Similar to mental models of the earth, children's mental models of the day-night cycle also shift from intuitive to synthetic to scientific models as they grow up. The authors claim that mental models of the earth impose on the mental models of the day-night cycle, and that students are sensitive to accuracy, logical consistency and simplicity of explanation (criteria identified by Kuhn which scientists use to evaluate adequacy of a theory). We note however, that there is no noticeable similarity between the reported mental models of the day-night cycle and the kinds of explanations found in the history of astronomy.

For simple phenomena such as day and night, specifying a mental model (as one of those listed above) is perhaps equivalent to explaining the phenomenon. In general, a mental model and the reasoning based on it influence each other. However, for phenomena which require complex explanations, it might be fruitful to separate the mental model from the explanation. The mental model consists of elements and their relationships which include the spatial and physical properties of the system. The explanation (or the reasoning leading to the prediction) connects the mental model with the observation(s) through the activities of mental simulation and perspective change. This distinction between the model and explanation which parallels the distinction between representation and processes that is standard in cognitive science, is particularly useful when more than one explanations are possible with a correct mental model or more than one phenomena are to be explained based on the same mental model.

The third study in the series by Sumarapungavan et al. (1996) looked at Indian students' mental models of the earth and the sun and the influence of folk cosmology on their mental models. One culture specific model of earth, "ring earth" had earlier been found by Brewer and others in Samoan children. The sample of Sumarapungavan et al. (1996) consisted of 38 students (19 first graders and 19 third graders) of Ramakrishna and Sri Chinmaya mission schools in Hydrabad. In terms of cultural influence these students had access to mythological material and hence to indigenous cosmology through their parents, TV serials, comics and other printed material. The first grade children had been taught one unit on shape of the earth. The 3^{rd} grade children had been taught a unit on motion of earth and day night cycle in second grade and a unit on solar system in third grade (globes were shown during the teaching). The models identified for shape of earth were (numbers in brackets indicate the numbers of students who held that model in the first and third grades):

Scientific: Sphere in space (3, 8); **Synthetic** (3, 9): Sphere on water (0, 4), Spheroid in space (0, 3), Hollow sphere in space (2, 2), Hollow sphere in water (1, 0); **Initial** (13): Disc in space (4, 1), disc on water (4, 0), rectangle on water (3, 1) (1 child - Shape of oil lamp); **Mixed or undetermined** (2, 0).

Thirty-four percent of the Indian sample presented the earth as floating on water, which clearly indicates the effect of indigenous cosmology. The 'dual earth' model (which was found in 20% of American students in Vosniadou and Brewer (1992)) was not found among Indian children. On the other hand, the disc model held by only 1 American child, was present in 24% Indian students. The disc model is consistent with folk cosmology and it also accommodates scientific information.

The differences in proportions of the scientific, synthetic and intuitive models the among the two grades were significant:

First Grade (16% scientific + 16% synthetic + 68% initial), Third Grade (42% scientific + 47% synthetic + 11% initial). The difference in frequencies of the various models between the Indian and American children (mixed models <5% in Indian students and 23% American students) was attributed by the authors to difference in methodology, namely use of 3D models in place of drawings.

To study aspects of the movement of the earth, sun and moon in students' models, factual (which celestial body moves) and generative (if the earth stops moving, what will happen?) questions were asked. The explanations for the occurrence of the day-night cycle were, **Scientific** (1, 5): Axis rotation; **Synthetic** (9, 11): Revolution, Motion of moon and sun; **Initial** (8, 2): Occlusion of the sun and the moon; **Mixed** (1, 1).

The influence of the popular mental model of the earth floating in water was seen in the response that the sun sinks in and rises from the sea. In contrast, American children said that the sun goes behind hills.

Children's overall cosmologies were studied by using all the above explanations and in addition, a picture of solar system was shown and children were asked to identify what it was; then asked to locate sun, earth and moon in the picture; finally shown a planet (Saturn) and asked what it was. Depending on their responses, children's models were classified as, **Heliocentric** (3, 9): Scientific (1, 5), The sun at center of earth's orbit, orbit of moon is parallel to that of earth (0, 1), The earth's orbit goes from in between stationary sun and moon (2, 2), The earth moves around stationary moon and sun (0, 1); **Geocentric** (14, 8): The spherical earth (in space or floating on water) rotates around axes. The sun and the moon are stationary and at the two sides of the earth (0, 2), The stationary spherical earth, Sun, moon revolves around it with opposite phase (0, 2), Flat-floating/ hollow stationary earth. Up-down motion of the sun and the moon (11, 4), A square earth floating on water. The sun and the moon above in two corners. Occlusion due to clouds (3, 0); **Mixed** (2, 2).

Expected development due to age was seen in all the cases. The Indian children showed a considerable degree of internal consistency, and sensitivity to empirical and logical consistency in their representations. Observations, naive presuppositions and cultural information all influenced the initial models. Synthetic models appeared to come from an attempt to assimilate scientific information. Like scientists, children took help of physical analogy (e.g. egg shell to explain hollow earth) and tried explanations based on that model.

The framework and the results obtained by Vosniadou and her colleagues faced two kinds of challenges. According to the sociocultural view of conceptual change, cognition is closely shaped by the use of tools, and conceptual change involves the development of tool-using practices, or the way that tools are used by learners in various contexts. The criticism is that Vosniadou and her colleagues have not paid attention to socio/cultural influences on the development of children's understanding of elementary astronomy, and, particularly, they have ignored the role of cultural artifacts. Two experiments investigated elementary school children's reasoning about the earth and gravity using physical artifacts such as a globe and a map. Schoultz et al. (2001) used globe while interviewing 25 Swedish children (Grades: 1, 2 and 5; age: 6-8 years and 10-11 years). It was found that when the participants had access to a globe, they could all identify the globe as a representation of the earth, they all considered that people could live all across the earth without falling off, and 77% could refer to gravity as an explanatory concept. Ivarsson et al. (2002) used a map of the world while interviewing 18 children (age: 7-9 years). Both these studies report that performace of children was significantly better than that reported by Vosniadou and her colleagues.

In response to Schoultz et al. (2001) and Ivarsson et al. (2002), Vosniadou et al. (2005) interviewed 42 children (20 first graders, mean age: 6 years, 1 month, 33 third graders, mean age: 8 years 5 months). The globe was presented to children in the second part of the interview (instead of drawing and play-dough models of the earth as used in the earlier parts). The presentation of the globe affected children's responses in three ways:
1. There was an increase in the overall number of scientifically correct responses given by the same children.
2. There was a decrease in the internal consistency of responses, with "mixed" responses almost completely replacing children's alternative models of the earth obtained in the first part of the questionnaire.
3. The children seemed to be unaware of the changes in their responses and the fact that they gave internally inconsistent responses after the presentation of the globe.

Vosniadou and her colleagues concluded from this experiment that:
1. Only some (the older) children can profit from the presence of the artifact to construct an internally consistent scientific model of the earth.
2. Many children employ a mixed way of responding, sometimes basing their an-

swers on the externally provided model and sometimes on their prior knowledge.
3. These latter children are not aware that by doing so they are becoming internally inconsistent. It appears that in the absence of an external, cultural model, children can form internal representations which they can distort in ways that make them consistent with their prior knowledge. But, when the cultural artifact is present, such distortions are not possible. Children reason on the basis of the externally provided artifact when this is unavoidable, but when the answer cannot be derived directly from the external model they rely on prior knowledge. The children do not seem to be aware of this process that somehow distorts their rationality producing internal inconsistency.

Nobes et al. (2003) interviewed (which included selection from a set of plastic models and answering forced-choice questions) 167 Gujarati and white British classmates' (age: 4-8 years) to probe their understanding of properties of the earth. Nobes et al. found that the distributions of students' combinations of responses provided no evidence that they had mental models. Instead, these distributions closely resembled those that would be expected if children's knowledge in this domain were fragmented. According to Nobes et al. (2003) *"Vosniadou and her colleagues' approach involves searching for mental models derived from their participants' responses, and then classifying the same responses according to these mental models. With this post-hoc, circular process there is a danger of 'finding' consistency- and therefore evidence of mental models- when in reality there is none"*. Also, there was no significant differences in the overall performance of Asian and White children after language skills were partialled out.

Siegal et al. (2004) report two studies in which children's knowledge of cosmology in relation to the shape of the earth and the day-night cycle was investigated using explicit questioning involving a choice of alternative answers and 3D models. In the first study, 59 Australian and 71 English children (age: 4-9 years) were compared and it was found that Australian children offered the 'scientific' answer often at a significantly earlier age. Study 2 was designed to compare the children's responses under different questioning conditions. Forty-five Australian children (age:4-6 years) were interviewed in two ways: using explicit questions and questions drawn from (Vosniadou and Brewer, 1992, 1994). The results showed that the children could perform better on explicit questioning, may be because young children are not adept at drawing and interpreting 2D representations of spatial relations.

In response to objections by Siegal et al. (2004) and Nobes et al. (2003), Vosniadou et al. (2004) argued that use of forced choice questionnaire was methodologically flawed. Vosniadou et al. (2004) demonstrated through an empirical study that a forced choice questionnaire got more number of scientifically accepted responses but their internal consistency was less. On the other hand, an open questionnaire got responses which indicated synthetic models, but their internal consistency was more. The authors claimed that a forced choice questionnaire limits the range of responses available to children, so it does not capture synthetic models, and it creates possibility of false positive responses. Also a forced choice questionnaire has potential for biasing children towards the scientifically accepted responses, to which they may have been exposed but which they may not fully understand. Presenting the model of a spherical earth along with others may force children to choose the socially accepted model. This may result in reproducing "inert knowledge", but may not capture the mental models of children. Vosniadou et al. argue, it is known that children have been exposed to the scientific information. They were interested in finding out whether they fully understood that information and hence their mental models.

Nobes et al. (2005) and Panagiotaki et al. (2006) argued back in favor of fragmented knowledge and claimed that combination of 3-D models and forced-choice questions elicited more scientifically correct responses and higher proportions of scientific and inconsistent mental models than the combination of drawings and open questions.

Hannust and Kikas (2007) attempted to address this debate with a study which involved 5 year old kindergarteners (18 in experimental group and 16 in control group), 6 year old kindergarteners (22 in experimental group and 17 in control group) and 7 year old 1^{st} graders (20 in experimental group and 20 in control group). The interview questions about the earth's shape and gravity were modified from Vosniadou and Brewer (1992), and for some questions, students were asked to respond through drawings. Importantly, the authors note that children at this age are poor at drawing three-dimensional objects and they have difficulty in with showing perspective and hence were also asked to choose amongst concrete objects to specify the shape of the earth. They found that the majority of students do not construct consistent models and that even the identified models are rather labile. Young children's knowledge was mostly fragmented (as suggested by Nobes and others) but their pre-existing knowledge was low (unlike suggested by Nobes and colleagues).

Albanese et al. (1997) address the questions 'what are the problems that children face in understanding the heliocentric model' and 'do researchers take importance of observations and experiences of phenomena into account'? To see the interplay between observation and theory, first Albanese et al. (1997) discussed the historical development of the heliocentric model. They claim that observations and experimentation are at the base of the science. Primary models which are at a descriptive level are formed on the basis of these observations. Secondary models provide explanations by introducing theoretical constructs that may unify different phenomena under more general laws. Keeping these two levels in mind, the authors classifed the earlier research in the following groups:

1. Research related to a theoretical model that is in apparent conflict with direct experience (e.g. (Nussbaum and Novak, 1976; Vosniadou and Brewer, 1992; Mali and Howe, 1979; Sneider and Pulos, 1983; Klein, 1982)).

2. Research related to a theoretical model which for an understanding, requires more information on the observational side, in addition to direct experience (e.g. (Baxter, 1989; Klein, 1982; Vosniadou and Brewer, 1994)).

3. Research on comparison between traditional and scientific models (e.g. (Mohapatra, 1991)).

They concluded *"A better probing is needed of the observational capacities of children in the here and now, and about their ability to generalize from "here and now" to "elsewhere and in another time"* Albanese et al. (1997).

Feigenberg et al. (2002) wrote a paper on models in the history of science and students' mental models. On the background that astronomers consciously or unconsciously visualize a model to arrive at an understanding of the relative dimensions involved and the pedagogic importance of models, they suggested that mental models and their role in perception and in the teaching process must be taken in to consideration. In the studies reviewed by Feigenberg et al. it was seen that on the one hand by the age of 15 to 16 years, most students hold notions that are close to generally accepted modern scientific views of the cosmos (such as earth as a cosmic body), but on the other hand, most of them are seen to be unable to draw consequences or explanations where large scales are involved. It has been seen that correct response may not be due to correct reasoning. To reveal these incorrect intellectual models that differ from scientific understanding, but lead to correct oral statements is an important task for the researcher and the teacher.

In a pilot experiment it was seen that out of 23 students in a teacher training course none of could provided correct answer for the following question:
On the summer solstice in Aswan, Egypt, the sunlight at noon comes down from the zenith overhead; while in Alexandria, 800 km north of Aswan, it is ... degrees from the zenith. Why? Give your explanation with a diagram of this phenomenon.
Two major mistakes done by the participants were:
1. Sun rays were not considered to be parallel (Almost all participants drew diverging rays of sun in response to the question).
2. Earth's curvature was not taken in to account (Flat earth).

The mistakes are not because of lack of concrete knowledge but because students were unable to handle large dimensions and their relationships. According to the authors, the reasons of these mistakes can occur due to:
1. Limitation of representations: Only one aspect of the phenomenon can be clearly demonstrated, while the other must be neglected using a representation. (e.g. it is possible to show the distance between the earth and sun in a picture, preserving the proportion, but it is impossible to show the curvature of the earth in the same picture.) Students may miss this point and misinterpret the representations.

2. Limitation of students' actual zone of activity: Actual zone of activity of a student is defined by that part of surrounding reality with which she interacts directly or indirectly, both intellectually and physically; and the understanding of which provides her with the ability to pattern her behavior in it. There is strong correlation between objective parameter (distance) and subjective comprehension (meaning) in the actual activity zone. Since students do not deal with very small and very large distances in day to day life, it is difficult for them to understand them (a similar problem happens in case of time when one is supposed to imagine an interval of 10 years in ancient time). As a result of this, students find it difficult to distinguish between a situation in which curvature can be ignored and the earth's surface is considered to be flat, and a situation in which the curvature is significant; or situations where sun rays can be considered to be parallel and situations where they are not parallel (Feigenberg et al., 2002).

In the main experiment three written tests were administered to 83 students from different Jerusalem secondary schools. The first test was given in the beginning of the school year in order to reveal the students' conceptions at the very beginning. It contained both direct questions concerning distances and dimensions of astronomical bodies in the solar system and questions demanding diagrammatic representations. The treatment consisted of one lesson of 2 hours per week and a large number of lab activities, including problem solving and computer simulation. Scaling activities (to consider one of the objects (say earth) of typical size and calculate the relative sizes and distances in solar the system), zoom method (removing part of the picture and presenting it in another scale), and studying the historical development of ideas, were used by the researchers to present relationships involving large scales. The second test was administered in the middle and the third test was administered at the end of the course. All three tests consisted questions which required students to assume the sun-rays to be parallel (Feigenberg et al., 2002).

The authors concluded that students' difficulties in studying optics with elements of astronomy are not because of a lack of concrete knowledge. Understanding and evaluating large dimensions and their relationships, and limitations of students' actual zone of activity, are the main reasons for these difficulties. The techniques used in our intervention address these issues.

2.4.2 Simulation in a mental model

In order to use mental model for the purpose of reasoning leading to a prediction or explanation, one needs to mentally simulate or 'run' the model. Research which demonstrates this kind of thinking has been done in cognitive science in the context of simple mechanical systems. Hegarty studied reasoning with mechanical system such as pulleys and gears. Through a series of experiments with American undergraduate students, Hegarty and her colleagues showed that people visualize and simulate a mental model to draw inferences. Hegarty recorded the reaction times, and errors in judging static and dynamic statements about parts, at different position of a pulley system. She found that for dynamic statements the errors and reaction times increased with the distance of the referent from the beginning of the causal chain. For static sentences the errors and reaction times were independent of the position of the referent (Hegarty, 1992).

Schwartz and Black (1996) administered problems, related to a series of even or odd number of gears arranged in open or closed chain configuration, to 24 university graduate students. The participants were asked to mentally derive the consequences of rotation of one of the gears. When participants first encountered the open-chain version of the problem, they modeled the full motion of gears requiring relatively long problem solving and gesturing times. But after encountering several similar problems they generalized to a parity rule (which predicted the direction of rotation depending on whether the gear was at an even or odd position from the starting gear). When they were subsequently presented with a locking closed chain problem, their initial rules were insufficient and they fell back to a depictive strategy of prediction. Thus mental modeling occurred when people confronted a novel problem, or when people needed to generalize rules and when their rules failed.

Hegarty and others concluded that mental models of mechanical systems are piecemeal, they have natural sequence of operating, and reasoning related to these systems mainly involves mental rotations and translations. The models used by Hegarty and Schwartz were designed to function serially: cause applied at one end leads to an effect that transmits across the system. Models in elementary astronomy however are holistic: they do not have an inherent order for simulations. Further, the reasoning based on these models to explain or predict astronomical phenomena involves both mental rotations and perspective taking. Another major difference between the mechanical models, studied by Hegarty and by and the models in astronomy, is that the former are two dimensional and hence they can be easily translated into diagrams. Mental models in astronomy cannot be reduced to two dimensions, and hence diagrams have an inherent limitation in expressing these models. First, appropriate view needs to be chosen for drawing the diagram, and then a 3d to 2d projection has to be made.

Rapp (2005) summarizes the current state and challenges related to mental models in research in as,
"Mental models provide a description of the contents of memory for complex concepts, including the understanding of scientific principles and theories. Mental models are mental simulations that can be run, akin to a software program, to apply knowledge in novel ways, in novel settings, for novel problem sets. Science educators have been interested in mental models as a means of evaluating the efficacy of teaching methodologies and to account for students' comprehension of lesson material. Visualization researchers have also been interested in mental models, viewing them as a hopeful final product of experience with novel visualizations. While there is ample evidence suggesting that, at least in theory, visualizations may have the capacity to influence learning, there is less evidence that visualizations are being designed in a way that actually fosters the construction of mental models. ... A major goal for the future should be the critical evaluation of visualizations as tools for helping students to build mental models for scientific understanding".

Rapp is writing in the context of computer-based "visualizations", i.e. visual softwares for teaching science. He thus uses the term in a different sense from that used in this thesis. However we feel that the quote holds true for other kinds of visual teaching and thinking tools such as diagrams and concrete models.

This formulation follows the representation-process dichotomy from Artificial Intelligence (mentioned in Section 2.3, Subsection 2.4.1). Mental models are considered as mental representations and they are mentally simulated (or processed) to draw inferences. Some of the students alternative explanations can be explained using this formulation. Consider for example the following common alternative explanations (documented in Section 2.1):
1. Occurrence of seasons due to varying distance between the earth and the sun as the earth moves in the elliptical orbit.
2. Phases of the moon occur because the shadow of the earth falls on the earth.

The facts or the premises used in both the explanations (the earth moves in the elliptical orbit, and since the moon revolves around the earth, considering the sizes and distances of both these bodies, it may come into shadow of the earth) are true. However, in both the cases, if the models are processed carefully, they do not produce the desired inference (in the first example, that there will be variation in temperature, particularly different in two hemispheres and, in the second example, there will be phase cycle of 30 days). Thus the students had a correct but incomplete model and thus were unable to visualize the correct consequences.

According to Gilbert (2005) models make it possible to visualize entities, relationships, causes, and effects (at both macro and micro level). Development and representation of models is crucial in production of knowledge. Visualization is central to learning, especially in sciences, for students have to learn to navigate within and between the modes of representation. Thus although visualization and spatial transformations are processes to be carried out on a mental (or expressed) model (representation) as argued earlier, they are always fused and influence each other. The distinction is a formal one and made mainly to characterize students difficulties.

Ramadas (2009) reviews evidence from history of science, studies on the practice of science, cognitive science, developmental psychology and science education to identify transformational reasoning as a crucial component in the process of making meaning through visual representations. Reasoning with mental models could be described by the umbrella term 'transformational reasoning', a characterization that may help integrate visual-spatial with verbal and other modes of reasoning. Transformational reasoning has been used to study students' mental visualization of human body systems (Mathai and Ramadas, 2009). Model-based reasoning in science is arguably a combination of verbal and visual, as well as symbolic and mathematical modes.

2.5 Mental visualization

The studies on mental models assume that images are one kind of mental representations, and it is possible to process them to draw inferences. Although historically images were assumed to be an inseparable part of human thought, this assumption was challenged in the early 1900s after psychology became a subject of scientific enquiry. As the positivist influence on science and the behaviorist and AI influence on psychology reduced, interest in imagery was reasserted (Kosslyn, 1994). The debate on whether mental representations are principally propositional or are a combination of sensory images and propositions, continued for many years. Now however a large number of researchers are working in the area of imagery and visuospatial thinking, and thus practically have voted in favor of imagery.

Paivio and others proposed the dual coding theory around 1960s, according to which mental representations contain distinct verbal and nonverbal symbolic modes which retain properties of the concrete sensorimotor events on which they are based. Nonverbal representations include modality-specific images for shapes, sounds, actions, skeletal or visceral sensations related to emotion and other nonlinguistic objects and events. Referential connections join corresponding verbal and imaginal codes and potentially allow linking of operations such as imagining to words and naming to pictures. Associative connections join representations within the verbal or nonverbal system (Clark and Paivio, 1991). Several empirical studies showed that images can be systematically used as a mnemonic aid and as the informational base for cognitive operations such as judgement, computations, inference and new learning (Paivio, 1980).

Conclusive evidence for mental imagery came from a series of experiments by Shepard, Cooper, and their colleagues. It was found that the time required to rotate an object mentally (referred as a mental rotation task) is directly proportional to the angle through which the object is to be rotated (Shepard and Metzler, 1971). Extensive research in neuroscience and cognitive psychology demonstrated further parallels between visual perception and visual imagery (Kosslyn, 1994).

These imagery studies follow a 'bottom up approach' as termed by Tversky (2005), in which one begins from sense modalities and perception to study how complex thinking is built up. The methodology of these studies relies on hi-tech experimental techniques in neuroscience (such as PET (Positron Emission Tomography), MRI (Magnetic Resonance Imaging)) and in psychology (e.g. eye-tracking). On the other hand, visuospatial thinking can be approached 'top down' by studying complex reasoning that has a visuospatial basis. This approach is closer to some of the studies in education in which higher level cognitive activities are explained in terms of basic cognitive abilities.

Visual and spatial cognition are often thought to be integrated, and together referred to as 'Visuospatial'. This however is not a necessary connection. Two different brain pathways have been found for processing of visual and spatial information (Kosslyn, 1994). Blind people are seen to have good spatial abilities, but lack visual experiences and hence perhaps mental imagery. Properties which are available *only* to vision such as colour and brightness are primarily visual, whereas shape, size, distance and manner of movement, available to the visual as well as other modalities, are visuospatial properties (Tversky, 2005). In Section 2.6 we discuss spatial cognition in more detail.

As the mental model of the sun-earth-moon system consists of information about visuospatial properties, visuospatial transformations play an important role in model-based reasoning in astronomy. Mental simulations carried out on models to draw inferences must require visuospatial abilities (see Subsection 2.4.2). We next review the literature which argues that visualization has been important in scientific discovery and in science education.

2.5.1 Visualization in science and astronomy

Although visual and spatial thinking is an integral part of doing and learning science, and although the interplay between imagination and perception has been a topic of interest since the time of Aristotle, literature in this area was limited till relatively recently (Ramadas, 2009). A recent series of books edited by Gilbert and others have brought together much of the recent research on visualization in science education (Gilbert, 2005; Gilbert et al., 2008).

There are several anecdotes about scientists using mental imagery and visualization. Kekule's day-dream of a snake seizing its own tail inspiring the discovery of Benzine ring and Watson's visualization of DNA structure are well known examples (Gilbert, 2005). From her case-studies of major conceptual changes in the history of Physics, Nersessian (1992) found that the following are the most common heuristics used in scientific discovery.

a. 'Analogical reasoning' and 'Imagistic reasoning': Analogical reasoning creates a bridge from existing to new conceptual frameworks through mapping of relational structures from the old to the new (e.g. Maxwell used analogy of hydrodynamics to formulate electrodynamics; earliest formulation of electromagnetic field by Faraday)

b. 'Thought experiment' and 'Limiting case analysis': In a thought experiment a mental model is constructed and a sequence of events is imagined (Galileo and Einstein are known for their convincing thought experiments).

These heuristics commonly rely upon imagination, simulation and other visuospatial transformations. A flavor of these kinds of reasoning would be an interesting and fruitful experience for students.

Trafton et al. (2005) analyzed interactions of two sets of scientists (one set of astronomers and another of fluid dynamics physicists) while conducting their own research to study their use of internal and external representations and related spatial transformations and 'visualizations'[2]. These scientists were found to use computer visualizations along with, rather than as a replacement of their own mental representations. Mentally manipulating both internal and external representations was found to be extremely important to these scientists. They were found to perform more spatial transformations on their own mental representation than creating new computer visualizations or changing these visualizations. Spatial transformations were found to play an important role in connecting the internal and external 'visualizations'.

Kikas (2006) performed a 1 year longitudinal study on 176 1^{st} Grade students from 5 schools of Estonia, Europe, to find whether young students' knowledge related to astronomy depends upon their visuospatial or verbal abilities. Pre-intervention individual interviews (at the end of Grade1) were followed by instruction about the planetary system, the spherical planet earth, its rotation around its axis and reason for day-night. A post-intervention interview was conducted at the end of Grade 2. Interviews included tasks demanding verbal answers and drawings which

[2]Note that Trafton & Trickett are writing in the context of computer-based "visualizations", in this case, visual softwares for science research. They thus use the term in different sense than used in this thesis.

were similar to those used by Vosniadou and Brewer (1992). Astronomy scores were further divided into 3 categories: Factual, Synthetic and Scientific. Three tests on visuospatial abilities and 3 tests on verbal abilities were also conduced.

It was found that scores of astronomy and cognitive tasks improved with age (Kikas, 2006). Factual knowledge (which can be based on memory and not on understanding) was better than generative. Verbal abilities had a significant positive effect on scientific knowledge of 2^{nd} graders. Verbal reasoning is needed for synthesizing information; children with better verbal abilities might have understood the interviewer better and were better in explaining. Importantly, visuospatial abilities appeared to affect factual knowledge significantly and positively in the first grade and synthetic knowledge (i.e. scientific models mixed with intuitive models) negatively in the second grade. Good level of visuospatial abilities was concluded to be necessary to understand the visual information observed in daily life and also for answering generative questions and completing the drawing task.

As pointed out in Section 2.1, Sneider and Pulos (1983) found that students' performance on the 'Spatial Reference system' test contributed to the attainment of advanced notions about the earth (Notion III: unlimited space but absolute up-down directions; Notion IV: up-down directions related to the earth, but always vertical; and Notion V: scientifically accepted notion).

The importance of visuospatial thinking in practicing and learning science has now become evident. Ramadas (2009) argues in her editorial article for a special issue of the IJSE on "Visual and spatial modes in science learning" that given appropriate task situations, creative mental visualizations can be easily elicited from ordinary lay persons, but that creative visualizations of scientists are different since they are built upon a deep and extensive knowledge of their field. School education emphasizes verbal and algebraic thinking. New experimental techniques in psychology, cognitive science and neuroscience, studies in the history and practice of science and new visual softwares in teaching have revived interest in areas such as children's drawings, visualization and spatial reasoning abilities. The relevant literature in the last 35 years, needs to be brought into the context of science learning and science classrooms.

2.6 Spatial cognition

Understanding of space is essential not only in science but to our survival in the world. Early hunter-gatherers needed skills of navigation in order to track their prey, locate and get at food, hunt prey or avoid predators, as also to design tools, houses and landscapes. In today's world spatial competence is required primarily for everyday activities, and further, in specialized professions such as architecture, sculpture, sports, engineering, surgery, and in numerous other areas of pure and applied science.

The nature and understanding of space has engaged the attention of philosophers. For Kant, space and time were basic forms of intuition, not materially real but a priori structures through which we make sense of, and organize, all our experiences (Scruton, 2001). Poincare (1952) made a distinction between geometrical space and representative space. Representative space, which develops through sensations, is said to be constituted of visual, tactile and motor spaces. Geometrical space on the other hand is a mental construct, though guided by experiment, which is used for organizing and reasoning about the world (Poincare, 1952). Poincaré's stance however carries a danger of over-simplification in that it may lead us to assume that representational images and geometrical ideas are a mere copy of existing sensori-motor constructs. Piaget and Inhelder (1956) addressed this problem by taking an interactionist position, attempting to experimentally trace the path of development of spatial understanding.

2.6.1 Results from developmental psychology

Piaget and Inhelder (1956) began their description of spatial understanding with sensori-motor schemes such as sucking and grasping. Grasping is a scheme that leads to the development of spatial properties like, shape of an object, and its deformation and displacement due to force applied on it. Experiences of this kind result in the 'topological' representation of space which is the first stage in Piaget's theory of development of spatial understanding. Next comes understanding of 'projective' space and finally, understanding of 'Euclidean' space. Although this stage theory has been severely challenged by later research (Newcombe and Huttenlocher, 2003) Piaget's fundamental conceptualization of spatial understanding has stood the test of time. In this conceptualization, spatial relations develop at two levels: **1.** perceptual space, and **2.** level of thought and imagination. Perceptual space develops predominantly through two modes: visual and haptic. Thus Piaget's methods emphasize handling of objects, and use knots and object manipulations, along with children's drawings.

Later experimental studies have confirmed that the child's understanding of space develops through an interaction between visual and kinesthetic-tactile experiences. From birth infants code spatial locations in terms of bodily movements that result in perceptual contact. Coding of spatial locations gradually gets more complex, moving beyond body-centred cues to include cues and landmarks in the environment, and also elaborating into hierarchical schemes of coding. Beyond about two years children are able to understand and use symbolic devices like models, maps and plans to navigate in space (Newcombe and Learmonth, 2005). The progressive use of environment-centred cues, leading towards the representation and coding of space that is not directly perceptible, indicates development in understanding of space at the level of thought and imagination. This development is shaped through an interplay between visual and motor experiences.

2.6.2 Results from cognitive psychology

Psychometric studies found that spatial ability is an amalgam of several correlated factors, and there was consistent evidence for three factors of spatial ability (Hegarty and Waller, 2005):

1. Spatial relation and orientation: ability to understand the arrangement of elements within a visual stimulus, primarily with respect to one's body frame reference (e.g. Guilford-Zimmerman spatial orientation test).

2. Visualization: mental manipulation of objects (e.g. paper folding test); and

3. Kinesthetic imagery: associated with left-right discrimination (Hands test).

Hegarty and Waller (2004) provided evidence for distinction between 'Mental rotation' (e.g. card rotation task) and 'Perspective taking' (e.g. object perspective) spatial abilities.

Large individual differences are found in different spatial abilities. These individual differences arise because people differ on speed of processing, strategies, quality of spatial images, active maintenance of spatial information, and central executive processes (Hegarty and Waller, 2005).

Persistent gender differences too have been found in spatial abilities. Levine et al. (2005) tested spatial abilities of 547 American students (276 boys and 271 girls) from 15 schools of different socioeconomic status. The average scores on verbal comprehension tasks were the same in girls and boys in all three groups. But (consistent to earlier studies) boys from middle and high socio-economic status outperformed their female counterparts in both arial maps task and mental rotation tasks. Remarkably, boys and girls from a low socioeconomic group did not differ in their performance level in these tasks. This indicates that boys from certain cultural context engage more in the activities which promote spatial skills. Sorby (2009) reports results of studies done over 15 years of remedial teaching in spatial skills over the course of an engineering curriculum. The study showed that training, particularly involving sketching practice, can lead to large gains in performance, not only in engineering but also in science and mathematics in later years, and even significantly stem the drop-out of women from engineering courses.

2.6.3 The body as perceptor of space

The connection between perceptual space and imagined space is further indicated by evidence that perception and mental imagery draw on most of the same neural machinery (Kosslyn, 1994). As a consequence of mental rotation and scanning studies, which are largely concerned with visual stimuli, perception and imagery are sometimes assumed to share representations that are primarily visual in nature. However processing of even visual signals occurs through two different pathways, one for object features (including shape) and the other processing information on spatial location and relationships (Kosslyn and Koenig, 1992). Mental rotation tasks do activate motor areas in the brain (Wraga et al., 2003) and complex visuo-spatial reasoning also is acknowledged to have not only perceptual but also motor foundations (Tversky, 2005). The link between motor action and mental imagery is seen most obviously from experiments with blind subjects, who are found to encode visuo-spatial stimuli through haptic input and by forming spatial rather than visual mental representations (Vanlierde and Wanet-Defalque, 2004).

Our body, in occupying and moving through space, acts as perceptor of space. Studies of reaction times show that we code locations in our immediate vicinity with respect to our three body axes: up-down, front-back and left-right (Tversky, 2005). Motor perception is crucial to our understanding of imagined space, as is seen in experiments on orientation change. Tasks calling for changing one's own orientation (heading) by visual imaging are very difficult to perform, but they get greatly facilitated with use of kinesthetic feedback, i.e. by carrying out the body motions required for that orientation change, though it be (even in sighted subjects) without the use of vision (Klatzky et al., 1998). Thus gestures and actions play an important role in spatial cognition.

2.7 Gestures and actions

2.7.1 Gestures as a tool for communication

Gestures are produced by speakers from all cultural and linguistic backgrounds. Blind speakers also gesture, showing that gestures need not be learnt by imitation. They gesture even when speaking to a blind listener, showing that gestures require neither a model nor an observant partner. Gestures produced by blind people convey spatial information similar to those produced by sighted people (Ferris and Palenik, 1998; Iverson and Goldin-Meadow, 2001).

We suggest that our body not only plays an important role in internalizing space and forming mental representation of space, it also acts as mediator to form external representations of space. This mediation is done through systems of gestures and actions. In communication even non-spatial concepts are conveyed through spatial metaphors (Tversky, 2005) and gestures may facilitate such communication. Mime and drama are well-known media where gestural and body language communication are used effectively.

Gestures are produced as part of an intentional communicative act which usually involves speech (Goldin-Meadow, 2006a). We extended the scope of the act to include communication through drawing. Ordinary adults have been found to extract substantial information from children's gestures: information that was not found anywhere in speech, and even when the gestures were unedited and fleeting (Goldin-Meadow and Sandhofer, 1999). When adults were presented either videos or live observations of Piagetian conservation tasks performed by children, and asked to check the explanations produced by children on a checklist, they were significantly more likely to check when the explanation was produced uniquely in gesture than when that same explanation was not produced at all on the same task; speech-gesture match was more likely to get checked than only speech. This and other research reviewed below has provided evidence for the role of gestures in communication, at times independent of its function in speech.

2.7.2 Gestures and language

Gestures emerge in young children before the development of natural language. Vygotsky (1978) proposed that the child embellishes his first words with highly expressive gestures, which may compensate for his initial difficulty in communicating meaningfully through language. Gestures are found to be an important indicator of development in the early years. Children who may be slow to develop language but who perform well in early gesture tests are more likely to catch up later with their peers in language development. For children with Specific Language Impairment (SLI), gestures can take on the function of language (Goldin-Meadow, 2006b). Though gestures usually do not have the syntax of language, yet deaf children, who are not exposed to sign language, spontaneously develop a gesture system which has language-like properties. Untrained adults when asked to describe a videotaped scene without the use of speech, produce spontaneous gesture systems similar to language. Thus when the burden of communication falls on gestures they do take on language-like form (Goldin-Meadow, 2006b).

Gestures may convey information that is complementary to speech. For instance, consider a peculiar but pervasive phenomenon called "gesture-speech mismatch" which refers to information conveyed in gesture not always matching the information conveyed in the accompanying speech. Children who produce such mismatch tend to learn faster than those who do not. Teachers give different instructions to mismatchers than they give to matchers, and use more mismatches themselves when teaching mismatchers. Instruction on solving addition problems was more successful when teachers produced gesture-speech mismatch than when the gestures were matched with speech or when there were no gestures (Singer and Goldin-Meadow, 2005). These results show that gestures may convey some unique information which is not present in speech. Two possibly overlapping explanations have been proposed. Students may produce mismatch when the information manifested only through gesture is implicitly present with them, but not yet become explicit to get conveyed in their speech. Or, generally in communication, some information might be of a nature that is more readily available in gestures than in speech. In any case, paying attention to gestures, particularly when they do not match speech, would not only provide information about the thinking process which is not obvious from verbal discourse, but also, gestures may be designed so as to convey information that is not easily conveyed through speech. This is a promising direction for use of gestures in pedagogy.

2.7.3 Gestures and drawing

An interesting observation by Vygotsky (1978) is that a child's first graphic signs are the fixation of gestures, and that gestural depictions continue to accompany later depictions through drawing. A case study by Gardner (1980) shows how the child's first scribbles are produced when he gestures with a marker in his hand. In older children, gestures have been seen to be precursors to arrows in scientific diagrams (Roth, 2000). Imagery-related behaviors in physics problem solving include personal action projections, i.e. spontaneously re-describing a system of actions (consistent with the use of kinesthetic imagery), depictive hand or pencil motions, and reports of static or dynamic imagery (Clement et al., 2005).

2.7.4 Gestures as a tool for spatial and scientific thought

The supporting role of gestures in scientific thinking is indicated by studies which show that people use their hands while solving problems of mechanical reasoning (Hegarty, 2005; Schwartz and Black, 1996; Clement et al., 2005) and geology (Kastens et al., 2008). In inquiry-based science learning, deictic and iconic gestures are found to precede and lead verbal scientific discourse. As students get more familiar with the domain, their gestures begin to coincide with talk (Roth, 2000). Subramaniam and Padalkar (2009) have found that educated adults used considerable amount of gestures while attempting to explain the occurrence of phases of the moon, particularly in cases where they did not know the correct explanation to begin with, and therefore had to reason through the situation. Body configurations can also help in mental visualization for spatial reasoning. This same study found that imagined situations involving anthropomorphic models, e.g., a friend's half-lit face, are more effective than configurations replacing the friend's face with a half-lit ball, despite the fact that the latter model is more akin to the physical situation of a half-lit moon.

In a study of sex difference in spatial abilities Ehrlich et al. (2006) found that explanations containing gestures were correlated with performance. Five-year old boys, who performed better than girls, expressed movement in gestures significantly more than did girls, although there was no difference in the number of times that boys and girls referred to movement only in speech or in gestures combined with speech. Thus gestures might be regarded as a unique personal tool to support spatial thought.

Actions and configurations of parts of the body and the whole body may play an important role in spatial thinking and reasoning: a role that needs more attention in cognitive as well as educational research.

2.7.5 Gestures as a pedagogical tool

From the above discussion, it is clear that gestures are produced spontaneously during speech and drawing. Most recent research focuses upon these spontaneous gestures and the functions they might have in communication and thinking. The use of designed gestures is being recognized in maths instruction, as seen in a special issue of Educational Studies in Mathematics (Radford et al., 2009).

Wagner Cook and Goldin-Meadow (2006) focused on pre-designed dietetic gestures used during instruction on solving math problem. Students who were instructed using both speech and gestures benefited more than the students who were instructed only through speech, although explicit instructions to copy the gestures did not prove to be beneficial. The phenomenon of gesture speech mismatch has been mentioned in Subsection 2.7.2. Our aim in this thesis was to see how gestures can be useful as a pedagogical tool in astronomy education.

2.7.6 Analysis of gestures

There exist in the literature several different schemes of classification of spontaneous gestures. A recent scheme, described by Goldin-Meadow (2006a) classifies gestures into five types: 'affect displays' (e.g. smile, disagreement), 'regulators' (e.g. nodding, beat gestures), 'adapters' (e.g. smoothing hair, pushing glasses), 'emblems' or 'iconic gestures' (e.g. thumbs up) and 'illustrators', consisting of 'deictic' (pointing) gestures and 'metaphorical' gestures, both of which deal with content of the communication, rather than with attitudes. McNeill (as described in (Radford et al., 2009)) classifies the gestures slightly differently. According to his scheme, first three types of gestures falls under the category of gestures used for 'social-interactivity'. Whereas 'deixis' (pointing to existing or virtual objects); 'metaphoricity' (referencing an abstraction); 'iconicity' (where the form is directly related to the semantic content of speech); and 'temporal highlighting' (simple repeated gestures used for emphasis) for four different categories of gestures which are directly linked with the content of the speech. Our interest lies in the last four categories of gestures, 'deixis', 'metaphoricity', 'iconicity', and 'temporal highlighting', which are made with conscious intent, and have the potential to convey scientific information.

2.8 Diagrams

According to Tversky (1999) drawing is one of many cognitive tools invented to facilitate memory and thinking. Drawings represent visible aspects (such as shape and arrangements of objects) as well as thoughts and aspects (such as functions and activities enabled by elements) where space is used as a metaphor to represent non-spatial elements. Drawings are interactive, cyclic and dialectic and hence can simulate new ideas.

Drawings differ from mental images in that, they omit or distort perceptions or add extra information which is not there in perception. Thus drawings reveal people's conceptions of things and not their perceptions (Tversky, 1999). According to Ramadas (2009) images in science are not simple perceptual entities. This is true not only for the sophisticated images of high-level science. Images occurring in school science too carry a great deal of conceptual, abstract and often mathematical content. Unlike images in art, and less so than images in design and technology, images in science rarely stand on their own. They need to be supported by text and other formalisms (Ramadas, 2009). Mental models, being combinations of visual, spatial, temporal, causal, or other types of information, the diagrams depicting them are abstract.

Apart from being abstract, diagrams are two-dimensional and static representations and hence have limitations in representing three-dimensional reality and motion. Therefore the conventions, to depict three-dimensions onto two-dimensions and dynamic aspects, need to be learned and created whenever necessary (Tversky, 2001).

Mishra (1999) pointed out three types difficulties in dealing with illustrations particular to the pedagogy of science:

1. All forms of illustrations depend on artistic conventions that are not 'natural' and have to be learnt.

2. Scientific illustrations function within the matrix of science, with its hidden assumptions and biases.

3. Illustrations have a contingent, zig-zag history and their copying and recopying leads them to evolve far from what they began with.

Illustrations are treated (created/ read) differently by different domain or sub-disciplines within science, which shows the prevalence of subjectivity in comprehending illustrations. Importantly, understanding how illustrations work in science cannot be done in a generalized manner-it must be grounded in the dynamics of a specific discipline.

2.9 Computer 'visualizations'

Two major limitations of diagrams (being two-dimensional and static) are pointed out in the previous section, and computer graphic devices, namely 3D rendering and animations, can be useful in overcoming these limitations. When and to what extent these devices are useful is a topic of research (Tversky, 2001). However, these involve simultaneous motions which are difficult to comprehend (Morrison et al., 2002). Narayanan and Hegarty (2000) compared the effectiveness of interactive multimedia presentations and static mixed-mode presentations. The effectiveness of static mixed mode (diagram + prose) presentation was found to depend on their match with the comprehension process, rather than with the medium of presentation. Narayanan and Hegarty caution that the benefits of interactivity and animation are likely being overstated in the current milieu with the predominance of multimedia.

We conclude that concrete models and diagrams could be made dynamic with a mechanical provision and computer animations respectively. Haptic and kinesthetic affordances computer simulations are also limited in scope. Moreover, there are practical problems in using computer based tools in our settings. Computers, good software packages, electricity, related facilities and maintenance is not available in most of the schools in India. Our impression is that teachers and students (especially from rural and tribal background) are unfamiliar with these tools, and thus are sometimes too cautious and sometimes overenthusiastic to use these new tools. Such extreme attitudes could influence results to a large extent. There are thus many unknowns in introducing technology based interventions in settings such as ours.

2.10 Multimodality

Perception has limitations at very small and very large scales. Distances from a few millimeters to a few kilometers can be perceived through our direct senses, but microscopic distances of nanometers to fractions of millimeters and vast distances of the order of thousands of kilometers or even light years, are beyond our bodily apprehension. For such spaces we take the help of external representations or tools like models, maps and diagrams. However, perhaps due to the lack of possibility of direct perception, understanding of these spaces remains a challenge. To create functional internal representations of spaces beyond sense perception, one needs effective mediating cognitive tools. For example, building and manipulating concrete models, and constructing diagrams, preferably from multiple perspectives, are activities that might possibly facilitate the transition from external to internal representations.

Lemke (1998) sees science learning as the acquisition of cultural tools and practices. He analyzed the behavior of a final year high school student in a science classroom and showed that this student as well as his classmates were constantly integrating, translating, comparing, and synthesizing information presented in various forms such as different forms of complete and incomplete verbal phrases (sentences, question-answers, mathematical terms and equations etc.), text, graphs, diagrams, tables, charts, and information conveyed in the form of actions and procedures. The complete meaning is not possible to convey through a single medium, but it gets conveyed through a combination of different media. The errors and inaccuracies inherent to a single medium get masked due to multimodal communication. Lemke remarks that it is our responsibility to teach students how to explicitly integrate these different modes of representation, how to shuttle back and forth among them, how to reason with them in complex combinations and how to communicate ones ideas and results through synthesis of the results from these various modes.

2.11 Relevance of the literature review to our study

We have documented the widespread and persistent problems in students' understanding of elementary astronomy. We have identified the broad problem as one of students' inability to use visuospatial thinking in this particular area, namely astronomy. Results from science education and cognitive science (Sections 2.1 to 2.6) have helped us probe students' knowledge (Chapters 6, 7) and further to develop a pedagogy which could help students develop a sound understanding of astronomy, and in turn enhance their visuospatial thinking abilities (Chapter 5). Thus our study hopes to bridge the gap between science education and cognitive science by borrowing ideas from cognitive science and applying them to science education. Incidentally, while our own motivation is to enrich science education, we also hope that cognitive scientists might gain insights from the applications of these ideas to classroom interactions, which demonstrate theory in action.

Chapter 3

Research Design and Sample

Our study follows a 'conjecture driven research' design. This being a comparatively new kind of research design, is explained in some detail in the beginning (Section 3.1). A preceding smaller study helped to formulate an initial conjecture. This study with its salient findings is given in Section 3.2. The section on the main study (Section 3.3) gives the aims (Subsection 3.3.1), related research questions (Subsection 3.3.2) and then describes the conjecture (Subsections 3.3.3 and 3.3.4). The characteristics of sample are given next (Section 3.4). The methodology (Section 3.5) begins with the exploratory interactions (Subsection 3.5.1). The next three Subsections describe: 'Assessment of astronomical knowledge' (Subsection 3.5.2), 'The intervention' (Subsection 3.5.3) and 'Testing effectiveness of the intervention' (Subsection 3.5.4). The last Subsection in the methodology summarizes the methods of data collection and analysis (Subsection 3.5.5).

3.1 Conjecture driven research design

Several kinds of research designs such as, ethnographic, historical, descriptive, correlational, action, evaluation, casual-comparative and experimental have traditionally addressed different problems in educational research (Charles, 1995). Much of science and mathematics education research however is aimed at influencing educational practice in certain ways that are, in some preliminary fashion, already known to the researchers. The researchers' aim is to fully develop and design the new (e.g. teaching) methods while at the same time studying their effects through a dynamic process of interacting with the real system. Lesh et al. (2000) edited the Handbook of research design in mathematics and science education which provides description of these newer research designs that have been pioneered recently by mathematics and science educators; have some distinctive characteristics, and have proven to be especially productive for investigating the kinds of complex, interacting, and adapting systems that underlie the development of mathematics or science students and teachers, or for the development, dissemination, and implementation of innovative programs of mathematics or science instruction (Lesh et al., 2000).

The following characteristics of conjecture driven research design are described by Confrey and Lachance (2000):
Conjecture based design is situated in a real classroom setting rather than a laboratory setting, to come up with new widely applicable instructional strategies. It is believed that our values and beliefs frame our choice of research problem, selection of method and interpretation of data. The conjecture driven teaching experiment is motivated by researcher's commitment of equity. In this kind of research, researchers come up with a conjecture, design an instructional method assuming that the conjecture is true and finally test the effectiveness of their instructional method. The planned intervention takes place over a significant period of time. As the intervention proceeds, the conjecture evolves and becomes precise and the study is usually fairly flexible to incorporate the insights gained during the intervention (Confrey and Lachance, 2000).

What is a conjecture?
Conjecture is an inference based on inconclusive or incomplete evidence drawn from literature and researcher's experience. It is always situated in a broader theory and influences the choice of content and pedagogy. It is not an assertion waiting to be proved or disproved but a means to reconceptualise the way in which to approach both content and pedagogy.

Typically, the main study is preceded by small related studies in the same area of research and pilot studies which provide the conjectures and insights. Conjecture driven research is a complex research design and mostly done by a team of researchers, with one of the researchers or a regular classroom teacher who is well familiar with the study (or preferably, part of research team) acting as a teacher. The teacher's role is more like that of a facilitator. The researchers decide how the instruction will be structured, the mode of instruction (e.g. problem solving/ lecture/ activity), whether the students will work individually, in small groups or as an entire class. Multiple methods of data collection are used and the data are analyzed at two levels:

1. Ongoing and primary analysis: Day-to-day interaction in the classroom is captured and is continuously discussed and assessed by the team of researchers while the investigation is going on. Some data could be collected on individual students by interviewing and giving paper-pencil tasks. Daily classroom works and homeworks provide this data. Smaller investigations (eg. working with a small group of students for a short period of time) to explore a single aspect of the conjecture contribute to the data. Following a group of students is also a valuable method of data collection.

Importantly, data need to be collected about the researcher's thinking about actions during the interventions, which can be achieved through careful notes of classroom observations and classroom videos.

2. Final data analysis: A coding and analysis scheme is developed on the basis of the conjecture and the class-room videos and written responses of students. Like the experiment itself, the coding scheme also develops during the analysis. It is finalised after the intervention is over.

The two major expected academic outcomes of a conjecture-driven study could be:

- To propose an elaborated articulation of the conjecture (possibly in the form of a model as in Confrey and Lachance (2000)) which will contribute to the theoretical framework and propose new experiments.
- To propose a well developed novel instructional method with its assessment.

These two types of outcomes are reported in Chapters 5, and Chapters 4, 6 and 7 of the thesis respectively.

Confrey and Lachance (2000) describe conjecture driven research design in the context of mathematics education research. We feel that this research design is equally suitable for science education research. We therefore adopted this design for our purpose to explore students' understanding of elementary astronomy in the context of visuospatial reasoning. Our methodology, conjectures and classroom experiment are described in what follows.

3.2 Preceding related project: Moon In The Sky (MITS)

As part of the field-work requirement of my graduate course work at HBCSE, I studied educated adults' understanding of the phases of the moon. This study was carried out under the guidance of Professor K. Subramaniam, a faculty member at HBCSE. The study is reported in full in Subramaniam and Padalkar (2009) & Padalkar and Subramaniam (2007). In this study we examined how subjects set up, transform and reason with mental models that they establish on the basis of known facts as they seek to explain a familiar everyday phenomenon: the phases of the moon.

After several pilot (both formal and informal) interviews, a questionnaire and an interview schedule was designed to elicit subjects' reasoning, and in the cases where explanations were mistaken, to induce a change in explanation.

3.2.1 Sample and methodology for MITS

A total of eight participants were selected based on their prior degree (architecture or physics), gender, and convenience. Two female and two male participants were students of a "Master of Design" programme, with a college degree in architecture and a "Visual Communication" specialization in their current course. The remaining two female and two male participants had a Master's degree in Physics and were working on projects related to physics education. Both samples had 12+5 years of education. The architecture and physics groups were expected to have contrasting and complementary capabilities relevant to solving the task - experience with making and using visual representations and knowledge of physics - respectively.

Questionnaires followed by detailed interviews were conducted individually with these 8 participants. In the questionnaire, participants were asked to draw the observed shapes of the moon and were asked to explain this change. Two hint sheets were prepared to see whether participants modified their incorrect explanations on the basis of a minimal set of hints. These hint sheets served to structure the interview as follows:

Depending on their initial responses to the questionnaire, one or both the hint sheets were given. The interviews could be conceptually divided into three segments. The first segment was aimed at understanding the participants' initial model and mechanism as found in their written response and accompanying diagram. In this segment, participants were also asked whether they wished to change their explanations after going through hint sheet. The second segment was aimed at leading the participants to a correct and detailed explanation of the mechanism underlying the moon's phases. In the third segment, participants were asked to determine the correct shape of the moon in each of the phases. The interviews were videotaped and the participants' reasoning analyzed to highlight the difficulties encountered, the interaction between physical and geometrical aspects of their understanding, and their use of simplification and idealization processes, interplay between facts, concepts and visualization, and finally, their use of external representations such as through gestures and diagrams. The important findings from this study are summarized next (See for details Subramaniam and Padalkar (2009)).

3.2.2 Salient findings of MITS

The most frequent explanation of the lunar phases given by the participants involved the "eclipse mechanism". Four of the participants drew the eclipse-like shape in place of the observed gibbous shape of the moon's phase (Figure 3.1).

Participants' diagrams were in general consistent with their verbal explanations and both diagrams and speech reflected a correct mental model of the sun-earth-moon (SEM) system. However, their explanations for the moon's phases were wrong. Thus, even if a participant held a structurally correct mental model in terms of shapes and relative positions and motions of the SEM system, s/he was not able to

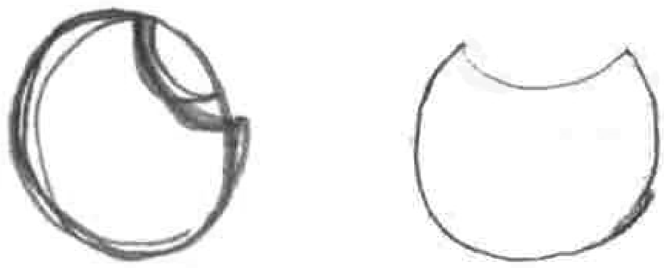


Figure 3.1: Eclipse-like gibbous drawn by educated adults (MITS)

reason based on it to come up with correct explanation or inference. This mistake is consistent with the metal model-reasoning distinction discussed in Subsection 2.4.2.

Participants were engaged for long time-periods to arrive at the correct explanations (1 hour for the questionnaire followed by interviews ranging from 24 to 110 minutes).

Although none of the adults could explain this phenomenon correctly to begin with, in the course of interviews, through a series of guiding questions, the architects, who were well equipped with drawing techniques, were much better and faster at explaining phases of the moon than were the participants who held Master's degrees in physics. The average interview time for the architects was 53 minutes and that for the physicists was 92 minutes.

Two factors seemed to have induced the changes of explanation. The first was the interviewers' questions which led to an awareness about the difference in the durations of the lunar eclipse (a few hours) and the lunar phase cycle (one month). Second were the visualizing situations described in the hint sheets and the anchor situations (especially their anthropomorphic versions; G35 as explained in Section 4.4), and presented in the interviews.

The following are some major difficulties faced by the participants

1. To identify which factors are relevant to the situation and which are not (e.g. to understand that the earth's rotation or the observer's position on the earth have no causal role in the occurrence of the lunar phases, but only determine when and whether the moon is visible at all). In this case the problem could be addressed considering the relative dimensions of the earth and of the moon's orbit.

2. Projecting curves on the sphere (three dimensions) on to two dimensions (e.g. a circle get projected to an ellipse when seen from an angle).

3. Simulations and spatial transformations (e.g. Half a moon will be lit at any time irrespective of distance of the moon from the sun).

The cognitive demands that arise from attempting to incorporate all the available information into mental simulations are heavy. One can only solve the task through a reduction of the dynamic aspects. We found three ways in which such reduction was achieved by participants:

1. Simplification by ignoring aspects of the problem such as the earth's rotation or the observer's position.

2. Taking snapshots of the dynamic configuration. This was visible in the drawings that participants made showing multiple positions of the moon as it moved in its orbit.

3. Identifying and representing invariants such as, circle of illumination and the boundary of visible part of the moon.

Using more than one positions of the moon, or viewpoints, choosing the correct viewpoint for explanations, and mixing text with diagrams, were some of the key features of the diagrams which seemed to help in explanations. These features were more frequently found in diagrams drawn by architects.

Participants used considerable amount of gestures. Imagining anthropomorphic situations (i.e. involving role-play, even in imagined form) was particularly helpful in visualization and reasoning.

The MITS study concluded that visualization is an important process in elementary astronomy education, and external representations such as diagrams and gestures are potential spatial tools for reasoning in this context.

3.3 Main study

The content in this Sections and Sections 3.4, 3.5 is also presented in Padalkar and Ramadas (2009).

3.3.1 Aims of the study

This study was carried out with three aims in mind:

1. To investigate Indian students' understanding of elementary astronomy.

2. To design a pedagogic sequence of intervention based on insights from literature on spatial cognition and visualization to teach elementary astronomy to Grade 8 students.

3. To test the effectiveness of the pedagogic sequence.

3.3.2 Research questions

With this background on students' difficulties in astronomy (Chapter 2) and the inadequacies of textbooks in use (Section 1.4), the work has the following three broad aims, each of which naturally suggest several interrelated research questions to explore.

Aim 1. To investigate Indian students' understanding of elementary astronomy.

Students' observation about the phenomena which they are expected to explain is crucial. Our first question therefore is, 'What are students' observations about celestial bodies and phenomena (sun, moon, stars, planets, shooting stars)? Have they understood the patterns in the cyclic phenomena (day-night, daily motion of stars and moon, phases of the moon, changes in the path of suns due to seasons, changes in night sky over the year)? What kind of observations (qualitative/ quantitative, observations about visual/ spatial/ temporal properties) do students record?
...Addressed in Section 6.1.

Do students know the basic facts (which are taught in the textbook) about the solar system?
...Addressed in Section 6.2.

Given the close connection between astronomy and astrology and the active influence of indigenous knowledge related to astronomy, do students know about the connection between observational astronomy and indigenous calendars? Do they know the common terms and their meanings used in indigenous astronomy?
...Addressed in Section 6.3.

What is the level of students' understanding about the model of the round rotating earth? Can they present this model coherently? Can they provide satisfactory explanations of the phenomena that they have learnt in their textbooks? Can they make prediction in the hypothetical situations based on the model?
...Addressed in Chapter 7.

What aspects of students' knowledge change with level of schooling? In which aspects of knowledge do students from rural, tribal and urban background differ?
...Addressed in Section 7.4.

Aim 2. To design a pedagogic sequence of intervention based on in-sights from literature on spatial cognition and visualization to teach elementary astronomy to Grade 8 students.

What are some useful cognitive tools? If concrete models, gestures and actions, and diagrams are identified as useful spatial tools, how should they be placed in the pedagogy with respect to each other?
...Addressed in Section 3.3.

What are some useful concrete models that can be used to teach the sun-earth-moon system?
...Addressed in Section 5.1.

Assuming that gestures might be a useful spatial tool in learning elementary astronomy, we ask:
What can be a reasoned basis for designing gestures for teaching astronomy?
How should these gestures be placed in relation to other common spatial tools?
...Addressed through argument and examples rather than through data, in Subsec-

tion 5.2.1.
What types of spontaneous gestures are produced by students during collaborative problem solving?
Do these gestures vary according to the problem tasks?
How do students' spontaneous gestures compare with the pre-designed gestures used in the intervention?
...Investigated empirically using video data, in Subsection 5.2.2.

What do diagrams in astronomy represent and what are the characteristics of each of these kinds?
What characteristics of diagrams can be used as criteria to evaluate students' teachers' and textbook diagrams?
...Addressed in Section 5.3.

What are the difficulties related to content and how can these difficulties handled?
...Addressed in Chapters 6 and 7.

Aim 3. To test the effectiveness of the pedagogic sequence.

Which aspects of students' knowledge change significantly after the intervention?
Which aspects of students' diagrams change significantly after intervention?
With respect to which aspects of knowledge do students from the treatment group performed significantly better than students who did not go through intervention (comparison group)?
Which alternative conceptions and explanations continued to exist even after instruction?
Could students correctly answer/ predict in novel situations?
...Addressed in Chapters 6, 7 and 8.

3.3.3 The initial conjecture

From the literature survey, the MITS research and exploratory interactions we proposed a framework of loosely interrelated conjectures as follows:

Understanding elementary astronomy requires constructing mental models. Mental models in astronomy include significant spatial components. One needs to link these mental models and observable astronomical phenomenon through visuospatial reasoning. In the process one refines both mental models and observations. Spatial tools such as concrete models, diagrams and gestures help in this process. Gestures and actions, which are spatial tools to link mental models with observations, could be used in classroom teaching to link concrete models with diagrams.

The rationale behind these conjectures is provided in detail in the 'Literature Review' (Chapter 2) and their merit is judged in the 'Conclusions' (Chapter 8).

3.3.4 Operationalizing the conjecture

For model based reasoning, concrete models, diagrams and gestures are all spatial tools. These tools represent either the phenomenon or the mental model and further serve to link the phenomenon with the mental model. Our conjecture about the role of gestures in astronomy has helped us to design the pedagogical gestures. We have formulated this conjecture to have two dimensions which are illustrated in Figure 3.2.

The vertical dimension of our conjecture, shown in Figure 3.2, arises from the limitation of perception for comprehending astronomical models. Gestures represent, communicate, and most importantly internalize the spatial-temporal properties of the phenomena and scientific models. We further conjecture that gestures help in changing one's orientation and frame of reference, and through these two functions, the link between the scientific model and the phenomenon is manifested, and strengthened (these intended functions are elaborated with examples in the Subsection 5.2.1). Also one has to go to and fro from one's mental model to the phenomenon and back, in order to refine one's understanding, a process that is indicated by the two-way vertical arrows in Figure 3.2. We call this the 'mental model - gesture - phenomenon' link of our conjecture. Its instances are indicated in Table 5.1 in the column 'Purpose'.

The horizontal dimension of our conjecture, shown in Figure 3.2, arises from

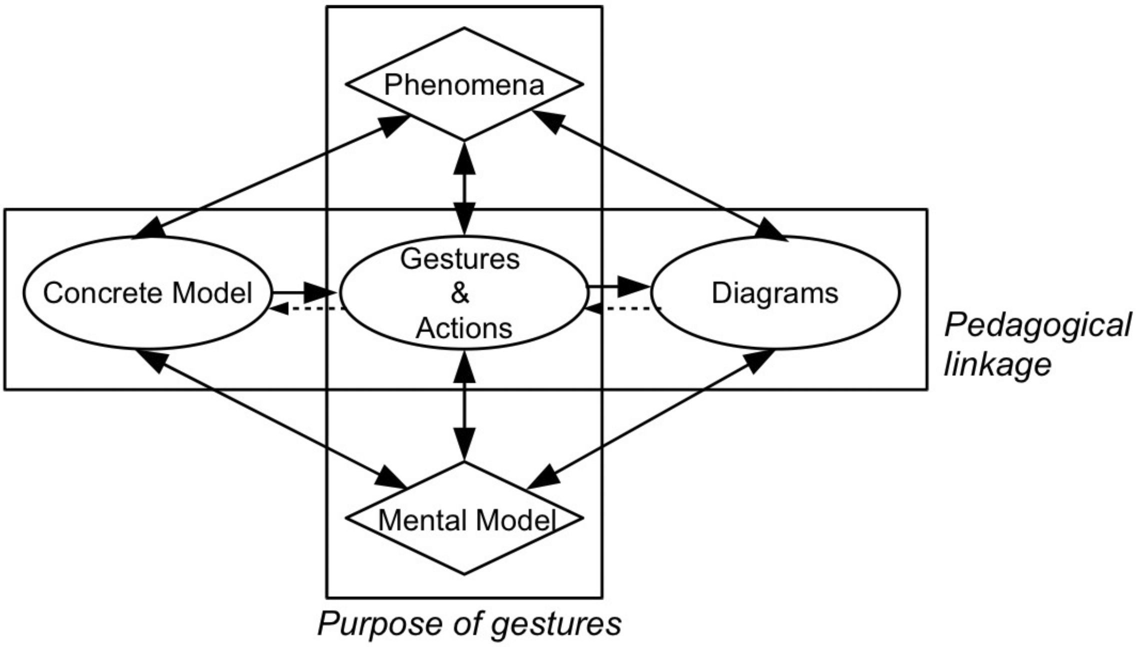


Figure 3.2: Purpose of gestures in linking phenomena with mental models and their pedagogical role in linking concrete models with diagrams

the limitations of use of any single representation like a concrete model or a diagram. Diagrams are visually economical and precise in capturing analytical relationships, but diagrams being two-dimensional, static and abstract, pose difficulty for students (Tversky, 2005). Concrete models on the other hand, are easily constructed, three-dimensional and movable, but because of their crude and often inflexible nature, they are not amenable to the abstraction and manipulability required for reasoning. Gestures too are three-dimensional and dynamic, and in addition they are fluid and transformationally flexible, so they can potentially be used to traverse the conceptual distance from concrete models to diagrams. Figure 3.3 summarizes the properties that gestures share with concrete models and diagrams to hypothesize that gestures could provide a possible link between concrete models and diagrams. The arrows in Figure 3.3 indicate the shared properties of gestures with either concrete models or diagrams. Figure 3.3 is an elaboration of our rationale for the ‘concrete model - gesture - diagram’ link in Figure 3.2. Instances of this link are indicated in Table 5.1 in the column ‘Type of linkage’.

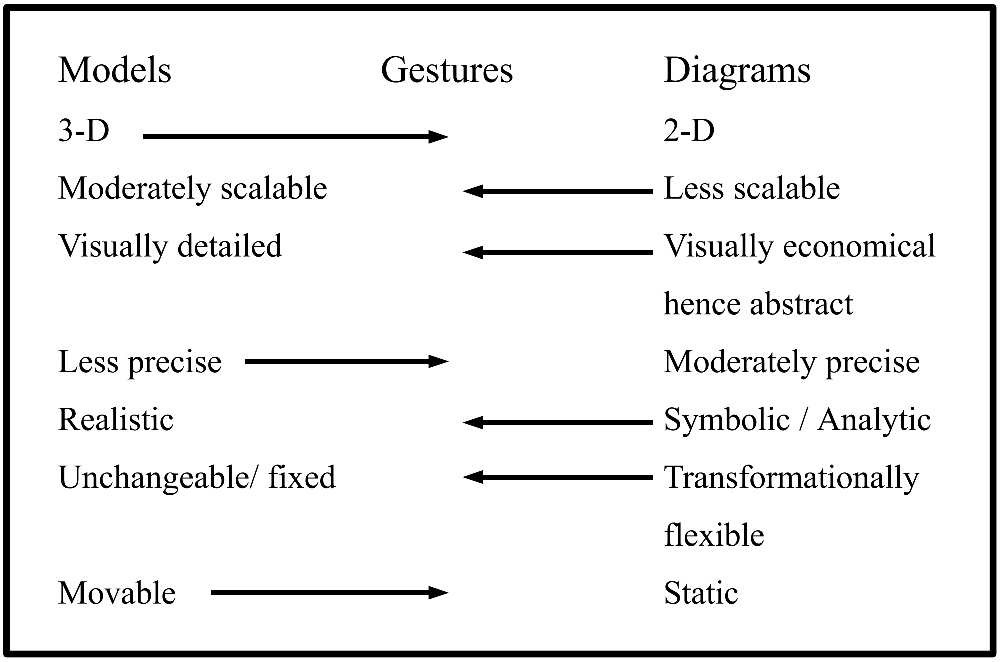


Figure 3.3: Gestures can be used to link concrete models with diagrams: Arrows denote the properties that gestures share with either concrete models or diagrams.

Given the economic and abstract nature of diagrams, the desired direction of the ‘concrete model - gesture - diagram’ link in Figure 3.2 is from concrete models towards diagrams. In terms of pedagogy however, at the initial stage one needs to go to and fro until mastery over the diagrammatic medium is achieved. This backward link is shown by the dotted arrows in Figure 3.2.

In reference to multimodality (Section 2.10), the three spatial tools under consideration use a combination of different sensory modes. Concrete models are perceived through the visual and tactile mode, gestures rely upon the visual, kinesthetic and vestibular senses, and diagrams are amenable to use of the visual and kinesthetic senses. The visual sense is common among all these three tools, a fact that may make it easy to mediate between one tool and another. However, the visual mode in all these cases is coupled with other modes, which makes the combination of these tools rich and powerful for communication and internalization of the content.

Note that in Figure 3.2, the focus of our interest is the central cell, ‘Gestures and Actions’. However, links such as ‘mental model - concrete model - phenomenon’ or ‘mental model - diagrams - phenomenon’ and extended links such as ‘mental model - concrete model - gesture - phenomenon’ or ‘mental model - gesture - diagram - phenomenon’ are also possible, as indicated by the oblique arrows in Figure 3.2. Finally, in a different analysis with a different focus of interest the horizontal cells might well be substituted or complemented by Verbal (e.g. ‘speech’ or ‘writing’) or other Visual media.

3.4 Selection of sample

The sample consisted of students who were about to finish Grade 4 (end of primary school) and Grade 7 (end of middle school). Grade 4 and Grade 7 students are referred to by ‘Gr4’ and ‘Gr7’ respectively in all the Tables.

Our aim was to select student samples representative of the socio-economically deprived majority population of India. According to the 2001 census (Cen, 2001), more than 72% of the Indian population lives in villages. More than 8% Indians of the population are classified as “Scheduled Tribes”. Maharashtra being one of the progressive States, is more urbanized: more than 42% of its population is urban. 15% of the total urban population of the country lives in slum areas or shanties in the towns and cities, and out of the total slum population in India, 26% (highest in the country) reside in the State of Maharashtra. The rural, tribal and urban slum populations tend to be poorly educated; their economic status is low and they belong to socially low and exploited classes; in the rural and tribal populations however, the students who attend school might be more privileged than others in the village who remain out of school. Schools which serve all these population have limited resources in terms of space for classrooms, laboratory equipment and other materials. The school textbooks may be the only written materials available to the students. They do not have access to extra science books, educational videos or computers; in fact they often come to class without even minimal tools such as pencils, erasers or notebooks.

Considering this population profile and the low resource situation in the majority of schools, we have chosen our samples from three groups in the State of Maharashtra, which we feel are fairly representative. One sample is from a rural school, another is from a residential school for nomadic tribal children and the third sample is from a school which serves a slum area in Mumbai. In the rural and tribal areas equivalent schools were selected for treatment and comparison samples; in the urban school the comparison sample was selected from the same school. The representation of girls in both treatment and comparison groups was around 30% because of high drop-out rate among girls in the primary school years.

3.4.1 Rural sample

The rural sample was selected from a village in South-Western Maharashtra close to the town of Kolhapur (co-ordinates: 16.6N, 74.2E). This being one of the relatively more developed regions of the country, schools and other basic infrastructure (roads/ public transport/ water supply) do exist. There are two schools in this small farming village, which has a population 4428 (according to the 2001 census) and an area 12.84 sq. Km. (including farm land). Most students' parents own their own land and cattle, so they perhaps have better economic status and access to natural resources (fresh air/ food/ water) than the other two samples. However the importance accorded to education remains low and hence the drop-out rate is high (higher amongst girls). Consider that out of the 90% students (boys and girls) who enroll in Grade 1 in rural Maharashtra, only about 69% reach Grade 8 and only 18% continue their studies beyond Grade 10 (Nat, 2002). Most students do learn skills which are useful for farming and they, particularly girls, have to take major responsibility in helping out their parents in household as well as in agricultural work. One of the schools in this village, which is located in the local temple, was chosen for the treatment group and another which has its own small building served as the comparison group. No differences were noticed or reported by villagers in terms of economic, social and educational background of students from these two schools.

3.4.2 Tribal sample

"Nomadic tribes" are ones that left their original habitations, did not settle in villages or towns, but have been wandering for generations doing various odd jobs. They have some unique problems. Under the British rule they were declared to be "criminal tribes" and kept in confinement. Although they were set free in 1960, their social and economic status remained extremely low. Their original jobs such as digging wells and shepherding were made redundant due to technological advancement and changing lifestyles. So now they work as casual labour or hold small jobs such as brewing local alcoholic liquor, but most of them are still not settled. There are around 30 lakh (3 million) nomadic tribals in Maharashtra in whom the percentage of education is less than 0.1% (Shipurkar, 2006). So most of the students who attend school are first-generation learners. Residential schools devoted to nomadic tribes have been operational in this area since 1988. Run by socially progressive organizations with leadership from within the community, the motivation levels of students and teachers in these schools tends to be high. Two such schools near the town of Kolhapur (co-ordinates: 16.6N, 74.2E) were chosen: one for the treatment sample and another for comparison. The tribal school from which the comparison group was drawn was also a residential school in another village run by the same organization. Students from this school come from similar nomadic background, but their parents have now settled in nearby villages (which is why this location was chosen for the school). Due to their nomadic origins, the tribal groups were more heterogeneous in terms of their cultural and linguistic background than the urban and rural groups.

3.4.3 Urban-slum sample

The third school serves a suburban slum area of Mumbai (co-ordinates: 19.0N, 72.9E), which is the capital of Maharashtra and the largest metropolis in India. Most of the students' parents are migrants from villages of Maharashtra and work as labour or do small jobs such as doing embroidery on cloth. Their families may continue to hold some land and often their grandparents live in those villages. Only a few fathers (and fewer mothers) have completed their primary education; many of the parents are illiterate. Living in Mumbai they earn more than the tribal and rural populations, but with a higher cost of living they are not able to fulfill their basic needs. They are also conscious of their very low social status as compared to that of middle and higher classes living in the big city. The educational level of parents of students from all the tree samples are shown in Table 3.1. Table 3.2 shows indicators of socio-economic background (The data for all the students was not available, so the averages and percentages are calculated over the number of students whose data was available).

The urban students attended our sessions voluntarily outside of school hours. Some students from the same grade level who did not attend our sessions formed the comparison group. The rural and tribal treatment and comparison samples consisted of an entire class in each school.

In Tables in further sections, the rural, tribal and urban samples are indicated by 'T', 'R' and 'U' respectively.

Table 3.1: Educational level of parents in percentages

	Rural		Tribal		Urban		Total	
Educational Level (*N*)	Father (*20*)	Mother (*21*)	Father (*29*)	Mother (*27*)	Father (*9*)	Mother (*9*)	Father (*58*)	Mother (*59*)
Illiterate	3	14	39	32	0	17	15	21
Primary	6	6	0	14	11	0	5	7
Middle School	17	37	4	18	11	11	11	25
Secondary	29	20	18	7	6	6	20	12
Higher Secondary	17	0	4	0	6	0	10	0
College	6	0	7	4	0	0	5	1

3.4.4 Local learning opportunities (rural and tribal samples)

Although students from all the samples are deprived of formal out-of-school science learning resources, from the viewpoint of informal opportunities for astronomy learning, the tribal and rural samples are in some ways different from the urban sample:

Table 3.2: Socio-economic background of samples

	Rural	Tribal	Urban	Total
Total No. of in the class students (N)	*35*	*28*	*18*	*81*
Average age (on Jan 2008)	13;08	14;05	13;02	14
Caste of family (Maratha+Other)	29+8	1+29	No data	
Economic status: Numbers indicate percentages				
Own Farm	96	67	100	86
Own Cattle	82	52	67	69
Own Tractor	11	14	0	11
Own Two-wheller vehicle	50	48	0	44
Own Cycle	79	67	67	73
Access to media: Numbers indicate percentages				
TV	75	67	100	75
Cable	36	38	50	38
Radio	79	86	67	80
Phone/ Mobile	25	43	100	40
News paper	39	43	100	47
Calendar	86	95	100	91

Other Castes include Mahar, Mang, Beda-Jangam, Lingayat, Lohar, Dhangar, Gopal, Davari, Laman, Vaidu, Kaikadi, burud, Kanjar-Bhat, Ramoshi (Only first 6 in rural sample). Most of these belong to belong to Scheduled Castes and Scheduled Tribes.

• They work in farms and hence they have experiences of working in open spaces and handling or estimating (relatively) large areas. We were interested in probing whether this experience has influenced their spatial cognition.

• They have better access to sky observation for two reasons. First, the skyline is not obstructed by tall buildings as is so in Mumbai and secondly, both air and light pollution are considerably lower. Although the villages are electrified, people suffer more than 14 hours per day in power outages. Thus the night sky is very clear except in the monsoon season. We anticipated that these factors might have affected the quality and quantity of students' observations of astronomical phenomena.

• They are less influenced by modern science; satellite TV is less accessible. On the other hand, they are more exposed to indigenous traditions as compared to urban society in general (although our specific urban sample was derived from a section of society that has not completely cast aside traditional practices). Adults in this society commonly use indigenous calendars to regulate agricultural activity and festivals. As a result perhaps, astrology plays an important role in their lives. Nonetheless one of our aims was to see whether this indigenous cultural tradition could contribute to students' understanding of astronomy.

• Although the local language as well as the language of instruction in all the samples is Marathi, the spoken language of rural students differs moderately, and that of tribal students differs considerably, from standard Marathi. Hence these students are at a disadvantage in understanding the standard Marathi in textbooks and reproducing rote-learned answers to score well in examinations. This feature of language, that the spoken language or a dialect is different from the standard, is true not only in the case of Marathi but in most other Indian languages as well. Hence we were interested to equip students with other, non-verbal, modes of learning, thinking and communication.

Although we did not test the spatial abilities of these students, we assumed that they have normal spatial abilities, that boys and girls do not differ in their spatial abilities significantly, and that the pedagogy would be equally beneficial to both the sexes. The assumption regarding difference between boys and girls have support that, although persistent sex differences are found in spatial abilities, sex differences were not found significant in students from low socioeconomic status (Levine et al., 2005).

3.5 Methodology

3.5.1 Exploratory interactions

As a preliminary step to design the first questionnaires, the parts related with astronomy in the curriculum for Maharashtra State up to Grade 10 were studied (Section 1.4). A set of questions were then prepared for pilot testing, to get a general idea of students' level of understanding. These questions were orally asked in Grades 3, 6 and 8 in the schools which we expected to take up for the study (the final sample for the study consisted of students from Grades 4 and 7 in the same schools). The exploratory interactions with students at different grade levels gave us a broad view of their range of development over the school years. This information was used in development of a set of tests which were administered to the sample for our study. The exploratory interaction also provided an opportunity to introduce our project to the school teachers and principals, and to a build up a rapport with the staff of these schools. The pre-tests which were prepared for assessment of students' astronomical knowledge (Subsection 3.5.2) incorporated some of these questions which were orally asked in the exploratory interaction.

The one-year pedagogical intervention was then undertaken only for students who were about to complete Grade 7 (during March 2007 to May 2008). At the end of the intervention, these students had reached the end of their Grade 8. The assessment of our intervention was carried out at this point using post-tests (as described next) on the three (tribal, rural and urban) treatment groups. Three comparison groups of Grade 8 students were administered a post-test only.

3.5.2 Assessment of astronomical knowledge

During the exploratory phase 3.5.1 we interacted with the students in the same schools that we chose for the main study, but from different Grades (Grade 3 and Grade 8). Based on our informal assessment of these samples, an open-ended discussion session in each class, the astronomy content covered by Maharashtra board textbooks by Grade 4, and anticipated familiarity with some astronomical phenomena, we prepared four tests as follows - Test 1: Observations, Test 2: Textbook Facts, Test 3: Indigenous Knowledge and Test 4: The Sun-Earth Model. An extra test based mainly on the content on the moon, which students learn during Grade 8, was administered in the beginning of the third part of intervention (Test 5: The Moon). At this point students had learnt the sun-earth moon system and explanations of phenomena related to the moon as part of their regular school syllabus but not as a part of the intervention. These tests served as pre-tests and, one year later, at the end of the intervention, the same tests (with some extensions), were also used as post-tests. The questions in these tests were simple and we expected that working through these tests might motivate students to observe and think beyond their textbooks. The pre-tests therefore can be considered to be a pedagogic experience that was part of the intervention.

The tests were administered in written form to the students of Grade 4 and Grade 7 except for the Indigenous Knowledge test, which was administered orally to the entire Grade 4 classes. The reason was that in pilot testing we found that the whole class together could answer the questions, but individually, they knew very little. Besides it was too much of a burden for the younger students to read, understand and to respond in writing to four tests on successive days. The Grade 7 students responded to all the four tests in written form. The tests were followed by informal interviews of a few students to probe their ideas and to get a feel about the reliability of the tests. The number of students who answered the tests (including two sets of post-tests) and interviewed are summarized in the following Table 3.3. The number of students from both the treatment and the comparison group who attempted the post-tests are also listed in Table 3.3 and explained in Subsection 3.5.4.

Previous research in astronomy education as reviewed in Sections 2.1 is largely focused on identifying alternative conceptions in astronomy. The wide prevalence of these alternative conceptions is well known and we expect that similar conceptions may be found among Indian students. We were not so interested in the alternative conceptions themselves but in the micro-details behind them. What kind of mental models lead to these alternative conceptions, what skills are required to arrive at the correct explanations and so on. While the content covered in our study is similar to that in earlier studies, the nature of our enquiry was different. We were interested in the qualitative details of students' models rather than the gross categories of alternative mental models or alternative conceptions. Therefore **a.** we preferred open-ended questions rather than forced choice questions and **b.** while analyzing these responses, the presence (or absence) of different elements and aspects of the written and diagrammatic responses were looked for, rather than classifying the response according to a single scheme. Instead of the gross conception, we were interested in identifying which of its several identified aspects improved after instruction and perhaps facilitated correct understanding and problem solving.

Table 3.3: Number of students who attempted the questionnaires (Gr7 is equivalent to pre-tests and Gr8t is equivalent to post-tests)

Grade	Girls + Boys	Test 1	Test 2	Test 3	Test 4	Test 5	Interview
Gr4-R	16 + 16	32	30	–	32	–	3
Gr4-T	8 + 5	10	13	–	11	–	
Gr4-U	21 + 27	45	45	–	45	–	7
Gr4	**45 + 48**	**87**	**88**	**–**	**88**	**–**	**10**
Gr7-R	12 + 23	27	26	27	26	24	
Gr7-T	7 + 21	17	15	15	17	19	2
Gr7-U	4 + 14	18	17	17	16	–	4
Gr7	**23 + 58**	**62**	**58**	**59**	**59**	**43**	**6**
Gr8t-R	12 + 23	26	28	27	28	24	9
Gr8t-T	7 + 21	21	20	21	21	23	5
Gr8t-U	4 + 14	6	6	6	6	6	7
Gr8t	**23 + 58**	**52**	**54**	**54**	**55**	**53**	**21**
Gr8c-R	16 + 24	34	37	37	37	35	4
Gr8c-T	11 + 33	35	37	38	36	42	6
Gr8c-U	0 + 3	3	3	3	3	3	2
Gr8c	**26 + 60**	**72**	**77**	**78**	**76**	**80**	**12**

Total number of students in the column 'Girls+ Boys' is taken from school records at the end of intervention. Several students in Grade 8 remained absent during intervention as well as for tests. Some used to come occasionally. Since the middle school education completes at Grade 7, many students dropped out only after first part of the intervention. On the other hand, some of the government run tribal schools are only up to Grade 7. So some new students joined (especially in the tribal school) in Grade 8 (Part II onwards) since their earlier school was only up to Grade 7. This newly joined students did not go through pre-tests and Part I of the intervention, and found it difficult to cope with the content in Part II. A few remedial classes were taken for these students, but we feel that they were not as effective as Part I. This might have affected (subsided) the average performance in the post-tests.)

3.5.3 The intervention

The intervention was carried out by the author with the help of a local academic assistant. The academic assistant did all the video shooting. Our intervention was divided into three parts (cycles) of about 10 classroom sessions of one and half hour each. The first part dealt only with the earth, its roundness and rotation (Section 4.2). These ideas were sufficient to explain the change in apparent position of the celestial bodies due to change in one's position on the globe, as also their daily apparent motion as seen from a given position on the globe (Padalkar and Ramadas, 2008b). The second part dealt with the sun-earth system and consequences of revolution of the earth around the sun such as, seasons and changes in the night sky over one year (Section 4.3). The content in first two parts of the intervention, which were held at the end of Grade 7 and in the middle of Grade 8, was already dealt in Maharashtra board textbooks by Grade 7. The phenomena related to the moon were dealt in the beginning of Grade 8, and hence the sun-earth-moon system and explanations of phases of the moon and eclipses were dealt in third part of our intervention (Section 4.4). Thus the content addressed in our intervention was the same as the content addressed in the Maharashtra board textbooks.

There was a gap of about 5 months between two successive parts. We thought that this gap might be useful for students to reflect over the taught content, carry out new observations on the gradually changing sky, and thus to come up with new questions and achieve further clarity in understanding. Students were asked to take careful notes on suggested observations such as, length and orientation of the shadow of a pole, phases of the moon and positions of the stars and moon at particular times. They were also given six homework sheets, 3 each within the two 5-month periods following the first and second parts of the intervention (Section 4.5). These we thought would remind students of the content of the earlier part as well as prepare them for the next part of the intervention.

Two kinds of homework tasks were given during the actual contact period. Homework related to the content taught on that day was given to make students think over it and to ensure that they were following the content. To enhance students' spatial abilities, they were given a daily homework sheet containing various spatial tasks (like shape-puzzles and paper-folding). This was done during the second and third parts of the intervention.

The pedagogy is described in detail in Chapter 4 and that of the first part is published in (Padalkar and Ramadas, 2008b). Here we list some general features of the pedagogy, whose overall aim was to construct a working mental model of the sun-earth-moon system and a skeletal model of the solar system. Students were also expected to explain and predict everyday phenomena based on the model of the sun-earth-moon system. The pedagogy used low cost and easily available methods along with local aids such as indigenous calendars and specific experiences to develop visuospatial reasoning. The pedagogy used the following modes:

Teaching by Socratic questioning: We avoided telling facts, instead students' models and explanations were continuously questioned and they were encouraged to upgrade their models and explanations. According to Gilbert and Boulter (1998) in this method students are encouraged to form a mental model, but the substance and the use of these will largely governed by the teacher's inputs and evaluations and there is a worry that students' narratives will be marginalized. However, we preferred the method of Socratic questioning over the 'dialogic arguments' which are more open for expressions and argumentation of students to maintain the pace of the teaching, otherwise there is a danger of students getting bored or losing interest. Moreover, the students were given opportunity to express their models during the tests and interviews which served as data.

Use of spatial tools: The pedagogy was built around three main spatial tools: concrete models, gestures and actions, and diagrams (rationale explained in Subsection 3.3.4). Neither of these tools were used in the regular course of teaching in the schools from which we chose our samples. Detailed description of all the concrete models, gesture and actions, and diagrams, is given in Chapter 4.

Concrete models: In all 22 concrete models were used during teaching. Students were familiar with globe, but rest of the models were new to them. Some of these were prepared by students and all of them were available to students to handle and experiment with. The models were made out of easily available material, and even these materials could be easily replaced by others.

Gestures: Although gesturing is common in our daily communication, they are not used in classroom context. Students were initially shy to make broad gestures, but after encouragement started to use gestures more freely. Forty groups of gestures were designed as pedagogic gestures and students spontaneous gestures were also studied.

Diagrams: Regular school experience in India provides little opportunity for students to develop their diagrammatic skills. The traditional teaching and examination pattern emphasizes neat and stereotyped diagrams which 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 putting together their accessories: sharpening pencils, cleaning erasers, fussing with ruler and compass. We found it necessary to break the barrier of this so-called neatness, towards making students self-reliant in drawing. Students were therefore encouraged to draw profusely in freehand, on blackboard as well as on paper. To make drawing easier for students, the teacher drew a skeletal diagram on the blackboard, and students one-by-one added elements in that diagram and drew inferences. Thus a diagrammatic dialog was a central part of the teaching. Students were given photographs of the sun, earth, moon and solar system (model). Forty groups of diagrams which were used in the pedagogy are given in Tables 4.1, 4.2 & 4.5.

Collaboration: The role of collaboration in cognition, scientific enquiry and learning is undisputed (Rogoff, 1998). Empirical studies (usually based on the theoretical framework of 'social cognition') have investigated different aspects such as collaboration among same-sex and mixed-sex groups, use of different tools, etc.. Although studying the aspects of collaboration was not the main aim of our study, insights from some of these studies were used while designing the pedagogy and classroom situations (for example making the groups). In the context of teaching three different types of collaboration are seen: **a.** adult-child interaction, **b.** peer interaction, and **c.** community aspect (Rogoff, 1998). We designed the pedagogy in such a way that students could collaborate on all three levels. We tried that the teacher-student interaction was as less authoritarian as possible. In 'guided collaborative problem solving' and in 'observations' there was collaboration among students, and the community aspect was embedded in the use of 'sociocultural tools', and tools whose comprehension was based on shared understanding, such as, concrete models (globe) and schematic diagrams.

Natural collaboration: The classroom organization was flexible enough that students could interact and discuss in small groups. Such interactions also occurred naturally. The natural collaboration and consultation that occurred among groups of students, and often in the class as a whole was an interesting aspect of the classroom interaction. In reaction to any challenging question, students would go into a huddle, discuss intently for a few minutes and finally come up with a consensus response. Able students were ready and willing to share their knowledge with their less able peers. This seems to us to be reflective of a consultative process that is common in traditional rural and tribal societies. 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, ought form the subject matter of an independent study. We however hope to use this interaction fruitfully in designing specific collaborative learning situations for astronomy.

Teacher directed class: Concrete models were introduced and students collectively added different elements to it. Students together listed the differences between the model and the real system, correcting and adding into each others' responses. As for gestures, ten out of the 40 pedagogic gestures needed two or more persons to enact them. Diagrams too were collaboratively constructed on the board. Students added the required elements in a diagram in combination with an ongoing dialog.

Guided collaborative problem solving: Students were given 12 sets of questionnaires to solve in groups of three. While solving these problems, students used concrete models and gestures to communicate their ideas to their group-mates. Skeletal diagrams were followed by step-wise instructions to construct a diagrammatic solution to the problem. Note that spatial tools were used to create the collaborative situation and to study students' learning, rather than using verbal discourse, which is a more common method in studies of collaboration.

Observations: Observations of positions of stars, shadows of gnomon, shape and position of the moon, etc. were carried out in groups. It is acknowledged that keeping notes of observations of any scientific experiment is difficult and less reliable when done by a single person. This is more true in the case of astronomy, where observations need to be taken sometimes throughout a day or a night, and sometimes over a long period (a month or a year). Students shared common tools (a simple astrolabe which we will refer as an 'angle dangle meter') and charts, sometimes shared responsibilities for data collection and discussed them to arrive at pattern: a process that emulates to scientific research.

Use of sociocultural tools: The commonly available calendar turned out to be an important sociocultural tool for learning. This calendar is combination of the Gregorian calendar and a particular Indian calendar, derived from almanac called "*Chaitry Panchang*" (Date and Date, 2007) (Figure E.1). It is used in determining festivals and other social as well as the (often related) agricultural practices around the year. Importantly, it documents many observational facts such as the times of sunrise and sunset, moonrise and moonset on a few days, phase of the moon, in which constellation the moon would be seen, etc. (Figure E.1). This calendar helped place problems in astronomy within a cultural context, thus helping to bridge the gap between formal science and the shared cultural knowledge which was available to students.

Students were familiar with this calendar; all the urban and most of the rural households in our sample owned a copy of it. In addition, students were given a copy of this calendar (available in a portable size) from Part II of the intervention onwards, to help them connect observation with indigenous knowledge. This calendar is a complex text, but it becomes easier to comprehend through discussion among students, each of whom may notice a different feature in it. In the class students read aloud and interpreted notes from their calendars. Sometimes calendars were provided in groups to find out the pattern in a particular phenomenon. Tools such as a simple gnomon and an angle dangle meter were prepared by the students and used for observations. Observations from these and some other tools such as telescope and star-charts complemented the notes from calendars.

History of astronomy: We brought in the historical aspect in each part of intervention by giving some historical reading material in groups, and watching a short portion of Bertolt Brecht's play "Life of Galileo" enacted by teachers (in Marathi translation, with activities and gestures as suggested by (Brecht, 1947)).

Supporting activities included recounting mythological stories related to stars or festivals (festivals being associated with astronomical observations), watching an animated film on the solar system, etc..

3.5.4 Testing effectiveness of the intervention

After completion of Part III of the intervention, the pre-tests were repeated as post-tests on the treatment group, which had by then progressed to Grade 8 (referred to as 'Gr8t'). The tests 'Observations', 'Textbook Facts' and 'Indigenous Knowledge' were identical in the pre and post forms. Tests 'Textbook Facts' and 'Indigenous Knowledge' were sometimes administered on the same day, especially in the treatment group, since each needed less time. The test on the sun-earth model included four new advanced questions. 'The Moon' test was administered at the beginning of Part III of the intervention (towards the end of the 1-year intervention), included one extra question.

The same tests were conducted on the comparison groups of Grade 8 (see Section 3.4) to check the improvement of students who had gone through the intervention against the students who had not gone through the intervention (but had studied the content as part of their normal curriculum). The students from the comparison group were not given the pre-tests while they were in the Grade 7 (which is why the term 'comparison group' is more appropriate rather than 'control group'). This procedure avoided any learning through exposure to tests and thus priming in the comparison group. Post-tests in both treatment and comparison group were followed by individual interviews to informally cross-check the responses in the tests. Some further prediction questions were posed to students who could answer the common questions satisfactorily. This analysis is presented in the Chapters 6 & 7.

3.5.5 Data collection and analysis

Throughout the study data was collected from the following three different sources:
Written and diagrammatic responses:
i. Assessment of Astronomical Knowledge: The assessment was done through written (and diagrammatic) responses on a series of tests described in Subsections 3.5.2 & 3.5.4. The tests were administered to students of Grades 4 and 7 before intervention and to Grade 8 after intervention (Section 3.5). The written questions called for both forced choice and free responses and diagrams of descriptive and explanatory types.

The written responses were coded and analyzed qualitatively and quantitatively. Quantitative analysis compared the responses of students from different grades levels, in the pre and the post-tests and in the treatment and comparison groups. Pairwise z tests were done between Grade 4 and Grade 7 (Gr4-Gr7), Grade 7 and Grade 8 for the treatment group (Gr7-Gr8t), and the treatment group and the comparison group (Gr8t-Gr8c) for each category of response. The statistical analysis was done as follows.

If N_1, N_2 are the total number of students in each groups, and X_1, X_2 are the number of occurrences of a given response in each of these groups, then $p_1(=\frac{X_1}{N_1})$ and $p_2(=\frac{X_2}{N_2})$ are the proportions of students who gave that particular response from each of those two groups. The null hypothesis in this case was that there is no true difference between p_1 and p_2, i.e., the two samples are drawn from the same population. In that case p_1 and p_2 can be considered to be independent determinations of a common population parameter $\bar{p}$.

$$\bar{p} = \frac{X_1 + X_2}{N_1 + N_2} \tag{3.1}$$

The standard error of the difference between these two percentages (assumed to be uncorrelated) is

$$S.E. = \sqrt{\bar{p}(1-\bar{p})\left(\frac{1}{N_1} + \frac{1}{N_2}\right)} \tag{3.2}$$

Assuming the sample sizes N_1 and N_2 are larger than 50 and the proportions p_1 and p_2 lie between 0.05 and 0.95, the critical ratio as below is distributed normally (Garrett and Woodworth, 1950; Woodbury, 2002).

$$z = \frac{(p1 - p2)}{\sqrt{\bar{p}(1-\bar{p})[\frac{1}{N_1} + \frac{1}{N_2}]}} \tag{3.3}$$

The probability of the calculated z was found from the table for the normal distribution. If the probability was less than 5% (corresponding to z=1.96), we inferred that the two groups represent two different populations and the difference was significant at the 0.05 level.

The calculation of standard error used the formula for uncorrelated proportions.

In the case of the pre and post-test for the intervention groups the samples were not uncorrelated. However the same formula (equation 3.2) was used in these tests because it provided a more stringent criterion for testing significance. Although facilitated with

The total scores of all students were calculated for each test. The distribution of scores for each Class (Gr4R, Gr4T, Gr4U, Gr7R, Gr7U, Gr7U, Gr8tR, Gr8tU, Gr8tU, Gr8cR, Gr8cU & Gr8cU,) and Grade (Gr4, Gr7, Gr8t & Gr8c) and and samples (R, T & U) was tested for normality using one sample Kolmogorov-Smirnov test (using SPSS). The scores of rural, tribal and urban samples were collapsed to compare difference between Grades for each test (Gr4-Gr7, Gr7-Gr8t, Gr8t-Gr8c). Scores of Grades 4, 7, 8t and 8c were collapsed to compare the difference between the samples for each test (R-T, T-U & U-R). Average scores of different samples for each Grade were also compared for each test (Gr4R-Gr7R, ..., Gr7T-Gr8tT, ..., Gr8tU-Gr8cU). For correlated samples (Gr7-Gr8t) paired t-test (if data is distributed normally) or Wilcoxon test (if data is not distributed normally) were used. Whenever the samples were independent (Gr4-Gr7, Gr8t-Gr8c, rural-tribal, tribal-urban, urban-rural), unpaired t-test (if data is distributed normally) or Mann-Whitney test (if data is not distributed normally) was used.

All the coding and z tests were done using the NeoOffice software and SPSS (version 16) was used for the comparison of mean. The analysis of data from pre and post-tests is presented in Chapters 6 & 7.

ii. Guided Collaborative Problem Solving: These were responses to a series of 12 questionnaires given only to the treatment group (to solve in groups of three students). Students' questionnaires were analyzed to find the number of groups which produced particular responses. This data was used to gain insights of students' problem solving process and the kinds of difficulties they face, rather than assessing quantitative evaluation of students' understanding. Students' responses were categorized and are presented in the Subsection 4.3.3.

iii. In addition we analyzed individual responses on homework, spatial tasks and notes from astronomical observations. This data was used for formative assessment (but was not used for the final data analysis). The forthcoming classes were planned based on this data.

Video data

Classroom videos were observed to improve the teaching, to carefully watch students' involvement and responses, and to document the pedagogy. The use and functions of different media (concrete models, gestures, diagrams) and students responses to them were also carefully studied through classroom videos. The description of pedagogic sequence and the classroom observations based on this data are given in Chapter 4. The description and analysis of spatial tools is given in Chapter 5.

Students' spontaneous gestures were studied using the video-data of one group from each of two schools during Guided Collaborative Problem Solving of 11 questionnaires spread over 5 sessions during the intervention. Their questionnaires and teacher's notes were used as supplementary material. The analysis of students' spontaneous gestures is presented in Section 5.2.

Individual interviews were videotaped and summarized.

Notes and logs

An observer (sometimes another researcher and sometimes an academic helper) kept notes on one of the groups during Guided Collaborative Problem Solving. The teacher used to note any remarkable observations from the field and send it to her collaborator (thesis advisor) and used to get comments on it. Students' responses during Guided Collaborative Problem Solving, the observer's notes and the teacher's notes were analyzed together to identify the concepts or procedures which were difficult for students, and to comprehend the path of their progress (Subsection 4.3.3).

Chapter 4

Pedagogy

We begin this Chapter with a listing of the highlights of results from the pre-tests that were administered to the treatment group at the end of Grade 7 (Section 4.1). These findings gave us a starting point for the design of the pedagogic sequence which is described in the remaining part of the chapter. The pedagogic sequence is presented in three parts (Sections 4.2, 4.3, 4.4), that were implemented during three contact periods of 15 days each spread over one year. Subsection 4.3.3 describes the sessions of guided collaborative problem solving which formed a core feature of the pedagogy. Data on students' spontaneous gestures (Subsection 5.2.2) was recorded during these sessions. At the end of the Chapter (Section 4.5) we describe the homework tasks given to students during the intervention and between the two consecutive parts of the intervention.

4.1 Highlights of the pre-tests

From analysis of students' responses we found that:

1. Although most students could state a few observational facts, detailed and careful observations were rare. This was an unexpected finding, especially since we had hoped to find good observations in the rural and tribal samples (Subsection 3.4.4). Some outdoor activities and related exercises to address problem are described in Subsections 4.2.1 and 4.2.7.

2. Students were quite familiar with a large number of terms used in their textbooks, yet a few very useful concepts, such as horizon and axis of rotation, were unfamiliar, not surprisingly, since they were not introduced in the textbook. The classroom instructions developed to introduce these concepts are given in Subsections 4.2.2, 4.2.4 and 4.2.5.

3. Students could use the calendar to determine social and religious practices (fasts, prayers etc.). They knew the terms and facts from indigenous knowledge, though not their astronomical significance. Indigenous knowledge was tied up with astrology. This part was addressed in Part II ('Changes in the night sky' & 'Seasons' in Subsection 4.3.2) and Part III (Section 4.4) of the intervention.

4. Students had erroneous models of the earth such as flat earth (2%), hollow earth (15%) and spherical earth without direction of gravity integrated with it (60%). For classification scheme see Samarapungavan et al. (1996). Students did not have a good idea of shapes and relative sizes of astronomical objects. Explanations of facts were inadequate. The diagrams which they drew for explanation were identical to those in textbooks. This determined the starting point of our intervention as described in Subsections 4.2.2, 4.2.3 and 4.2.6.

Qualitative details of these findings along with some salient percentages of students' correct and faulty responses are documented in Padalkar and Ramadas (2008a) and the detailed analysis is presented in Chapters 6 and 7. While the detailed analysis of pre-test data proceeded in parallel with the intervention, the broad findings (as listed above) were available to us at the start of the intervention. Based on these findings and cognitive considerations (described in Section 1.3 and Chapter 2) we developed a pedagogy that we believe is appropriate for the low-resource situation present in most Indian schools. Apart from the pre and post tests which took place in the beginning and at the end of the total intervention, micro-data was gathered during the teaching sessions, which helped fine-tune the course of the teaching. Thus this Chapter describes not only the final sequence of the intervention but also the small data points which determined the trajectory of the teaching sequence. There were slight variations in the sequence in the three schools, but the sequence is described here in the order which we consider is most appropriate.

4.2 Pedagogic sequence Part I: The round rotating earth

The first four days of the first part of the intervention were taken up in administrating the pre-tests. The pedagogic sessions started on the fourth night with a star-gazing session. The sequence of activities that followed, along with the concrete models, observations, gestures, actions and diagrams used in this part of the intervention, is summarized in Table 4.1. Video clips showing all the designed pedagogic gestures are at http://web.gnowledge.org/pedagogic-gestures/. Abbreviations introduced in the Table are used in the detailed description that follows.

Table 4.1: Pedagogic sequence for Part I: The round rotating earth

Context or Concept	**CM: Concrete Model/ *Teaching aid*** **G: Gestures and actions** **D: Diagram/ *Visual representation on paper*** XX: Categary absent
Night sky observation	*Telescope* **G1**. Tracing star patterns by fingers/ hands. **D1**. *Star Charts*
Determining position (direction + degrees above horizon) of a star	**CM1**. Angle dangle meter (Figure 4.1) **G2**. Directions in local environment by extended arm, Angles estimate by fist/ palm and arm **D2**. 4 major + 4 minor directions in conventional way and in local environment (Figures 4.11a, 4.11b)
Showing round earth by hand	**CM2**. Globe (Figure 5.1a) **G3**. Moving hands with palms open to show sphere. **D3**.*Photographs of the earth*

Showing round part of spherical earth on circular earth on the blackboard	Globe (CM2) **G4**. Moving arm with open curved palm to show half sphere of the earth coming out of the blackboard, imagining circle as circumference of the earth and other half sphere inside the black board. **D4**. Circular Earth (Figure 4.3)
Understanding flatness of the earth	**CM3**. Balls of different sizes **G5**. Holding or imagine to be holding a very small to a very large ball and observe the change in curvature of palm and then arm. **D5**. Circles with increasing radii (Figure 4.7)
Horizon	XX XX **D6**. Tangents from person's eye to the curve on which he is standing: gradually reducing height (Figure 4.8a)
Horizon for a person on the globe	**CM4**. Globe + disk XX **D7**. Tangent to the earth at the point where the person is standing (Figure 6.8)
Axis of rotation	**CM5**. Notebook, pencil box, other objects **G6**. Rotating objects and body parts and identifying axis of rotation. **D8**. Objects+Axis **D9a**. Earth+Axis (Figure 4.5a)
Axis coming out of, or going inside the plane of diagram	Globe (CM2) **G7**. Index finger pointing inside or outside, perpendicular to the diagram. **D9b**. Earth + Axis (coming out of, or going inside the plane of diagram) (Figure 4.5b)
Gestures in Play "Galileo" to mimic the earth's rotation and perspective changes	**CM6**. Rotating chair **G8**. Sitting on a rotating chair to see occurrence of day-night. XX

Gestures in Play "Galileo" to mimic the earth's rotation, perspective changes and up-down	**CM7**. Apple (or any other round fruit) + tooth pick **G9**. Assuming apple to be the earth, and radially attached tooth-pick as a human. Rotating the apple around the axis passing through its stem to see day-night. **D9c**. Earth + horizontal axis either in the plane of diagram (c) + curved arrow for direction of rotation + human figures + parallel sun rays (Figure 4.5c)
Showing motion of the earth for the axis in the given diagram	XX **G10**. a) Showing a vertical index finger in horizontal circle in front of blackboard (or in half circle, with axis as center) b)Moving a horizontal index finger in a vertical circle around a point on the blackboard. **D9a**, **9b**. Earth + Axis either in the plane of diagram (vertical-a, horizontal-c, tilted-d, other orientation-e) or perpendicular to it (b) (Figures 4.5b, 4.5a)
Positioning human being on the earth	**CM8**. Globe + small human figure XX **D10a, 10b**. Earth (D9) + Axis either in the plane of diagram (a) or perpendicular to it (b) + Human figures (Figure 4.6)
Determining directions (Down, Up, North, South) of a person on the globe or in diagram of the earth	**CM9**. Model of three orthogonal axes (+ Globe + small human figure + disk) **G11**. Down: pointing index finger towards center of the earth Up: pointing index finger away from center of the earth North: Towards North Pole South: Towards South Pole **D11a**. Earth + Axis either in the plane of diagram (D10a) + Human figures + arrows for U,D,N,S directions (Figure 4.12a)

Determining directions (East, West) of a person on the globe or in diagram of the earth	Globe + small human figure **G12**. East: Orienting orienting one's self parallel to the North-facing person in the diagram so that the right hand indicates East in the diagram, OR find the direction of motion of the earth (West to East) with right hand thumb rule. East is indicated by the direction of curl of the fingers (G13). West: Opposite to East **D11b**. Earth + Axis perpendicular to it (D10b) + Human figures + arrows for U,D,N,S directions (Figure 4.12b)
Right hand thumb rule for determining direction of motion of the earth	Globe (CM2) **G13**. Gesture of thumbs-up. In (Figures 4.5a, 4.5b) align thumb of the right hand in the direction of axis and pointing towards the North Pole, then curl the fingers to show the direction of earth's rotation (or revolution)(West to East). Earth + Axis either in the plane of diagram (D9a) or perpendicular to it (D9b) + curved arrow for direction of rotation (Figures 4.5a, 4.5b)
Shadows and beams	**CM10**. Cardboard cutouts, sunlight, torch (Figure 4.2) **G14**. Shadow created by fingers/ parts of the body/ whole body, Keep palm perpendicular and parallel to source XX
Tracing ray diagrams	XX **G15**. Tracing path of light-beam/ ray by open palm (representing wave front) / finger on board. **D12**. Ray diagrams for point and parallel light source (Figure 4.15)
Day night	**CM11**. Geosynchron (Figure 5.1b) **G16**. One student becomes the earth, another student (or object) becomes the sun. Mark the objects around in egocentric frame (front/ back/ left/ right). Observe how the field of vision and positions of objects changes due to rotation from right to left. **D13**. Parallel sun-rays and day-night on the earth (Axis either in the plane of diagram (D10a) or perpendicular to it (D10b) + curved arrow for direction of rotation) (Figure 4.13)

Path of the sun	**CM12**. Gnomon XX **D14**. Draw shadow of the stick at different locations on the earth (Figure 4.16a)
Path of the sun	**CM13**. Large inverted Bowl **G16**. Move the stretched hand in vertical or inclined half circle from East to West. Inclination towards North or South depending upon whether one imagines herself in the Southern or Northern hemisphere. **D15**. Path of sun on equator, Northern hemisphere, Southern hemisphere (Figure 4.16b)
Position of the Pole Star remains the same	Globe (CM2) **G18**. Fix a point vertically overhead on the ceiling and check whether its position changes while rotating around the vertical body-axis. **D16**. Earth + Axis in the plane of diagram + human being in Northern hemisphere (D10a) + parallel rays from the Pole Star (Figure 4.17)
Geometry for sphere	*Sphere* XX **D17**. Radius, diameter circumference
Radius of the earth	XX XX **D18**. Eratosthenes's Method (Figure 4.18)

4.2.1 Star gazing

For most of the students this was the first time that they looked at the night sky carefully. Initially most of the students were not able to identify any of the stars except by a random guesses The Pole Star was shown to students and the 'North' direction was identified in the beginning. The other cardinal directions (South: opposite to North, East: on Right hand side if facing North, and West: Opposite to East) were identified and they were identified with local landmarks. Further discussion on directions was continued in the classroom (Subsection 4.2.5).

Then students were introduced to different stars constellations and planets which were visible that night. The Marathi names of stars and constellations (*Nakshatras*) were used, as students were familiar with some of them; the names of Marathi months (which students knew) are derived from the names of *Nakshatras*. Students were asked to mimic the shape either by making a specific gesture (eg. 'V' for the *Nakshatra: Rohini* in Taurus) or by tracing the pattern (G1). From the orientation and shape of their hands, we could identify whether they had assigned the name to the correct star pattern or not and, going beyond mere perception of distant star patterns, we believe that the gestures helped students to internalize those patterns (Subsections 3.3.4, 5.2.1).

Next, since students were unfamiliar with use of the world 'horizon' in a practical sense, they were shown the horizon - the concept was discussed in detail later in the classroom (Subsection 4.2.4). Then students were shown how to determine the angle of any star above horizon. Small angles ($10^0, 15^0, 25^0$) can be approximated by using a fist/ palm held at arms length and the larger ones ($30^0, 45^0, 60^0$) can be approximated by division of the 90^0 angle between a horizontal and vertically stretched arm (G2; Figure 5.7 shows estimation of the smaller angles).

The students were asked to check the position of the stars at different times of the night in order to observe that the position of the stars changes overnight, and all the stars appear to move from East to West, repeating the observations at least once in a week to track the changes in the night sky over the year. We wanted to later link this observation to the rotating model of the earth. Students were divided into groups and each group was given the responsibility of keeping record of one star and one constellation. Their group was named after the star/ constellation that they were to follow. Mostly the same groups continued to work together in different classroom activities. One star-chart (D1) was provided to each group to help them remember the stars and to learn how to use star charts in the following months.

In this session students were also shown the moon and the Saturn through a 4-inch telescope. In one of the classroom sessions students were provided a paper straw, a thread and a piece of card-board paper and shawn how to prepare an Angle dangle meter (referred as a simple Astrolabe in http://cse.ssl.berkeley.edu/AtHomeAstronomy/activity_07.html) (CM1; Figure 4.1). They were shown how to measure the angle of elevation of a star or any other object using it, and they were asked to keep further records of position of the stars using it.

Figure 4.1: Rural girls handling 'angle dangle meters' (CM1)

Figure 4.2: Rural students studying light and shadows (CM10)

A similar star-gazing session was conducted at the end of the first part of the intervention so as to revise the stars that they had learnt. Such star-gazing sessions were conducted twice (one in the beginning and one at the end) of all three parts of the intervention. The star-charts (D1) for the next four months were provided in each part. The stars seen in the first and second part of the intervention were different, but in the third part of the intervention, students could again see and identify the stars seen in the first part of the intervention, thus verifying the changes in positions of the stars over a year. Four easily identifiable planets (Venus, Mars, Saturn, Jupiter) were observed over the year.

4.2.2 Representation of the earth

Our starting point was to help students to construct a mental model of the round rotating earth. Students were first shown a satellite picture of the earth taken from space (D3). The Grade 5 geography textbook contains such photographs, so students were able to identify that the photograph was that of the earth. When asked the difference between the real earth and the photograph, students came up with difference in size; there are real oceans, and humans etc. on the real earth whereas the photograph has only pictures of the oceans and no realistic details. The difference that the photograph is a two dimensional representation, whereas the real earth is three dimensional, did not came up spontaneously. So the general question, "what is the difference between any object and its photograph" was asked. After a while students came up with the answer that objects have depth, or interiors, which their photographs do not. At this point we made it explicit that the earth too is a three dimensional spherical object and they should remember this when they see or draw its two dimensional photo or diagram.

After this students were given ample opportunity to handle the globe to emphasize the three dimensional nature of the earth (CM2; Figure 5.1a). They were also asked to trace the spherical shape of the earth with a gesture as if they were moving palms on a spherical surface (G3). This was not an easy step, because students first moved their hand in a circular fashion as if they were drawing a diagram of the earth. Subsequently, to link the three dimensional spherical nature of the earth to its two dimensional diagram (D4; Figure 4.3), students were asked to show the bulge of the hemisphere outside the circle on the blackboard (G4).

The concept of the axis of rotation was introduced in our intervention through gestures, by rotating different objects, body parts and the whole body around different possible axes (G6) and then students were asked to depict such motions in drawing (D8; Figure 4.4). The point to be conveyed through this exercise was that it is not the object itself but the motion of the object that defines the axis. Taking the analogy of the globe, the axis of rotation of the earth was shown in its diagram (D9a; Figure 4.5a).

To emphasize the spherical nature of the earth, we encouraged students to draw

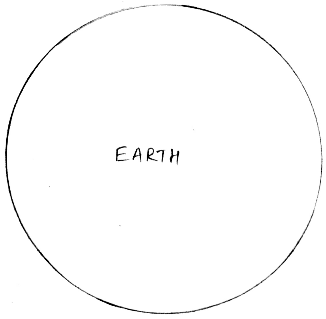
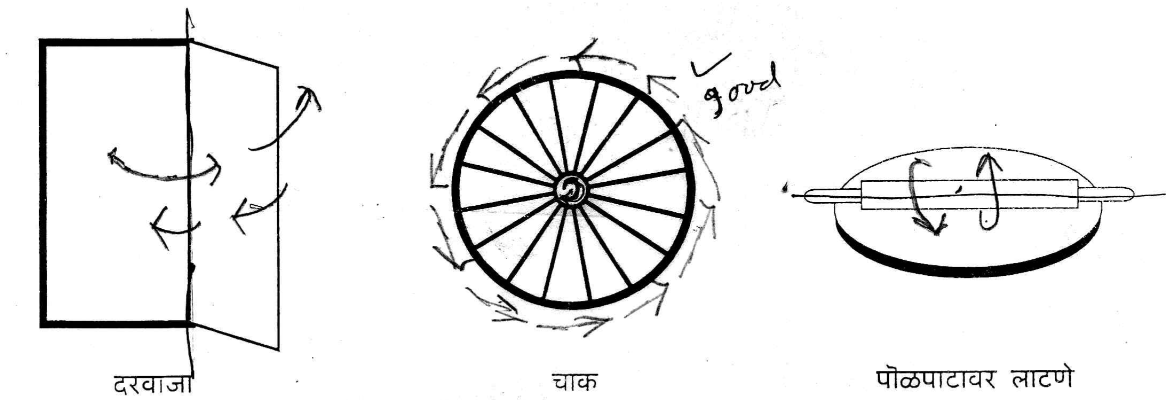


Figure 4.3: G4: Students were also asked to show the bulge of the hemisphere outside the circle on the blackboard (D4)

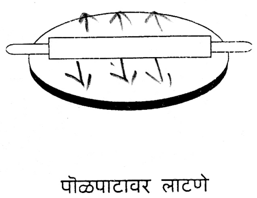
it from different perspectives, initially by looking at the globe from different perspectives. Since a sphere is a perfectly symmetrical shape in three dimensions, the projections are all circles - but the axis, poles and equator could be used to characterize the different views, along with a curved arrow around the axis to show the direction of rotation (D9a, b, c; Figures 4.5a, 4.5b, 4.5c). Students were already familiar with the terms pole, equator and axis (Finding 2 in Section 4.1), but these were clarified, and related activities were conducted, at this point and also during further intervention.

Students were asked to either draw the axis of the rotation of the earth in the plane of the blackboard (Figure 4.5a) or perpendicular to the board (Figure 4.5b). In the second case they were asked to indicate the direction of the line of axis as perpendicular to the board (G7). They were also asked to mimic the motion of the earth for the corresponding axis (G10). The right hand thumb rule (G13) was introduced to determine the direction of the motion of the earth. If the thumb is aligned to the axis with its tip representing the North Pole, the direction of the other four curved fingers gives the direction of rotation of the earth (Figure 4.5b). Incidentally this sole example of an 'iconic gesture' (Subsection 5.2.1) was later spontaneously used by students in collaborative problem solving Subsection 5.2.2.

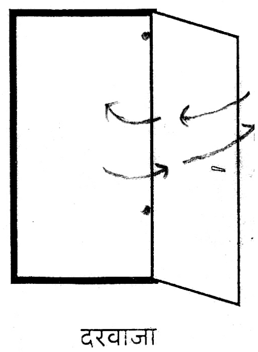
The reason for introducing a variety of diagrams is that in different situation we use different views. To depict phases of the moon we use a top view, while to explain seasons we use a side view with axis tilted. Such variations are usually



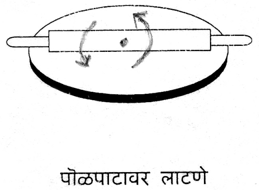
(a) Correct depiction of standard motions and axes of objects by a rural boy



(b) A rural boy could depict only the translational motion



(c) A rural boy could depict the motion correctly, but not the axis

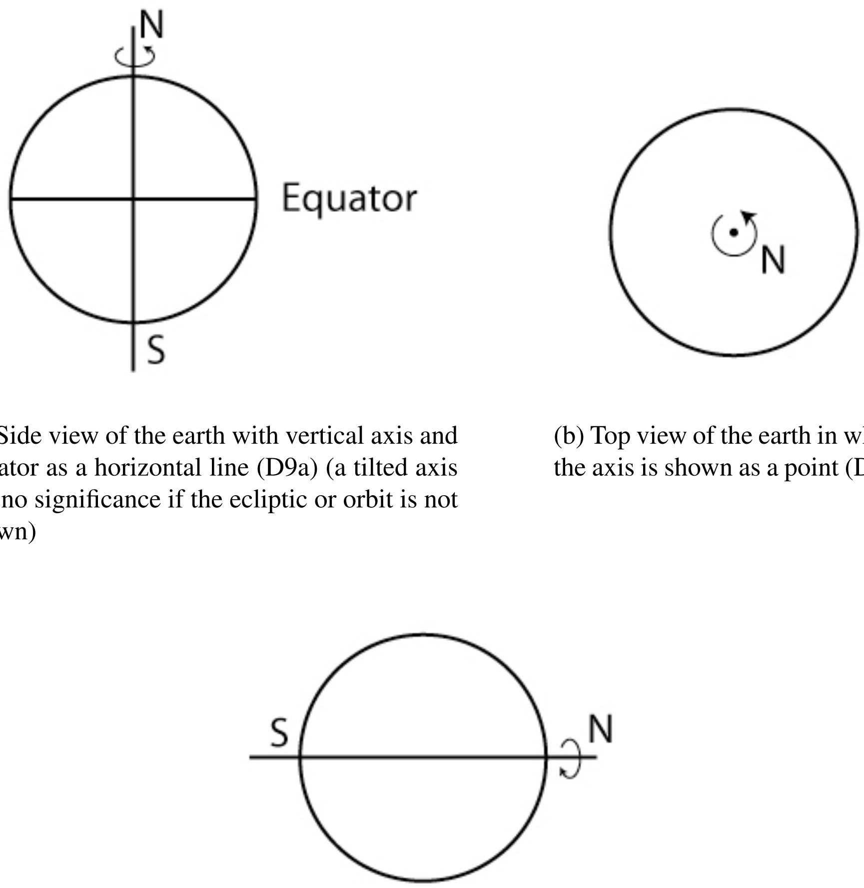


(d) A rural boy has shown the incorrect motion and axis of rotation

Figure 4.4: Students' difficulty in depicting motion and axis

done casually without explicit instructions. From the very beginning therefore we introduced different views and showed the relation between them, so that students could call upon and use the appropriate views where necessary.

Two interactive reading materials were given in groups of three students. Half the groups were given material on the development of a model of the round earth and half the groups were given material on historical development of the heliocentric model (the latter could be given in Part II of the intervention) (the materials are given in Appendix E). They included evidences of spherical shape of the earth and exercises such as drawing a human being in the given diagram of the earth. The material included skeletal diagrams which students were required to complete to draw



(a) Side view of the earth with vertical axis and equator as a horizontal line (D9a) (a tilted axis has no significance if the ecliptic or orbit is not shown)

(b) Top view of the earth in which the axis is shown as a point (D9b)

(c) Side view of the earth with horizontal axis (D9c)

Figure 4.5: Earth from different perspectives

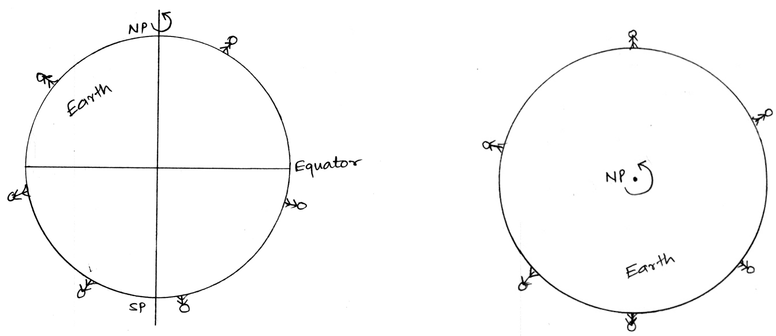
inferences. Students encountered similar but more advanced tasks in the guided collaborative problem solving sessions in Part II of the intervention. In comparison, the diagrams to be completed here were easier and were embedded in a story rather than in problem situations. Finally students were asked to explain the part of historical development included in their reading material to the entire class, and these developments were plotted on the timeline on a board, and the events were related to the Indian context at that time.

4.2.3 Placing human beings on the earth

Students began by pasting toy human figures on various parts of the globe and then in a diagram drew stick figures on different points on the circumference (CM8, D10a, b). This was followed by a discussion on why we in India do not fall off the earth. Thus roundness, which is a spatial property of the earth was reconciled with gravity which is a physical property. Corresponding diagrams were drawn (D10a, b; Figure 4.6) and the discussion led to determining up-down directions for a person on the globe (Subsection 4.2.5).

4.2.4 Horizon and related consequences

"Horizon" is a very useful concept in observational astronomy and in 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 of the 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 their altitude with respect to the line of the horizon (Subsection 4.2.1). The other position co-ordinate in this rough and intuitive procedure was provided by one of the eight directions.



(a) D10a (b) D10b

Figure 4.6: Placing human being on the earth

If the earth is round, why does it appear flat to us?

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 so as to hold it.[1] Then the size of ball was increased to a cricket ball to a football to the room-size big ball (seen in a circus) and ultimately we reached the largest ball they knew. Through these gestures the hand and arms became less and less curved and ultimately flat. The largest sphere one can hold is the earth for which one needs to fall down on the earth with stretched arms. These gestures helped students internalize how curvature decreases as the size (radius) of the sphere increases (G5).[2] In their interactive reading material (Appendix E) students were asked to draw concentric circles of increasing radii (D5; Figure 4.7) and they were asked: What happens to the curvature as the radius goes on increasing? What will a circle of infinite radius look like?

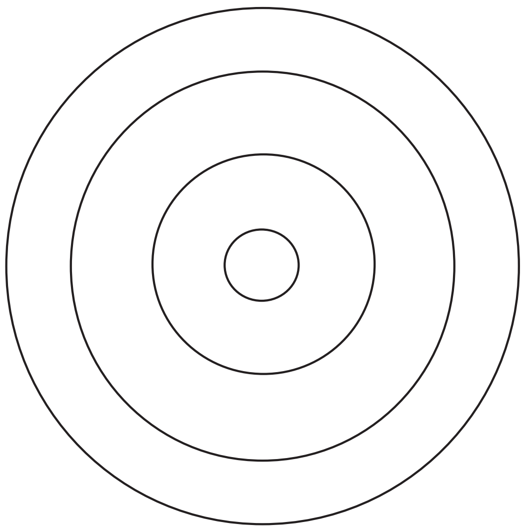


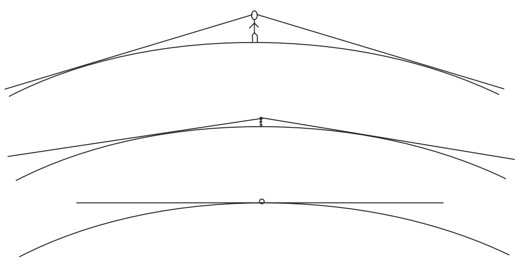
Figure 4.7: Curvature decreases as the radius increases (D5)

[1]Since the spherical shape of the earth is taught in the early Grades, concrete balls could be used for younger students (CM3). The relation between radius and curvature can be mentioned using qualitative terms (bigger spheres are more flat).

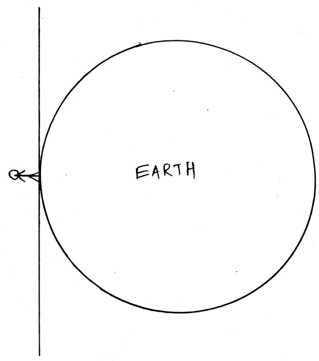
[2]Although G5 was used in this precise form in the intervention Part II, it is given here as it is more appropriate at this point, and connects well with the drawing activity that follows.

What is 'horizon'

In the classroom session, students were first asked to draw how much of the curved surface of the earth a person might see when (s)he is standing on that surface. Students intuitively drew tangents from the person's eye level to his/her sides. 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 4.8a).



(a) Developing concept of "horizon" (D6)



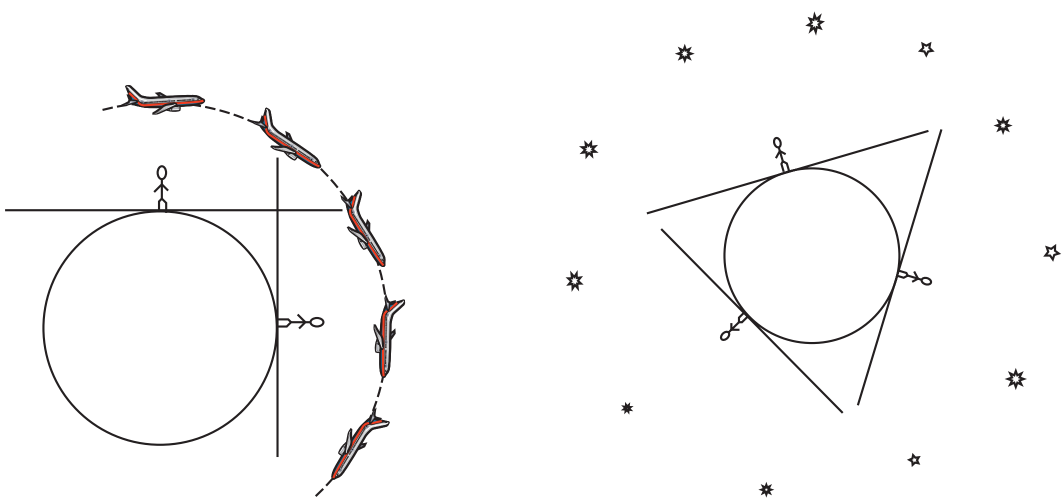
(b) Tangent represents horizon of a person on the globe (D7)

Figure 4.8: Local horizon provides frame of reference in observations

A person was placed on the globe, then a small disk was placed under her feet which represented her horizon (CM4). The cross-sectional view of this model evolved in the diagram which was used frequently in the entire intervention (D7; Figure 4.8b).

Observational consequences of the horizon

Then students were 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 4.9a). Visibility and apparent position of distant ships and airplanes were discussed. The interactive reading material about the history of the discovery of the shape of the earth contained a diagram (Figure 4.9b) with persons on the globe and projections of distant stars, and students were asked which of the stars each of them could see by drawing a line of horizon for the respective persons. This was presented as one of the evidences in the interactive reading material (Appendix E) on how model of the round earth developed historically.



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

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

Figure 4.9: Horizon at different locations

This discussion led the students to conjecture that the altitude 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 altitude) would not be overhead at all places on the earth. Felicitously, the day of this lesson was around 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 on the same longitude (where it was noon), but on a different latitude. From this students could derive that even at noon the sun was overhead only on the equator. From all other places on that longitude it appeared to be towards North or South (Figure 4.10). The prediction of position of the sun at the local noon (co-ordinates of Kolhapur: 16.6N, 74.2E, of Mumbai: 19.0N, 72.9E) was verified by observation of a shadow of a vertical stick[3].

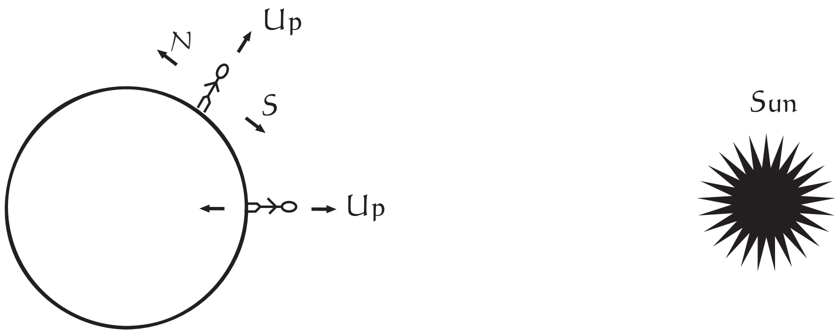


Figure 4.10: Is the sun overhead at noon?

Variation in the sun's position over the year was not discussed at this point since 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 (in the Northern hemisphere on the day of equinox) was verified by observation of shadows of the gnomon and other Northward shadows when the sun was at its highest altitude, which indicated that the sun was not at the zenith but a little towards South. The path of the sun over the day was traced from East to West by moving an extended arm (G15). This was an instance of an exercise combining observation and gestures linking up with the mental model and diagram (see Subsection 5.2.1).

4.2.5 Directions

Identifying directions for a given person on the earth (on a globe and on a diagram) was one of the most difficult tasks for students. The difficulty was probably related to the common notion of absolute directions. A round earth but with absolute vertical up-down is one of the well documented erroneous notions of students (Nussbaum and Novak, 1976; Baxter, 1989). We found that students in our sample confused directions in a map with directions for a person on the globe. Students

[3] A strict caution against looking towards the sun was given from time to time. The possible harm to eyes was discussed and students were told to be very careful while using standard filters such as aluminum foil.

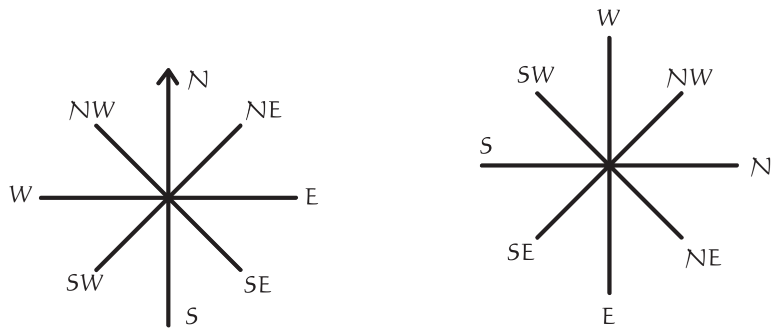
assumed that the 'Left side' must be 'West', the 'Right side' must be 'East', and that 'Up' and 'North' are synonyms!

The difficulty is compounded by prevalent pedagogical practices. In India, surprisingly and unfortunately, no less than 4 major (North, South, East, West) and 4 minor directions (NE, SE, SW & NW, each of which has a distinct name in Marathi) are taught in very early textbooks (Grade 4 geography) (see Section 1.4). But it is assumed that 'Up' and 'Down are intuitive and need not be taught. Importantly, students do not learn 3D Cartesian geometry in school (only X and Y axes are learnt in Grade 5 (geography) & Grade 8 (mathematics)). So students had heard about 4 directions and 8 directions but never about 6 major directions. So they usually recall the existence of four directions and, sometimes 'eight' but never 'six'.

Even if one knows that there are 6 directions to be identified, one has to mentally change the orientation of the imaginary axes to match them with the person whose directions are to be determined. This change of orientation has been identified as a difficult task by cognitive scientists (Section 2.6). So not surprisingly students often makes mistakes in determining the directions of a person on the globe or on a diagram. In a diagram there is an additional problem of showing all 6 directions on the paper. These problems were addressed in our pedagogy in the following way.

First all eight directions were drawn in the conventional way on the blackboard (Figure 4.11a). Then a discussion of local directions, which had been initiated in the previous outdoor stargazing session (Subsection 4.2.1), was continued indoors - Where is North? Which is the North end of the classroom? If you walk further North which places will you pass ... in the District, State and so on till you get to the North Pole? Which places are towards a particular direction from some other place? Gestures and body movements were used to determine all eight directions (which have distinct names in Marathi) (G2). The local directions were redrawn on a horizontal paper matching with the directions in classroom and then the paper was held vertical and a similar diagram was drawn on the blackboard (D2; Figure 4.11b).

Students knew how a point on a paper can be identified by using two (X, Y) axes. We introduced a third (Z) axis, and showed that solid things such as the earth,



(a) Conventional depiction of directions

(b) Directions found in one of the classrooms

Figure 4.11: Four major and four minor directions (D2)

whose exact shape cannot be depicted on a paper, are three dimensional. A concrete model of three orthogonal axes made up of three sticks was used to show the six major directions and also to give a feel for three dimensions (CM9). Space around us can be marked using two sides of each of these three axes as Up, Down, North, South, East and West. Co-ordinates of local objects were decided using an available co-ordinate system such as a corner of a classroom formed by two perpendicular walls and the floor.

Then students were asked to determine up-down for a person in space. Through this question it became clear that up-down are defined with reference to the earth, and also (thus) the earth does not have an inherent up-down direction. In this way we challenged the common misconception (that the earth has an inherent up-down), that is probably created by conventional drawings of the earth showing the North Pole towards the top of the paper - also matching the convention of maps in geography. We encouraged students to draw the earth in different orientations, in order to demonstrate that drawing the axis horizontal or the North Pole down is quite valid (Figure 4.5).

Directions of a person on the globe (in three dimensions) were identified in following 3 steps:

a. A toy person was placed on the globe, then a small disk was placed under her feet which represents her horizon and then a small model of three orthogonal axes (CM9), with no negative z axis was placed near her. Then we asked students to identify ‘Up’ and ‘Down’ (G11).

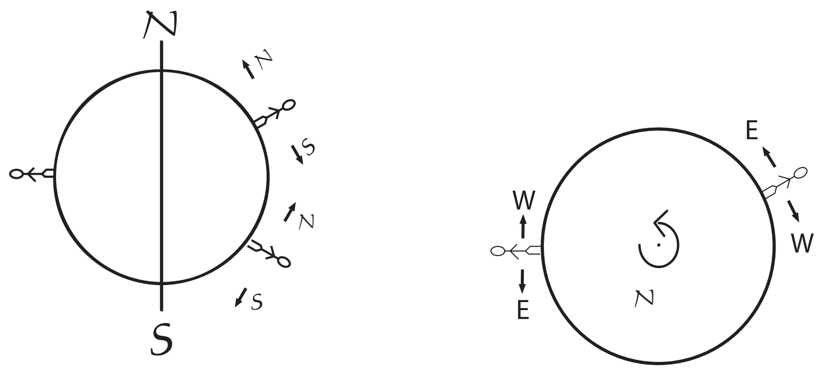
b. Then we told them that direction towards North Pole is always ‘North’ and that towards ‘South Pole’ is always ‘South’ (G11).

c. We always kept the toy person facing North. From local directions students knew that if a person is facing North, the right hand indicates East. Now students had to change their orientation to see which was the right hand for the person. This change in orientation is a demanding cognitive task and is greatly facilitated if accompanied with kinesthetic feedback. So we encouraged students to partially orient themselves like the person and decide which is the right hand, and hence East (G12).

To identify directions of a person in the diagram of the earth we asked students to carry out each of the above steps on the globe and then to draw it on diagram of a circular earth. We used 2 diagrams of the earth from 2 different perspectives.

a. as if looking in the plane of the orbit, where the axis is in the plane of paper, so that students could show North-South (D11a; Figure 4.12a).

b. as if looking from above the North Pole, so that the axis is perpendicular to the plane of the paper and one sees a point of North Pole (or axis) in the centre of the circle and the person can be situated on the equator. This enables students to show East and West (D11b; Figure 4.12b). Using these two diagrams simultaneously helps keep in mind the 3D nature of the earth.



(a) North and South directions for a person on the earth (D11a)

(b) East and West directions for a person on the earth (D11b)

Figure 4.12: Identifying major directions for a person on the earth

We introduced another way to identify the directions. The direction of rotation of the earth can be determined by the right hand thumb rule (G13) and we know that the earth rotates from West to East, so using this rule (G13) it is easy to determine 'East-West' directions for any person on the globe.

Even after following above steps, determining directions remained a challenge for some students. Representing the 3-D world in a 2-D diagram and constructing a 3-D reality from 2-D diagram is indeed one of the key pedagogic problems in elementary astronomy.

4.2.6 Rotation of the earth

In the sky-gazing session (Section 4.2.1) the students had observed the Pole Star and they had been measuring its altitude every day along with that of other stars. The concept of axis of rotation had then been introduced in representation of the earth (Subsection 4.2.2). We now told the students that the axis of the earth is aligned with the Pole Star and North is defined as the direction towards the Pole Star.

Then, in the school ground, the globe was hung on a stand in such a way that the axis of its rotation pointed towards 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 *Navnirmiti*, an Indian NGO concerned with popularization of astronomy (Monteiro, 2006) (CM11:Figure 5.1b). Critical 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 part of these teaching sequence were used in co-ordination with parallel situations on the globe or the geosynchron.

While rotating around themselves students experienced how the view changes as they rotate. Appearance and disappearance of landmarks like the door and the blackboard was 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 show day and night in particular (G16). The same gesture also serves to explain why the Pole Star does not appear to move. If the student keeps looking at the point overhead while rotating around herself she understands that the point on the axis does not appear to move

(G18).

Through observations of shadows and ray-diagrams for drawing shadows, described in Section 4.2.7, students knew that the sun-rays falling on the earth are to be considered parallel. Using this fact a diagram for day-night with parallel sun-rays was drawn with the help of students (D13a, b; 4.13). Students were encouraged to draw long sun-rays so as to determine the exact terminator especially since confusing the terminator with the axis of rotation was a common mistake. The rationale of drawing long sun-rays is explained in Subsection 5.3.2.

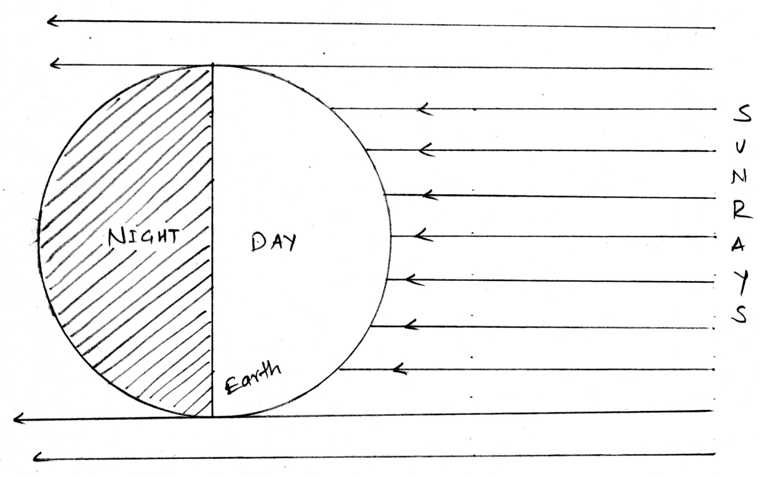


Figure 4.13: Explanation of occurrence of day and night (D13)

A part of the Marathi translation of Bertolt Brecht's play 'The Life of Galileo' (Brecht, 1947) in which Galileo explains his new theory about the motion of the earth, directions of a person on it, and the occurrence of day and night, to his young student Andrea, was enacted (Appendix E). Students were given a one-page information sheet about Galileo and extracts from the play to read in the beginning. In the urban group we asked students to do the enactment, including the gestures and actions described by Brecht. We found however that students had difficulty in doing the actions. Therefore the author and a friend, both experienced actors, carried out the enactment for the rural and tribal groups. In the enactment, Galileo first rotated a chair (CM6) in which Andrea was sitting and showed how positions of objects changed without the objects being actually moved, to explain why the sun appears to move (G9). Andrea continues to ask questions and Galileo explains the rotation of the earth using an apple as the earth and a small splinter stuck in it as a person on the earth (CM7, G9). Students were asked to follow Galileo's gestures using small globes or balls (G9) and draw the corresponding diagram (D9c; 4.5c).[4]

4.2.7 Parallel ray approximation and related consequences

As an object goes further away 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 4.14), approaching the limiting case, the two lines defining this angle became parallel. The sun-rays reaching the surface of earth are similarly approximated to be parallel, as the diameter of the earth is very small in comparison with the distance between the sun and the earth. This was again addressed during first two sessions of the guided collaborative problem solving in Part II of the intervention (Subsection 4.3.3).

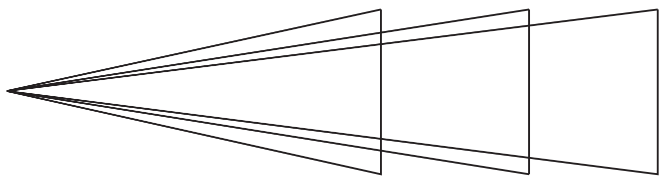


Figure 4.14: Distant object subtends a smaller angle

Another sequence of diagrams, linked with outdoor activities, was used to derive the shadows due to light from parallel-ray, point and extended sources (D12; Figure 4.15). The experiences of our own shadow at different times and points were recollected and if necessary demonstrated on the spot. This activity was followed by a sequence of activities to study shadows and light beams made by different concrete shapes, palm etc. (CM10; Figure 4.2). Students measured the size of the shadow of the palm while varying the distance between palm and ground (G14) and found out that the size remains the same, which demonstrate that the sun's rays are

[4]We came across this play after Part II of the intervention, so this enactment was used to help recall the earlier concepts in the intervention Part III. It is described here, because it is more appropriate here. Students' difficulty in carrying out the enactment even at this stage is remarked on in the concluding Chapter (8).

parallel. Thus a picture of the sun could be substituted by rays parallel to the ecliptic (on March 21). The considerable difficulties that persisted with this concept are described next and also in Subsection 4.3.3 (Session 1). Granting this assumption students drew the shadow of a vertical stick at different latitudes on the surface of the earth (D14; 4.16a); 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 observation of shadows cast in a gnomon (CM12).

The apparent paths of the sun as observed from different latitudes (North and South of the equator) were drawn on a large inverted bowl (CM13), then traced by a stretched arm (G16), and finally drawn on the blackboard (D15).

A similar exercise was carried out to show that the altitude of any star (in particular the Pole Star) changes due to change in inclination of the horizon, assuming of course its rays to be parallel as seen from any point on the earth (D16; 4.17). D16 was also connected to G18 (explained in Subsection 4.2.6).

The parallel ray approximation was one of the more difficult concepts for students to accept. Most of them agreed that sun-rays must be parallel, after we actually checked that in sunlight by measuring the area of the shadow while varying the distance of the object from the ground. Students found out that the size of shadow does not change, which is possible only if the rays from the sun are parallel. But it was very hard for them to accept that rays from stars were parallel, probably because the appearance of a star is like a point source. From this diagram onwards, wherever the parallel ray approximation was involved (particularly for stars, but also for the sun) the students showed less certainty in their responses.

The radius of the earth can be found from lengths of two vertical sticks (of the same length), their shadows at two different locations on the earth, and distance between the two locations. This method was first used by the Greek astronomer Eratosthenes (276 B.C. - 194 BC.). Basic terms used in the geometry of a sphere such as radius, circumference etc. were first clarified using D17, since students had thus far learnt only two dimensional geometry of a circle, but not of the sphere. A simple diagram to explain the Eratostenes's method was drawn (D18; 4.18a) along with a geometrical diagram to find the formula for radius of the earth (Figure 4.18b). It was expected that this part would be difficult to understand for middle school

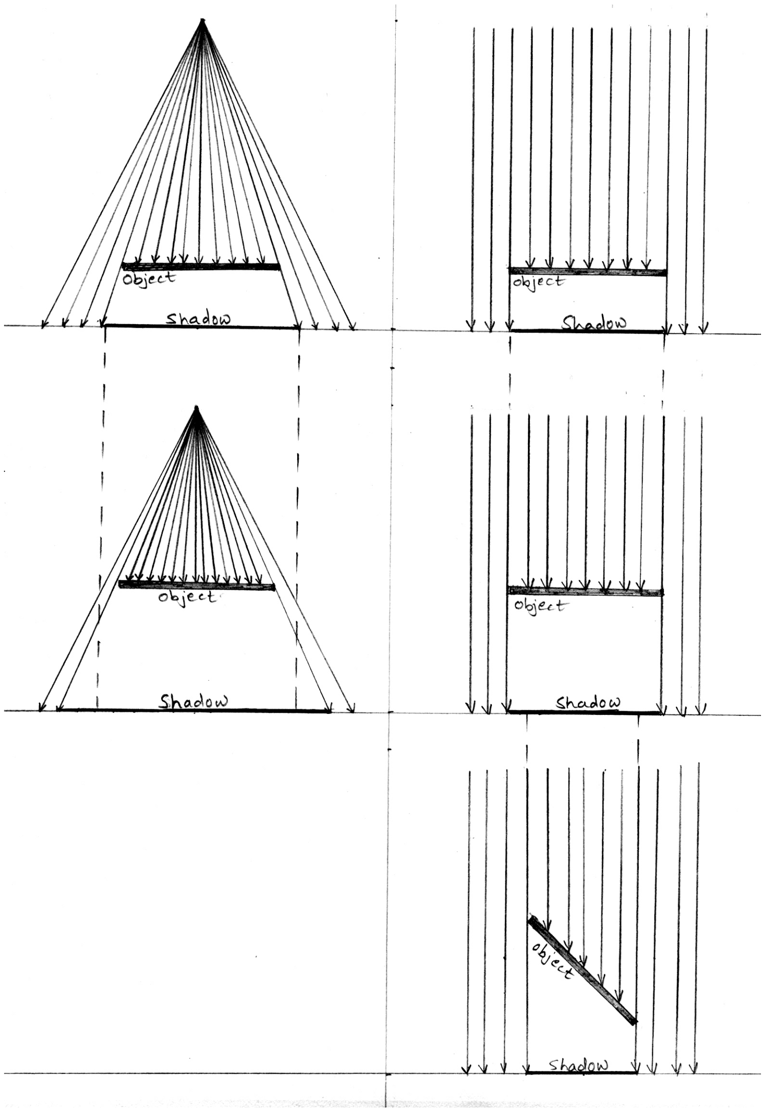
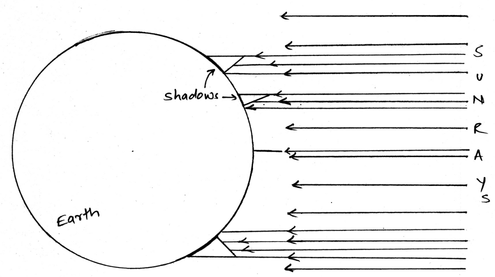
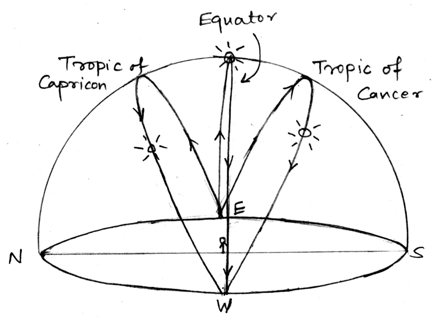


Figure 4.15: Ray diagrams for point and parallel ray sources; Size of the shadow does not change for a parallel ray source if the distance between object and screen changes (D12)

students as it needs a geometrical formulation with which they are not familiar. However we went ahead with the teaching, assuming that exposure to a historically significant event would be motivating, and further it might give them a sense of the size of the earth. Their reading material described how Eratosthenes found out the radius by a much simpler method than actually measuring the circumference of the



(a) Parallel rays and shadow lengths at different latitudes (D14)



(b) Path of the sun at tropic of Capricorn, Equator & tropic of Cancer on the day of equinox (D15)

Figure 4.16: Identifying major directions for a person on the earth

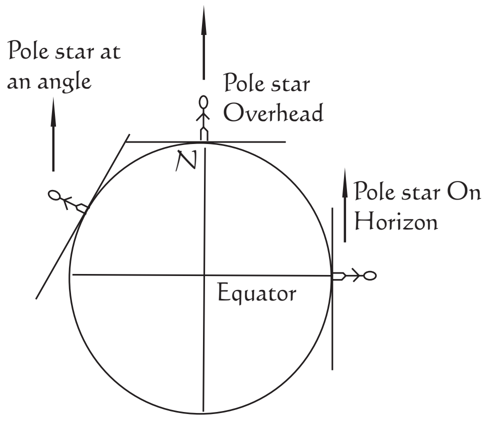
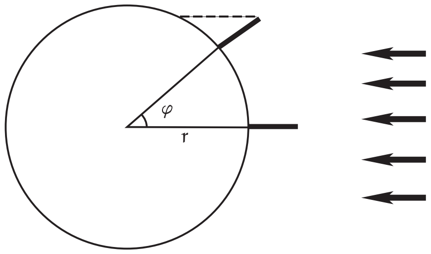
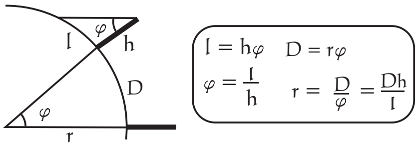


Figure 4.17: Altitude of the Pole Star from different locations (D16)

earth. The new formulae were introduced in the class and 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.



(a) D18a



(b) D18b

Figure 4.18: Eratosthenes' determination of the radius of the earth ($l = h\phi$ is an approximation, valid for small ϕ)

4.3 Pedagogic sequence Part II: The sun-earth system

The second part of the intervention dealt with content related to the sun-earth system and its observational consequences, such as, changes in the night sky over the year and occurrence of seasons. Since there was an interval of about 5 months between two parts of the intervention students were given homework tasks that would serve to revise the content taught in Part I of the intervention and to prepare them for Part II of the intervention (similarly between Parts II and III also). All the homework tasks are described in Section 4.5. In the first three sessions of Part II the three homework sets were discussed and the related concepts were clarified. Two of three sets of homework tasks dealt with measurement concepts for which separate models, gestures and diagrams were introduced for 'internalize concepts of space' (Section 5.2). A description of these sessions is given in Subsection 4.3.1.

The fourth session of Part II onwards followed a combination of teaching/ activity sessions and sessions of guided collaborative problem solving. These were interwoven so that students would not get exhausted with continuous problem solving sessions but rather, after learning the new content, some of it could be practiced and clarified using problem situations.[5] However, for the sake of simplicity, we first present the teaching sessions in Subsection 4.3.2 with the help of Table 4.2 and then present the nature as well as analysis of guided collaborative problem solving in Subsection 4.3.3.

[5]The terms 'problem situation' and 'problem task' are used interchangeably.

4.3.1 Measurement

During Part I of the intervention, we found that students do not have good idea of concepts and procedures of measurement. Many students did not know how much distance corresponded to units in common use such as millimeter, centimeter and inches. Most of them could not estimate distances in centimeters and meters. Some did not know how to measure angles, some were not aware of different units necessary for measuring length, area and volume, and the concept of 1, 2 and 3 dimensions was not yet known. Homework sets 2 & 3 were designed for familiarizing students with measurement, and considerable time of the first three sessions was spent on clarifying ideas of measurement. This was important for Part II of the intervention, which included activities related to sizes and distances of celestial objects.

Most of the students carried a 6-inch scale in their pencil-box and they were familiar with the foot-long scale which teachers carry. Several 6-inch, foot-long and a meter-long scales were distributed in the classroom and students were asked to carefully observe them (CM14). The meter and foot edges of the scales were pointed out to show different systems of measurement. The metric system was revised. Students were asked to estimate millimeter, centimeter and meter using their nails, fingers and arms and were asked to walk a few meters (say 10 meters) while counting their steps (G19). Students estimated and confirmed the lengths (sometimes heights) and distances of objects in their surroundings. They drew a scale and showed different markings on it (D19).

Measurement of angle was a major challenge. Students were shown how to use a protractor to measure angles (CM15) and then they were asked to incline their stretched arm at different angles to the horizon and make different angles using two hands (G20). In a similar gesture carried out in Part I in the context of measuring the angle of altitude of a star (G2), the focus had been on smaller angles determined by palm. Subsequently in Part III of the intervention, students classified angles in the surrounding as acute, right and obtuse angles and estimated their measures (G32). When they came across a pair of parallel lines, they were reminded that the lines will never meet, which means the angle between them is zero. This notion continued in the first session of guided collaborative problem solving (Subsection 4.3.3). Finally students drew and measured angles of different measures on the blackboard and on paper using a protractor (D20).

We found the concept of dimensions useful to clarify many concepts in astronomy such as shape of the earth, directions, and especially the relation between a real 3-D system and its diagram. A model of three orthogonal axes which was used in Part I was shown again (CM9). Students were asked to recall and mimic actions which represent roughly 1, 2 and 3 dimensions such as walking, spreading cow-dung on the floor (a common practice in rural/ tribal households to make the floor even, usually carried out by girls) and filling a container of water or grain (G21). An example of identifying an address in a hypothetical town (x road, y lane, z floor) was used to illustrate the Z-axis and a diagrammatic representation of Cartesian axes was used (D21).

Table 4.2: Pedagogic sequence for Part II: The sun-earth system

Context or Concept	**CM: Concrete Model/ *Teaching aid*** **G: Gestures and actions** **D: Diagram/ *Visual representation on paper*** XX: Category absent
Measurement	**CM14**. Six-inch scale, foot-scale, meter-scale **G19**. Measuring 1mm to few meters by using body parts. **D19**. Picture of scale and different units (mm, cm, few cms.)
Angle	**CM15**. Protractor **G20**. Rotating hand from 0° to 180°. **D20**. Acute, right and obtuse angles in different orientation
1, 2 & 3 dimensions	*Daily examples*, Model of three orthogonal axes (CM9) **G21**. Length: walking, Area: flat palm, Volume: Filling up **D21**. *Locating an address*, Cartesian coordinates on board

Rotation + Revolution gives motion of the earth	**CM16**. The sun-earth system (Figure 4.19) **G22**. Only rotation (facing changes); only revolution (facing does not changes); 1 rev + 1 rot; 1 rev+ 2 rot; 1 rev + 4 rot; imagine 1 rev + 365 rot. **D22**. *Photographs of the sun and the sun-earth system* **D23b**. Earth, axis, direction of rotation (D10b) + sun + orbit of earth's revolution as seen from above the North Pole (b: circular orbit) (Figure 5.11)
Shape of orbit of the earth (materials: *nails, thread, thermocol sheet*)	XX **G23**. Drawing ellipses using 2 nails: A series of diagrams which give kinesthetic feedback. **D24**. Ellipses for varying distances between foci (Figure 4.20)
Understanding ellipse with circle and line as extreme cases	XX **G24**. Making circle, ellipse and line by joining palm. XX
Perspective view of circle	**CM17**. *Bangle, bucket, other circular objects* **G25**. Observing loop made by thumb and index finger (or other objects) from top, side and oblique view. **D25**. Circle-ellipse-line (Drawings of circular objects from different perspectives)
Angle made by the earth's axis with the ecliptic plane	XX **G26**. Show axis tilt by forearm bent at elbow. **D23a**. Earth, axis, direction of rotation, equator, (D10a) + sun, orbit of earth's revolution as seen from within the plane of equator (a: horizontal line as orbit) (Figure 5.11)
Plotting the sun-earth distance on the ground	**CM18**. Marbles, measuring tape, thread for measurement, chalk **G27**. Find out ratios of distances considering an earth of diameter 1cm and plot them on the ground. XX
Solar system (*Chart of distances and speeds*)	XX **G28**. Each student becomes one planet and revolves around the student who is the sun, taking account of the relative speeds. **D26**. *Picture of solar system*

Changes in the night sky over the year *(Calendar)*	XX **G29**. One student becomes the sun, another becomes the earth and revolves around the sun. All other students become different *Nakshatras* representing a star background. Students predict which Marathi month and which solar *Nakshatra* is on, depending upon the position of the earth. **D27**. The sun-earth system from above the North Pole (D23b) + background stars (Figure 4.21)
Intensity changes as a function of angle of incidence	XX **G30**. Put your hand above hot lamp (or in rain) in different orientation, to sense that collection of heat (or water) depends on angle of incidence. **D28**. Intensity depends upon the angle between screen and incident rays (Figure 4.22)
	The sun-earth system (CM16) XX **D29**. Explanatory diagram for occurrence of the seasons (D23a + sun-rays) (Figure 5.13)
Trace path of the sun in different seasons	XX **G31**. Trace a semicircle with a stretched arm making different angles with horizon depending upon the season. **D30**. Path of the sun on equinox (a), in Summer (b) and in Winter (c) at different latitudes (Figure 5.12)

4.3.2 The sun-earth system

Photographs of the sun and the sun-earth system were shown in the classroom (D22). Some facts such as the sun is a star, and the earth is a planet and details such as sun-spots were discussed in the class.

A concrete model of the sun-earth system was presented to students in a dark room (CM16; Figure 4.19). The sun was replaced by a candle mounted on a stand and a small globe represented the earth. The earth was attached to the stand by a thin rod, which could move in a circle around the sun. The inclination of the axis of rotation of the earth could be changed so that the axis could be kept inclined in the same direction, similar to the axis of the real earth. (If it had been fixed, it would change its inclination with respect to the sun). This arrangement also allowed us to change the inclination of the axis and examine different situations. The rotation of the earth, the occurrence of day-night and revolution of the earth was demonstrated with this model. The time periods of rotation and revolution were recalled.

Figure 4.19: Rural students handling the sun-earth model

To clarify the difference between rotation and revolution, students were asked to perform a rotation and then a revolution around a fixed friend. Then to emphasize these two simultaneous motions, students were asked to include more and more number of rotations during one revolution (G22). This was difficult gesture, more so when the rotation and revolution were to be precisely matched, as happened in Part III for the orbit of the moon (Section 4.4). Finally a diagram of the sun-earth system was drawn on the board. We chose the view from above the North Pole so that the representation of a circular orbit remained circular. Students were already familiar with the earth's representation from above the North Pole (Figure 4.5a). A circular orbit around the sun was drawn and students were told that the direction of revolution is the same as the direction of the rotation and that it can be determined using the right hand thumb rule (G13), if the orbit is seen from above the North Pole. An arrow to specify the direction of the revolution was drawn (D23b; Figure 5.11).

Most of the students knew that orbit of the earth is elliptical, and they were not convinced by the circular orbit drawn in D22b. The elliptical shape of the orbit is greatly emphasized in textbooks without reference to any observational consequence of it (Section 1.4) and this idea gets incorrectly reinforced by the common diagram of the earth's orbit from an oblique perspective (Figure F.2c). This problem was tackled in two ways. Firstly an activity of drawing ellipses with varying distances between foci was carried out using two pins and a loop of thread (G23; this activity is considered as gesture-action because the shape was perceived through kinesthetic senses as well). Students could see that, as the distance between the two foci increases, the ellipse become more elongated, and as the distance between the two foci decreases, ellipse looks more and more like a circle (D24 4.20). Then they were told, that for the earth's orbit, the two foci are so close, that the orbit is almost circular. (A line and a circle are special cases of ellipses, which can deformed into each other (G24)). The sun-earth distance at the time of aphelion and perihelion (again, concepts that are unnecessarily emphasized in textbooks) was compared, and it was showed to be impossible to depict the variation in a diagram.

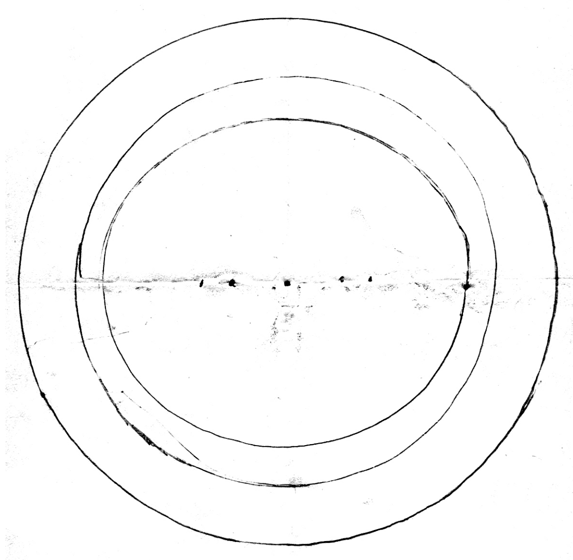


Figure 4.20: Ellipses for varying distances between foci (Students' diagram) (D24)

The elliptical orbit (commonly used in diagrams) was explained as a circle seen from oblique perspective. First students were asked to draw different objects which included a circle, such as a bucket, tiffin box etc. (D25). Students spontaneously chose oblique views and drew the circles as ellipses. This inconsistency was pointed out to students and they were asked to observe different circular objects such as bangle (CM17) and a loop made by the index finger and thumb (G25) from different perspectives. They drew these objects from top and side views which forced them to draw a circle and line for these two cases respectively. The sun-earth system was then drawn from three different perspectives: from above the North Pole (we avoided using the term ‘top view’), from within the plane of the orbit (ecliptic) (D23a) and an intermediate (oblique) perspective (D23c). While drawing D23a, students were reminded with the help of concrete model of the sun-earth system (CM16) that the axis makes an angle of 23.5° with the ecliptic. Students showed the tilt of the axis by their forearm bent at the elbow, and moved it in a circle, keeping the inclination constant (G26).

Distance scale

The ratios of diameters of the earth and the sun, diameter of the earth to the sun-earth distance, and distance of other inner planets, was calculated in the classroom. A marble (of 1cm diameter) was considered as the earth (CM18). Then the sun-earth distance was mapped on the road/ playground. The positions of the inner planets were also identified and a sun of diameter 108 cm was drawn on the road/ playground (G27). A discussion accompanying this activity was about ‘if we walk at a speed such that we take about 8 minutes to reach from the sun to the earth, and we continued with the same speed for 4 years 3 months, we will reach the nearest star in this scale (idea of a light year was discussed). A chart of ratios of sizes and distances was provided to each class (Appendix E).

Solar system

Students were familiar with the names of planets and had a general idea of the solar system. They were given a chart which tabulated sizes, distances and time periods of revolution of the planets (Appendix E). They were asked to carefully examine the time-periods to notice that, as the distance of a planet from the sun increased, its time period increased. Thus in the activity they took care that a planet never crosses another planet which is in an orbit closer to the sun. One student became the sun and other students became one planet each. The planets started in a line and performed the revolutions with rough relative speeds (time for about 2 revolutions of the earth equals the time for one revolution of Mars, and time for about 11 revolutions of the earth equals the time for one revolution of Jupiter) but ignoring rotation. A picture of the solar-system was also provided to each class-room (D26).

Changes in the night sky

From the night sky observations and from the star charts students knew that the position of stars observed at the same time changes every day. At this point students were given a commonly used calendar (Mahalaxmi) which is combination of the Gregorian and indigenous calendar (*Chaitri Panchang*) (Figure E.1a). This calendar follows the Gregorian months but also specifies the Marathi month (the Marathi month is named after the *Nakshatra* in which full moon is seen). The calendar also shows in which *Nakshatra* the sun will be. These pairs were written on the board. The names of all the *Nakshatras* were available on the calendar and students were asked to guess the name of *Nakshatra* from which the name of the Marathi month would have been derived.

Then each student became one *Nakshatra*, one student became the earth and one student became the sun. The *Nakshatras* stood a round forming a background of stars and the earth revolved around the sun slowly (G29). The students noticed that the *Nakshatra* behind the sun will not be seen when the *Nakshatra* opposite to it is seen, and these pairs match with those written on the board. The meaning of terms 'sun in a *Nakshatra*' or 'starting of a *Nakshatra*' was explained as the time when the *Nakshatra* will not be seen because of the light of the sun. The Marathi month on the other hand is named after the *Nakshatra* which is seen at mid-night. A short discussion on historical development of calendars in different cultures was held in the class. This was followed by Session 4 of guided collaborative problem solving (Subsection 4.3.3) which included questions related to visibility of *Nakshatras*. A chart on relation between Marathi month, *Nakshatra*, Gregorian month, seasons and prominent events (Appendix E) and a diagram explaining the relation between sun in a *Nakshatra* and the corresponding Marathi month (D27; Figure 4.21) was given in each class.

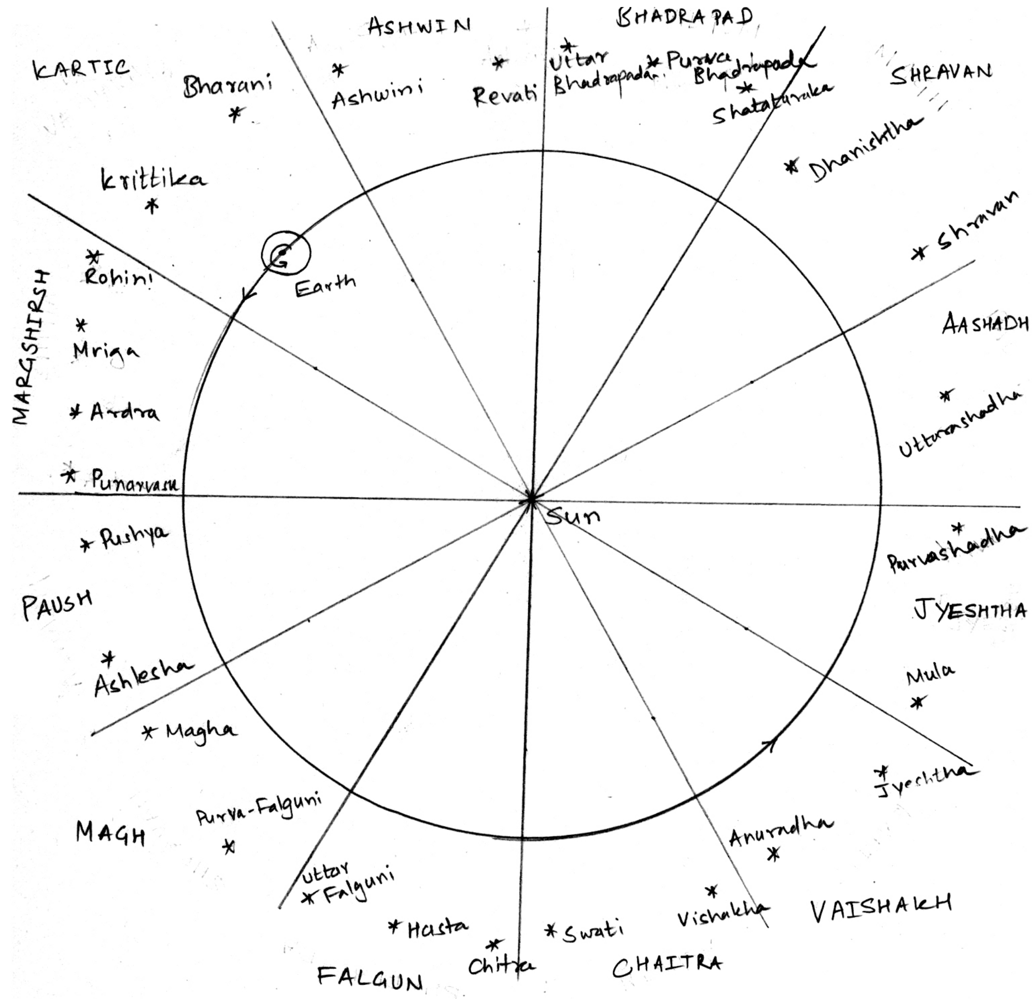


Figure 4.21: Relation between observable night sky and indigenous calendar (D27)

Seasons

Two basic reasons of occurrence of seasons are, change in intensity of light due to inclination of the sun in the sky and, change in the duration for which the sun is above the horizon. The first reason was explained using a combination of a thought experiment and a gesture (G30). Students were asked to imagine that it is raining and they want to collect water in a container. They were asked to show how would they hold the container. If they change the inclination of container, will it make any difference? Which way will be most efficient and which least efficient? Students could answer these questions easily. Then they were asked, if they put their palm above a flame, which way should they incline it so as to collect the maximum amount of heat? In continuation students were asked, when do we feel maximum warmth: in the morning or at noon or in the evening? Thus students concluded that if the incident rays are perpendicular to surface, then their intensity will be maximum, and as the angle increases or decreases, the intensity reduces. A ray diagram (D28; Figure 4.22) was drawn to show how the number of rays collected by a screen changes as we change the angle between the incident rays and the screen. Students were asked to take notes of length of shadows using a gnomon (CM12) (which unfortunately they did not take regularly). However, from whatever notes they took combined with observations from Parts I and II of the intervention (shadow of a vertical stick at noon was shorter in Part I and longer in Part II) it was clear that, the sun's angle with the horizon at the noon is more in summer and less in winter.

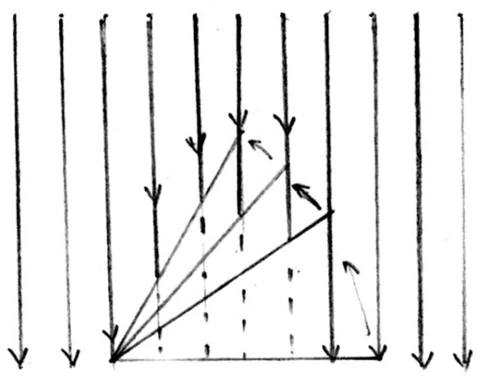


Figure 4.22: number of rays collected by a screen changes as we change the angle between the incident rays and the screen

Then students one by one read out the timings of sunrise and sunset on each Sunday from the calendar (available on the back of page for each month) for an entire year and these data were tabulated on the blackboard. Students observed the pattern that there is a variation of about 2 hours over the course of one year in the time of both sunrise and sunset (a rough graph was drawn for sunrise and sunset; one below another), and when the sun rises earlier, it sets late, and vice-versa. Thus the days are longer during June and shorter during December. Thus first students became familiar with two observable effects which are responsible for the occurrence of seasons, after which we turned towards the explanation based on the sun-earth model.

The concrete model of the sun-earth system (CM16) was used to show how the North Pole remains either lit or dark during one complete rotation, and that the sun-rays are normal on either on the Tropic of Cancer or on the Tropic of Capricorn (these lines were known to students) at the time of solstice. The construction of a set of diagrams (D29; Figure 5.13 and its variants for solstices and equinoxes) was covered under Session 5 on guided collaborative problem solving (Subsection 4.3.3). From these diagrams and from the observations of the length of shadows of the gnomon, students predicted the path of the sun in summer, winter and on the day of the equinox on the equator first, and then at different latitudes (less than 23°, at 23°, more than 23°, on Poles), towards North and South of the equator. The path at times was drawn on an large inverted bowl considering it as the dome of the sky, but more frequently it was traced by an extended arm (G31) and then drawn on the blackboard (D30, Figure 5.12).

4.3.3 Guided collaborative problem solving

Five sessions in Part II of the intervention were dedicated to guided collaborative problem solving. These sessions, of about 1 hour each, were distributed throughout Part II, interspersed between whole-class interactions, activities and other session formats. While the problems demanded from students rigor and independent thinking, the variety in the sessions helped to keep up their interest. During these five sessions students solved eleven questionnaires, each addressing one main problem which was divided into shorter questions. One questionnaire that was given in Part III of the intervention is discussed in the next section.

The questionnaires exposed students to complex problems which they were to solve collaboratively with minimum help from the teacher. These questionnaires, and the collaborative situations in which they were solved, formed an essential component of our pedagogical intervention. The problems in the questionnaires were novel (not a repetition of the ones which were solved in class) and they were composed in a way that students would learn some specific aspect of geometrical model-based reasoning through diagrams. The purpose of these questionnaires was first, to teach and to train students to solve problems. A second purpose was to observe how they went about it, what mistakes they made, had they understood the classroom teaching or had the teaching created some new misconceptions. It was thus a pedagogic purpose, rather than one of testing and marking progress. If a particular group persisted making some mistake, the teacher intervened with that group, and if more of the groups were making the same mistake, the required instructions (or explanations) were given to the whole class. Students were allowed to correct their responses after the teacher's intervention. The teacher however noted the mistake in her log.

The problem solving required application of old as well as newly learned content. The questionnaires were of 1-3 pages in length, in which multiple steps were required to arrive at the solution or inference. The complexity of the problem situations increased over successive questionnaires, which involved successively more elements (e.g. sun rays, shadows, local and global shadows and viewing angles, rays from stars, rotation and revolution of earth, and inclination of earth's axis), hence successively more steps of reasoning. Finally, the procedures required for each step were more varied in the later questionnaires than in the earlier ones. The original questionnaires and their English translations are given in Appendix B.

Session 1 included Questionnaires 1 and 2 which were designed to teach that very large distances between celestial bodies can be taken into account by drawing parallel rays from one to the other. Session 2 (Questionnaires 3 and 4) was based on application of the parallel ray assumption in real life situations (such as drawing shadows and predicting where a particular star would be seen). Questionnaires 3 and 4 opened with problems based on local situations (which could be easily observed locally), followed by similar situations posed at a global level (at two different points on the globe). From Questionnaire 5 onwards, all the situations were global in nature. Session 3 (Questionnaires 5 to 8) dealt with local time at different locations on the earth, apparent positions of celestial bodies at each of these locations, and changes in the apparent positions of celestial bodies as a result of rotation of the earth. Session 4 included only one questionnaire which related the observed night sky (*Nakshatras*) and the indigenous calendar. Questionnaires 10 and 11 in Session 5 were based on the occurrence of seasons. In Questionnaire 10, students had to complete and interpret the diagrams for the two solstice situations and in Questionnaire 11, the diagram for equinox was given and students were asked to predict effects related to day-night and seasons.

Nature of guidance

Prior to each problem-solving session, the pre-requisite content was addressed in the course of classroom sessions involving models, gestures and diagrams, as detailed in Sections 4.2 and 4.3. Thus students were expected to be prepared to solve the upcoming set of questionnaires. However we found in the initial trials that most of the students could not solve a whole problem on their own. If they did not know how to begin, they sometimes gave up. So multiple steps of the problem were made explicit and instructions were given for each step. Initiating a diagram by choosing the correct view, scale, etc., requires planning which we found was initially beyond the students' abilities. Besides, we know that if students are provided with a skeletal diagram their responses tend to be more explanatory rather than descriptive (Ramadas and Driver, 1989). Therefore, each questionnaire began with a skeletal diagram of the situation along with instructions required to complete the diagram. This device saved time while ensuring that every student had an opportunity to engage with the problem. Some crucial hints (such as a reminder to draw parallel rays from a star) were provided in the questionnaires, and some hints were also given orally. The hints ensured that students remained on the right track and proceeded with the diagrams. Finally they were asked few key questions, to respond to which they needed to interpret the diagram and draw appropriate inferences. The hints and questions are given in the description which follows.

Collaboration and Classroom Organization

Students worked in triads (occasionally in dyads or groups of 4) to solve the questionnaires (Figure 4.23). There were no mixed-sex groups, since, although the girls and boys in all these schools freely spoke to each other, they were not accustomed to working together. Their classroom seating arrangement too separated girls and boys. We felt that single sex groups would help students feel more comfortable in expressing their ideas and debating them with their peers. Each group usually contained one able student and two others who were somewhat less able in problem solving as judged by the teacher.

Figure 4.23: Guided collaborative problem solving in the rural class

Students in one group discussed and proposed solutions on the rough paper given to each of them. After everyone agreed to the solution they drew it on the actual questionnaire. The rough workings were preserved and attached to the group questionnaire. All the groups sat in the same classroom, keeping some distance from each other, to avoid disturbing the neighboring group.

One group from each class from the rural and tribal schools was videotaped and the data was used for analysis of gestures and communication (Subsection 5.2.2). The present section describes some relevant observations from the sessions derived from students' written and diagrammatic responses and the teachers' notes and logs (Subsection 3.5.5). The video data is presented in Subsection 5.2.2.

The following instructions were given at the start of every session:

- You have to solve these questionnaires in your group. Read and follow the questions and instructions carefully.

- Discuss each question amongst yourselves and make sure that every one of you agrees with the answer. Make use of the rough sheets to explain your ideas to the others. Do not discuss your responses with the other groups.

- Solve the questions one by one, and pass the paper around in your group so each of you gets a chance to write or draw the response.

Questionnaires were given one after another to avoid confusion and to make sure that students completed each problem.

There were several reasons for doing the problems in collaborative mode. The general advantages of collaborative learning are already discussed in Section 3.5. We expected verbal interaction between the students, involving communication, argument, explanation etc.. However our interest was more in students' use of spatial tools, specifically gestures and diagrams, which we expected would come about through these collaborative situations. The built-in requirement to speak, draw and gesture might have also contributed to the students' success of solving problem. Another advantage of the collaborative situations was that the communication took place in a more natural setting than would have been possible in, say, an interview (an adult asking questions and a student responding).

The collaborative situations gave additional responsibility to the able students to explain ideas to their peers, which we expected would help both the more and less able students to clarify their concepts. The less able students could freely ask questions to their peers and might also understand better, because the level of explanation was likely to match their own way of thinking. The mixed ability nature of the groups would also help maintain an equilibrium in the class (so that some groups did not go ahead much faster than others).

The urban sample was used as a pilot sample for these questionnaires. Whenever we found that some of the problems were too difficult for the urban students, they were simplified in the sessions for the rural and tribal samples. The data from the urban sample is therefore not considered in this analysis. The questionnaire numbers, and the number of groups (and students) present for each session, are summarized in Table 4.3.3.

Table 4.3: Number of groups present in each session

Session No.	Questionnaire Nos.	Rural				Urban			
		No. of groups (G+B)	Total Girls	Total Boys	Total No. of students	No. of groups (G+B)	Total Girls	Total Boys	Total No. of students
1	1 - 2	4+5	11	16	27	1+5	3	15	18
2	3 - 4	4+5	10	16	26	1+5	3	16	19
3	5 - 8	4+4	10	12	22	1+5	3	14	17
4	9	3+4	8	12	20	1+5	3	13	16
5	10 - 11	4+6	10	17	27	1*+5	5	15	20

* The girls' group did not submit their questionnaire

Since the problems were complex and required multiple steps, several kinds of mistakes were possible. We were interested in kinds of mistakes and responses to identify students' difficulties rather than classifying the responses in gross categories and finding frequencies if each kind of response. The data from rural and the tribal groups is collapsed and their responses are described here.

Session 1: Parallel Rays (Section B.1)

Parallel ray approximation for a distant light source.

Most everyday astronomical phenomena (day-night, seasons, phases of the moon, positions of stars) (but with the exception of eclipses) require for their explanation the assumption that the sun-rays reaching the earth are parallel. This assumption follows from the argument that the sun is at a very large distance from the earth in comparison with the size of the earth, and therefore the angle subtended by the earth at the sun (which is also the maximum possible angle between any two sun rays reaching the earth) can be considered to be zero. The argument was taught to students in Part I of the intervention using diagrams, but we found that students had considerable difficulty with it. The first session of guided collaborative problem solving was designed to guide students to construct this argument. This session consisted of solving Questionnaires 1 and 2.

Questionnaire 1: Measurement of angles between successively less divergent lines leading to parallel lines

Students were given three pairs of lines making of angle of 25°, 10° and 5°. The intersection point was not shown in the figure. Last in this series was a pair of parallel lines at a distance of 2 cm from each other. Students were to extend the lines so that they intersected and then measure the angle between them. In the last case, from visual appearance, one could guess that the pair was of parallel lines. Students were expected to measure the distance between the lines at at least two points so that they could conclude that the lines were parallel and hence would never intersect, and that the angle between them was zero.

The following hints were given at the stage of measuring the angles:
Hint 1.1: You may have to extend the rays.
Hint 1.2: Coincide the 0 point of the protractor and point of intersection in the diagram. Coincide the zero line of the protractor and one of the lines in the diagram.
Hint 1.3: Measure the angle from one ray to another (the smaller - acute - angle).

It was a novel experience for the students to add to a printed diagram that was given to them. Typically for the first few minutes they were not sure what to do, so tried different things such as measuring lengths, or tentatively placing a protractor at the end points of the rays. A few hints sufficed for students to measure the angles correctly, barring inaccuracies. Instead of persistently demanding too much accuracy they were asked to join another sheet of paper if the lines did not intersect.
Most of the responses (though conceptually correct) were not accurate in geometrical terms. If the measure of the angle was within ±2° of the correct measure, the response was considered correct.

The following problem areas were identified from students' responses:
1. Of the 9 rural and 6 tribal (total 15) groups who attempted this Questionnaire, 10 did not extend at least one of the pairs of lines smoothly. The rays got slightly bent at the point of extension, which led to incorrect measure of angle (Figure 4.24a). One particularly careful group of students in the rural school extended the rays and

measured the angle correctly, but then rubbed off the extended rays for the sake of neatness (Figure 4.24b). This may be because students are not used to working on a diagram that is given to them. It took time to convey that it is ok to interact and add into the diagram to aid our reasoning process, that the proofs (or evidences) of reasoning are as important as its final result.
2. Problem in measuring angle: Seven out of 15 groups measured the angle wrongly, perhaps due to faulty reading or due to movement of the protractor after placing it, in jostling between the students as they interacted, sometimes in a congested situation, or occasionally perhaps due to carelessness or lack of concentration. One group did not measure the angles at all, another group measured and noted the angle correctly in the diagram but wrote a different value in the statement below it.
3. Conceptual mistake: A few groups initially measured the supplementary angle at the point of intersection but corrected their mistake in response to the teacher's suggestion.

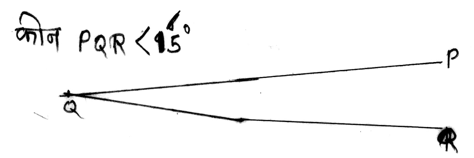
In the last situation, where the lines were parallel, some students still tried to extend them (sometimes even on an adjacent sheet of paper) in the hope that they would meet somewhere (Figure 4.24c). Others guessed that the lines were parallel, and would not meet. They were asked to verify whether the lines were really parallel by the following hint:

Hint 1.5: Try measuring perpendicular (minimum) distance between two lines.

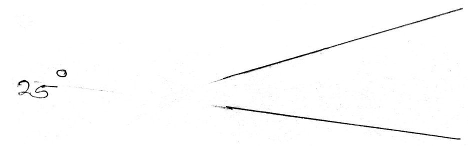
Despite this hint thirteen out of 15 groups merely asserted that the angle is 0° or the lines are parallel, without measuring the distance at two points. Two groups did measures the distances and showed that they were the same, however, one of these groups measured the distance incorrectly (2.2 c.m. instead of 2 c.m.) (Figure 4.24d). One group responded that the angle is 180° and another group did not respond this question.

Thus although finally only one mistake was found, and that too, due to lack of diagrammatic skills (measuring distance incorrectly), it is important to note that most of the groups did not realize the significance of verifying that the lines are in fact parallel. The culture of checking and verifying one's guess, which is an accepted part of scientific practice, was yet to develop in these students.

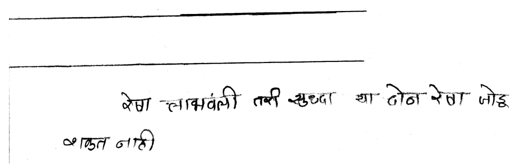
In summary, a seemingly obvious logical sequence, of confirming that lines are parallel by measuring the perpendicular distance between them at two points, then rephrasing ‘parallel’ in terms of ‘no intersection point’, again rephrasing this idea as, ‘the angle between the two lines is zero’, is not an easy argument for students to follow even in Grade 8 (although it was already taught once in Part I of the intervention). Yet parallel sun-rays are introduced at a very early stage (Grade 3) and never discussed or explained.



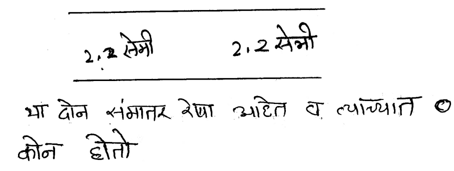
(a) A response by a group of tribal boys: The rays got slightly bent at the point of extension, which led to incorrect measure of angle



(b) A careful group of rural boys extended the rays and measured the angle correctly, but then rubbed off the extended rays for the sake of neatness



(c) A group of tribal boys has extended the pair of parallel lines to measure the angle between them



(d) A group of rural girls confirmed that the lines are parallel, but incorrectly measured the distance between them

Figure 4.24: Responses to Questionnaire 1: Measurement of angles

Questionnaire 2: Drawing rays from the sun at increasingly larger distances to notice almost parallel nature of rays near the earth

Questionnaire 2 opened with a diagram of round sun and the students ware asked to draw light rays in all directions. Textbook diagrams directly introduce parallel rays from the sun, which may give impression that the sun-rays are uni-directional. Students need to know that there are rays going in all possible directions from each point on surface. This exercise was expected to prepare students to treat the sun as an extended light source to explain umbra and penumbra during eclipses.

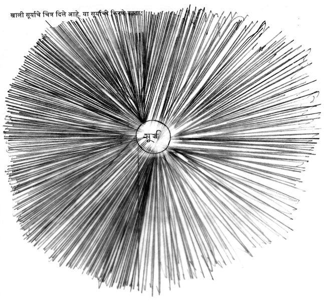
Then followed three diagrams, each containing the sun as a point and a small circle as the earth. Keeping the size of the earth constant, the distance between the earth and the sun was increased with each successive diagram. Students were to draw diverging rays from the sun. Then they were asked to colour only the rays which are falling on the earth and measure the maximum angle between them. Since the distance in each diagram increased sequentially, the angle subtended by the rays falling on the earth decreased ($25°, 12°, 7°$). At the end students were asked whether the angle increased, decreased or remained same, and what would happen if the distance goes on increasing further. Through this question we expected that students would realize that since the size of the earth is very small as compared to the distance between the earth and the sun (or any star, because any other star is farther away) the sun-rays falling on the earth can be considered parallel. Answering this question demanded limiting case analysis, which is said to accompany visuospatial reasoning (Nersessian, 1999).

In the first diagram students initially drew very few and short rays. The following hints were then given:

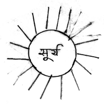
Hint 2.1: Sunlight goes in all directions so draw many long rays. Are there rays everywhere?
Hint 2.2: From each point rays go everywhere. Draw more than one rays from one point on the sun.
Hint 2.3: Light rays travel in a straight line.

Conceptual mistakes:
1. Out of 15, four groups drew radial and 6 groups drew almost radial rays (Figure 4.25a).
2. In 7 groups the length of rays was finite and sometimes too short. One of the 4 groups, which drew mostly radial rays, drew rays of 1 cm in length, as in a children's picture (Figure 4.25b. Two groups (one rural and another tribal) drew only radial rays, and one drew some rays longer and some shorter almost in an alternate pattern, also similar to sun-rays in children's pictures (Figure 4.25c). After the hints

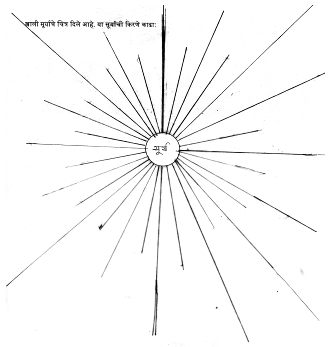
eight groups drew long rays, not all radial (correct response: Figures 4.25d, 4.25e).



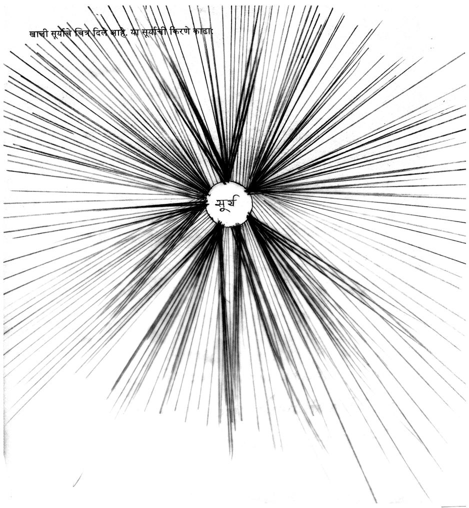
(a) Too many mostly radial rays drawn by a group of tribal boys



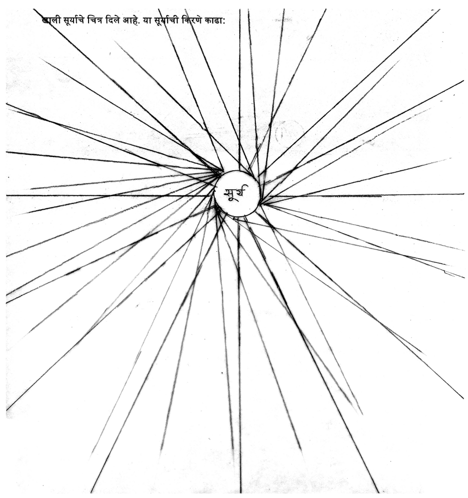
(b) A group of rural boys drew short and exclusively radial sun-rays



(c) A group of rural girls drew exclusively radial sun-rays, with a pattern of alternate short and long rays



(d) Correct response by a group of tribal boys



(e) Correct response by a group of rural boys

Figure 4.25: Responses to Questionnaire 2: Drawing rays from the sun

In the next three diagrams, while drawing divergent rays from the sun, initially most of the groups drew rays only towards earth. When I insisted they draw in all directions, they said that they would draw it later, but some of the groups did not do it (Figure 4.26a).

Several students were found to be measuring the angle incorrectly, so the following hint was given:

Hint 2.4 Measure the angle at the POINT of the sun.

Conceptual mistakes:

1. Problems with ray-diagrams: One group bent the rays so that they cross the earth and extend on the other side of the earth. Another group drew straight rays crossing the earth (Figure 4.26b).

The difference between the terms ‘darkness’ (absence of light) and ’shadow’ (blocking of light source) was brought out through discussion.

One group from the rural school in all three diagrams, bent the rays in order to make them parallel where they reach the earth (Figure 4.26c).

One of the groups did not draw all the rays from the sun. A boy from same group tried correcting it and when the boy who was drawing incorrectly ignored the correction the other boy urgently drew my attention, asking for my intervention.

Six out of 15 groups drew rays which did not meet at the given single point (Figure 4.26d). Some of these groups refused to treat the sun as a single point. They considered the given point as one of the points on a circular sun (which actually is the case). But instead of drawing all rays from this single point under consideration, they drew rays from several points in such a fashion that the starting points of the rays formed a circular arc (Figure 4.26e). In some questionnaires the sun was not considered to be circular, but their rays did not intersect in the given point. In one response, the rays were not drawn from the sun, but from an arbitrary point between the sun and the earth (Figure 4.26b). Thus 4 groups drew rays which did not have common starting point.

2. Problems in measuring angle: In spite of giving Hint 2.4, students continued to make conceptual mistakes while measuring angles: Six groups whose the rays did not start from the sun, could not measure the angle subtended by the earth (nonetheless a few groups wrote the measure, probably by copying from another group) (diagram).

One group measured angle from a middle ray to one of the extreme rays.

One group measured the angles incorrectly.

3. Difficulties with limiting case analysis: Three out of 15 groups did not understand that the angle was decreasing with increase in distance. Two of these three groups first wrote that the angle 'increases' but then they corrected their response to 'decreases'. The third group first wrote that the angle 'remains the same' and then changed it to 'increases' and finally corrected it to 'decreases'. Further, this group could not conclude that it would eventually become zero. Thus, for the limiting case analysis, all groups except one could conclude that the angle will eventually become zero or "almost zero".

4. Seven groups drew too many diverging rays. Many groups spend lot of time in drawing rays (Figure 4.26f). Students tried in their own way to be as accurate as possible. In this case perhaps they wanted to show that the rays are in all directions. Some diagrammatic constructions need to be accurate for the sake of quantitative analysis (eg. drawing exactly parallel rays) while other constructions express conceptual understanding, which need not be accurate quantitatively (Figure 4.26g). Students have difficulties in distinguishing the two cases and in expressing their understanding in optimum ways.

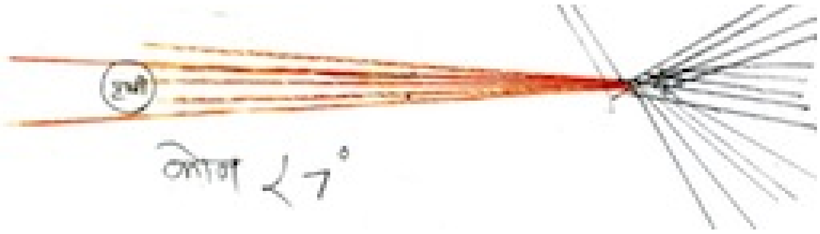
5. Students were asked to colour the rays which fall on the earth, but one group of students drew all the rays coloured (Figure 4.26d). This could be either because of their enthusiasm for using coloured pencils or because they did not read the question properly.

14 out of 15 groups gave the correct verbal response that the angle between the sun-rays subtending the earth decreased as the distance between the earth and the sun increased, and the angle can be considered to be zero for a very large distance.

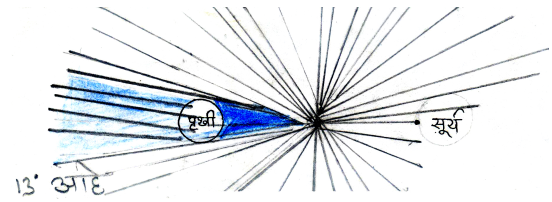
Most of the students remembered that in one of the classes in Part I they were taught that for large distances, the angle will reduce to zero. I had to emphasize that it is not exactly zero as the rays meet at the Sun. Students were reminded that the ratio of earth's radius to its distance from the sun was calculated in the earlier class as 1: 23,000, whereas in the given diagram, the maximum ratio was 1:10.

Session 2: Shadows (Section B.2)

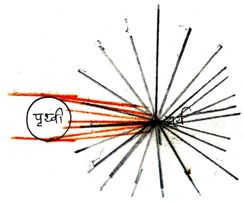
Correlating shadows with angles of elevation of a light source.



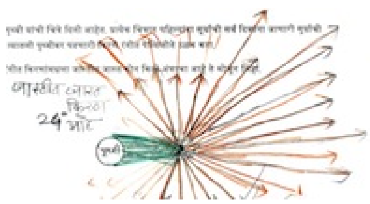
(a) A group of tribal girls did not draw the sun-rays in all directions



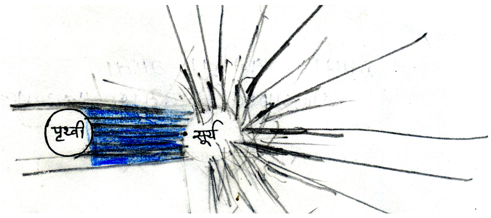
(b) A group of rural girls drew the sun-rays beyond the earth



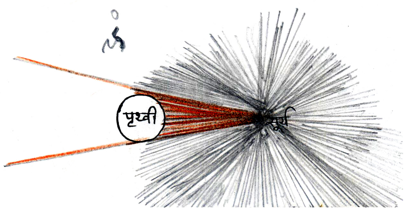
(c) A group of rural girls drew divergent rays from the sun but parallel rays near the earth



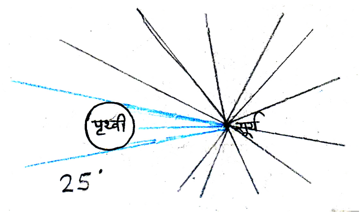
(d) A group of tribal boys drew rays which did not meet at the given single point. Notice the coloured rays all over



(e) A group of rural girls refused to treat the sun as a single point



(f) Correct response by a group of tribal boys



(g) Correct response by a group of rural boys

Figure 4.26: Responses to Questionnaire 2: Drawing rays from the sun at increasingly larger distances to notice almost parallel nature of rays near the earth

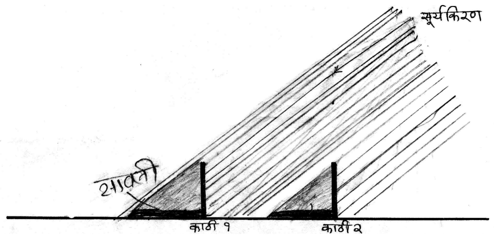
Questionnaire 3: Shadows cast by parallel rays of light at different inclinations to the ground or earth

Questionnaire 3 consisted of 3 problem tasks. In each situation, a sun-ray (direction of light) and two sticks inserted in the ground were shown. In the first situation, the ground was horizontal, in second, tilted, and in third, the sticks were at two different positions on the round earth. Students were expected to draw parallel rays in the direction of given ray and consequently locate the shadows of the two sticks in each situation.

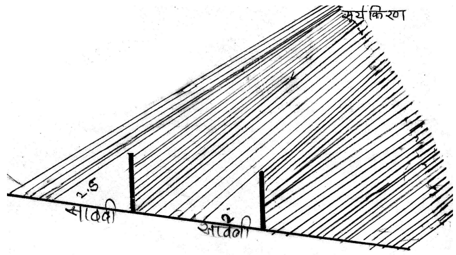
The following hunts were given in the class:
Hint 3.1: Are your sun rays parallel?
Hint 3.2: Extend the rays to find out the shadow.
Hint 3.3: The line at the bottom is the ground.

Conceptual mistakes:
1. Difficulty in applying parallel ray approximation: Seven out of 15 groups drew divergent rays and then corrected them to parallel after the hint (Figure 4.27a).
Nine groups drew approximately parallel rays (Figure 4.27b). Most groups did not know the technique of drawing parallel lines efficiently. Only one of the girls' group drew parallel rays very neatly marking two sets of collinear equidistant points on two sides and joining them.
2. Problem in constructing ray diagrams: Even when students successfully drew parallel rays, their understanding of the geometry of ray diagrams appeared to be inadequate. One group drew rays which were parallel to each other but not to the given ray and one group drew a set of parallel lines for one stick and another set of parallel lines (which are not parallel to first set) for another stick.
One group drew rays which were not continued up to the ground and hence the shadow was not drawn. In another group, rays (not the ones which were defining the length of the shadow) were bent so as to touch ground. For another groups, the rays were parallel, but were discontinuous (since they drew two sets of parallel rays joint to each other). Five groups did not show arrowheads to the rays.
3. Problems in drawing inferences from ray diagrams: Because rays were not exactly parallel, the length of the shadow on the ground was not the same for two of the groups. One of the groups who finished their task faster still did not notice that the shadow on inclined plane was longer (for the given problem) than that on the

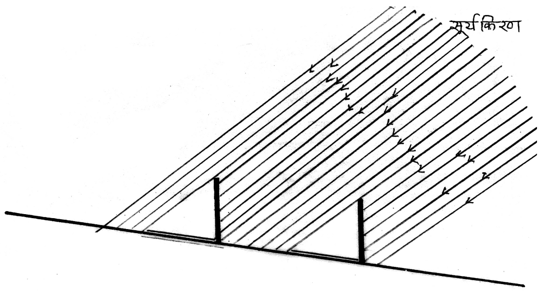
horizontal plane. One of the students thought that the shadow of stick that was 'farther away from the sun' would be longer than that of the stick 'closer to' the sun. He was quite sure about this so I asked him to check it by measuring the length of the shadow.



(a) Many groups first drew divergent rays and after instruction corrected to parallel rays (e.g. a group of rural boys)



(b) Approximately parallel rays by a group of rural girls



(c) A correct response by a group of rural girls

Figure 4.27: Responses to Questionnaire 3: Drawing rays and shadows

In comparison to the pre-test performance of these students there were several points to be appreciated about their diagrams:

The ambiguous shadows seen in the pre-test (see Chapter 6) were replaced by, shadows using ray diagrams. Five rural groups (in 13 diagrams) and 1 tribal group (in 3 diagrams) drew the shadow in the conventional way taught to them (line on the ground). This procedure however was found to be difficult by some students (especially from the tribal school). Hence in the classroom teaching they had been told to shade the entire part where the rays were not reaching. Consequently, perhaps, 5 tribal groups (in 15 diagrams) and 3 rural groups (in 9 diagrams) shaded the entire shadow region on the far side of the stick. Although this level of detail is not necessary (and hence, never used in textbooks), it may be indicative of good conceptual understanding. Further none of the groups drew a tilted line in air as they had done the pre-tests. One group in all three situations, drew only the essential rays which define the shadow and 3 rural and 1 tribal groups drew mature diagrams for all three situations. One group measured the lengths of the two shadows and showed them be same in the first situation.

Questionnaire 4: Drawing angle of elevation of a point or parallel ray source at different inclinations to the ground or the earth

Questionnaire 4 consisted of 4 problem situations. In the first situation, two cartoon kids Bimm and Kimm were standing on the ground, Bimm's shadow was shown, and Kimm's shadow had to be drawn. To do this, students had to find the direction of incident rays by joining the tip of shadow's head to the head of the Bimm and by drawing parallel rays to this ray, they can draw shadow of Kimm.

In the second question, the same two kids on the same distance were shown, but instead of shadow in the sunlight, a lamp on a lamp-post was shown. Students were asked to draw shadows of both the kids due to light from the lamp. These two questions together will show the difference between the sun light and the light on the lamp.

In third question, an incident ray towards Kimm was shown from the star Sirius at an angle 40° above the horizon. Students were asked to find, at what angle would Bimm see the same star? They were expected to realize that the rays from Sirius would also be parallel, as it is farther away from than the sun.

In the last question, Bimm and Kimm were at two places far apart on the earth. Kimm sees the Sirius at 50° above the horizon. Students were asked to find at which position (direction and angle) Bimm would see the Sirius. Students were expected to draw the horizon for both the kids, and find the direction of rays from Sirius to the earth by measuring 40° with respect to Kimm's horizon, then draw parallel rays and find the angle between these rays and Bimm's horizon. They were also expected to find the local directions for both the kids and specify the direction in which both kids see the star. The diagram was such that Kimm would see the star on his East, whereas Bimm would see it on his West.

The following instructions were written on the blackboard.
Hint 4.1: Measure the angle from level of the ground because the kid's height is very small.
Hint 4.2: Draw the line of horizon for 4^{th} *problem situation.*
Hint 4.3: Rays coming from distant light source are parallel.

Conceptual problems:
1. Problems with constructing ray diagrams: In the first situation, the head of Bimm needed to be joined with the shadow of his head to find the direction of the incident rays. Four out of 15 groups failed to this and hence the direction of incident ray was not correctly found (Figure 4.28a). Consequently, the shadow of Kimm was also incorrect.
Out of remaining 11 groups, six found the correct direction of incident rays, and drew a set of parallel rays near Bimm, however they drew another set of parallel rays from a different direction near Kimm (Figure 4.28b) or rays which were not parallel to the rays near Bimm.
Two groups first drew divergent rays and then corrected them to parallel rays.
In spite of instructions and corrections, the rays were not exactly parallel in case of 7 groups. While drawing the rays from the stars to measure angle of elevation of a star, students needed to draw rays up to the ground so as to measure the angle. However three groups drew rays which hit the head (or eye) of the person, instead of the ground.
In case of 1 group, some rays did not reach the ground.
Seven groups did not draw arrow-heads so as to specify the direction of rays at least in one problem situation. While determining the elevation of a star, one group drew arrowheads in the opposite direction.
One student who was usually quick in understanding, nonetheless drew some rays from a star (Sirius) which were not parallel. One (perhaps two) student in a group still did not know the meaning of 'parallel'. They measured the length of lines instead. Most probably this problem did not persist later.
Five groups drew too many rays. When I told them that draw fewer rays and try to understand which ones are important to determine the shadow. In 7 responses,

only the essential (or minimal number of) rays were drawn which shows that some students learnt this, though it is not clear whether all students in these groups understood it.

2. Problems in drawing inferences from ray diagrams: Six groups did not draw the ray which defines the length of shadow (Figure 4.28c). Two groups did draw the defining rays, but their shadow was shorter than that indicated by the rays (Figure 4.28d). These groups did not see a shadow as a consequence of absence of light-rays. Two groups did not draw the shadow.

3. Mistakes in measurement: Four group made mistakes in measuring angles. One group did not measure the angle in one of the questions.

In two groups, despite the ray diagrams being correct, the length of the shadow of the two sticks (for Questions 1 or 2) or angle at which star is seen (Question 3) were not the same.

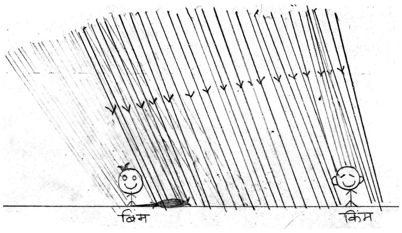
In the last situation, the position of the star was to be specified. Although the direction was not explicitly asked, it was important to specify it, since the measures of the angles were almost the same, but the direction was opposite, for the two persons at two different locations on the earth. Only one group specified the direction in which the star will be seen. However, 14 out of 15 groups drew the line of horizon to measure the angle.

Measuring angle at the level of the horizon was not a problem. The reason for measuring the angle from the level of ground was not discussed in class because of lack of time, but all the students did it correctly, as shown in the diagram, even before writing Hint no. 4.1 on the board. Nine groups drew shadows in the conventional way as a line on the ground and only 1 group shaded it.

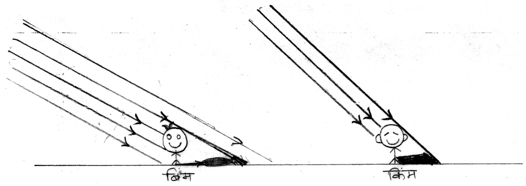
Session 3: Rotating Earth (Section B.3)

Correlating global cues with local directions and angles of elevations; time differences.

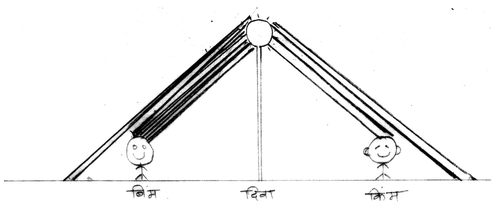
Questionnaires 5 to 8: Local time at different locations of the earth, position of celestial bodies at each of these positions and changes in the positions of celestial bodies as a result of rotation of the earth



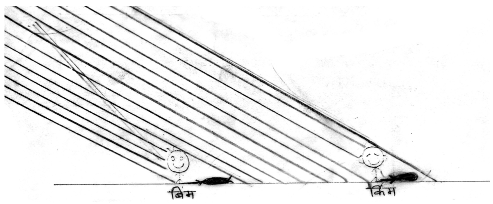
(a) Response by a group of rural girls. The head of Bimm was not joined with the shadow of his head



(b) A group of rural girls drew two sets of parallel rays from two different directions, one for Bimm and another for Kimm



(c) A group of rural girls did not draw the ray which determines the length of shadow



(d) A group of tribal boys drew a shadow that was shorter than that indicated by the rays

Figure 4.28: Responses to Questionnaire 4: Drawing parallel rays and shadows

Questionnaire 5 to 8 presented a series of logically connected situations, hence they were given sequentially in a single lesson. In all these questionnaires, students were given a diagram of the earth as seen from above the North ole and the direction of sun-rays. The direction of sun-rays was kept the same in all questionnaires.

Questionnaire 5: Determining local directions at a point on the equator, given the global direction of the sun

Students were asked to draw a girl called 'Rinku' in the given diagram, for whom it is exact noon. Then they were asked to draw the line of horizon and determine the directions (East, Wast) for Rinku, using the following hint:

Hint 5.1: To determine the directions for Rinku use the direction of rotation of the earth (earth rotates from West to East).

Questionnaire 6: Determining local directions at a diametrically opposite point on the equator and locating stars at given angles of elevation from this point

Students were asked to draw a girl called 'Sonu' for whom it is midnight. Then they were told that Sonu sees the star *Magha* overhead. They were asked to draw the light rays from *Magha*. At this point they were reminded by a written hint in the questionnaire that rays coming from any star are parallel. Then they were asked to draw rays from the star '*Rohini*' which is seen at an angle 20° to the West to Sonu. At the end, they were asked to draw rays from the star '*Swati*' which is seen at 45° to the East from the place where Sonu is standing. Here after drawing Sonu, students needed to draw line of horizon as a reference line to measure the angle and determine the directions (East, West).

Hint 6.1: Measure the angle of the star from the ground.
Hint 6.2: Do not draw the star, only draw rays (is the star so close?)
Hint 6.3: Are the rays parallel? (stars are farther than the Sun).

Questionnaire 7: Determining local directions at three different points on the equator and locating stars at given angles of elevation from these point; time zone differences

Students were asked to draw a boy called 'Mithu' at such a place that the evening sun is just setting. Students were asked to predict where Mithu would see the stars in that were seen by Sonu in Questionnaire 6. To determine the direction of rays coming from the stars, students first needed to draw the horizon and directions for Mithu. Then they needed to draw the diagram for Questionnaire 6 (i.e. Sonu, her horizon and parallel rays coming from all three stars), continue drawing parallel rays till they hit Mithu's horizon, then measure the angle of elevation of these rays from Mithu's horizon and spell out the direction and angle for each star. They were told, if you think that the star cannot be seen, you may write so.

Hint 7.1: East and west of Mithu- Which way is the earth rotating? Is the sun setting?
Hint 7.2: Draw stars according to Rinku and decide their directions for Mithu.

Questionnaire 8: Same as Questionnaire 7 above, six hours later

Students were asked to draw positions of Rinku, Sonu and Mithu 6 hours after the situation in Questionnaire 7 and then determine the apparent positions of stars with respect to Sonu (who could not see any star in Questionnaires 5 and 6, because it was noon for her.)

From the classroom logs, one of the major difficulty for students was determining directions. Although students were taught three dimensions and their relations with directions, which they seemed to have understood, drawing directions on paper was still a problem (Figure 4.29a). Some of the students did not understand that two of the directions will be out of the plane of paper, although most of them could correctly find the directions on the globe.

While drawing rays from the star (*Rohini*, 20° and *Swati* 45°) to Sonu's horizon, which was a vertical line in the diagram, only a few students had problem in drawing an angle the of given measure. Those who drew wrongly, did not join the line from their mark to mid point. That means they can measure angle. But although they had learnt about 'corresponding angles' in geometry, and had also revised it in the class, most of them found it hard to understand that if a ray makes an angle of 20° to the horizon, all rays parallel to that ray will make same angle. However out of 13 groups 4 did this correctly (Figure 4.29c). Drawing parallel rays was happily not a problem for them by now.

The procedure for the Questionnaires 7 and 8 involved several steps and though students were explicitly guided through the steps, difficulties remained. Students drew a different set of stars for each observer such that the stars would look at the same place to Mithu as Rinku sees them. This may be interpreted to mean that students thought that the stars also revolve with the earth. But more probably, their difficulty lay in taking the new observer's perspective, keeping few parts of the environment constant. So students were given a local example of a pillar. If I see the pillar at 45 on my West, VK (one of the students in the class) who was standing in front of me, will not see it at the same position as me. She might see it at 30° to her right. So the apparent position of a static object will be different when viewed from different locations.

The mistakes/ difficulties while solving Questionnaires 5-8 are as follows:
1. Position of a person and drawing of horizon: In 6 cases the person (Sonu, Rinku, or Mithu) was drawn at the wrong position then erased and corrected. In one case, the person was not drawn at all. The horizon was not drawn in two cases (for either

Sonu, Rinku or Mithu; Figure 4.29d). In 4 cases the horizon intersected the earth instead of being tangential. In seven cases, it was inaccurately drawn (the angle between horizon and radius at that point was not 90°; Figure 4.29e), which led to incorrect angle of elevation of the star. In one case, a horizontal line was drawn independent of the diagram as an absolute horizon and then erased.

2. Determining directions: Students needed to determine East-West directions for each person to predict where a particular star would be seen. Only one direction out of East and West was sufficient. In 7 cases directions were not determined and in 2 cases, absolute East-West directions (East to the right side and West to the left side of the paper) were shown and then erased. In two cases, the directions were determined incorrectly, but in one case they were corrected. A point to be appreciated is that in 6 cases, Up and Down directions were specified, even though not asked (Figures 4.29a & 4.29b).

3. Rays from the stars: In 6 cases, the rays from a star were drawn divergent (Figure 4.29f), but in 4 of these cases, they were corrected to parallel rays afterwards. In 4 cases, students meant to draw parallel rays, but they were not parallel, which led to incorrect measure of angle of elevation of a star. In 12 cases rays were drawn in incorrect or arbitrary directions (Figures 4.29g &4.29e); in 5 of these cases they were corrected. In 4 cases rays did not reach the horizon which made it difficult to know whether students have really measured the angle. In 3 cases, rays were not drawn at all. Arrow-heads were not shown in 11 cases.

4. Predicting positions of stars: In altogether 18 cases, the direction was correctly specified, but in 11 cases, the angle of elevation of a star was not specified and in 7 cases, the angle was incorrect. In altogether 13 cases, direction was not specified and the angles were: 6 correct, 6 incorrect and 1 not specified. In 2 cases, rays from stars were at 20° & 45° for all three persons (Rinku, Sonu, Mithu) or for any of the two of them.

5. Time and durations: Four groups incorrectly predicted the duration after which Mithu and Sonu would see the sky same as Rinku (last question in Questionnaire 7). Two groups did not respond to these questions. Two groups incorrectly answered the time for Mithu (Questionnaire 8).

Questionnaire 7 took a long time. Students took time to register the changes in position of stars due to change in inclination of the horizon. After telling them that positions of stars will change, they tried to give answers by guesswork. The procedure had to be repeatedly told, draw stars for Sonu first and then draw parallel lines to rays from those stars, and then find the angle for Mithu. For questionnaire 8, though the procedure was almost the same, all the instructions had to be repeated. On the whole, students enjoyed the teaching but did not like solving the questionnaires. We think the problem is not perhaps with the content, but with their ingrained learning habits, and the dominant examination pattern. Students are not familiar with problem solving and do not see it as a challenging and enjoyable activity. They treat the questionnaire as an exam which they want to finish as soon as possible, no matter even if it is solved wrongly. Students' self-reports also reflected their negative view of these particular set of questionnaires.

Session 4: Star-month (Section B.4)

Observed night sky 'Nakshatra' and indigenous calendar (Indigenous calendar and observational astronomy)

Questionnaire 9: Relation between the visible sky at a given point on the earth's orbit and the *Nakshatra* (star group) and month named in the indigenous calendar

A skeletal diagram of the earth's orbit as viewed from above the North Pole was given in the diagram with the background of stars. Some *Nakshatras* and some known bright stars formed the background of a total of 8 stars (or star groups). The position of the earth in its orbit was shown and students were asked to guess the perspective of the given picture, which stars will be seen at night, whether at any time of the day a person on the earth be able to see the stars on the other side of the sun, and which Marathi month and *Nakshatra* is going on. Students were not asked to make any addition to the diagram, but mental simulation of the earth's rotation was required for answering the question about stars visible from the earth at night. These questionnaire tested students' understanding of the correspondence between the indigenous calendar and the night sky.

Students solved this questionnaire very quickly and the responses were mostly error free, perhaps because they did not have to draw anything to arrive at the so-

lution (drawing is quite time consuming for students). There were however some inaccuracies in their responses. One minor error was, when asked the perspective of the given picture, all the students except one responded ‘Top view’. Words such as ‘Top’ / ‘Side’ do not have any meaning in space and we had scrupulously avoided such terms during the teaching. A better response would have been ‘if it is seen from above the North Pole’. This may have been just careless terminology. One rural group responded ‘West’.
In response to the question: “which stars will a person on the earth see at night?”, most students spontaniously responded on the basis of the snapshot-diagram presented in the questionnaire. They did not mentally simulate the rotation of the earth.

Session 5: Seasons (Section B.5)

Day-night and North-South elevations of the sun during solstices and equinoxes (explanation of occurrence of seasons)

The two solstice positions were dealt in Questionnaire 10 and the equinox position and some common misconceptions regarding seasons were dealt in Questionnaire 11.

Questionnaire 10: Day-night at the poles and elevation of the sun at the equator during the summer and winter solstices
In both the situations in Questionnaire 10, students were given a skeletal diagram of the earth and its orbit as seen from the plane of the ecliptic. The sun-rays were parallel to the line of orbit (plane of ecliptic), but the direction of rays in the second diagram was opposite to the direction of rays in the first diagram. Students were asked to draw the axis of rotation of the earth making an angle of 66.5° with the ecliptic, and the equator, making an angle of 90° with the axis. They were asked to label the poles and the hemispheres. Then they were asked to show day-night on the earth and colour the parts which will be always in light and those always in the dark (Polar regions). Finally they had to draw a person on the equator and answer few questions related to relative heating of the two hemispheres, considering the fact

that the sun is overhead in one of the hemispheres, so intensity of light and hence heating is more in that hemisphere than in the other.

Although observations related to seasons and their explanation were discussed in the class using a model (Subsection 4.3.2), the corresponding diagram had not been drawn in the classroom. Students, especially in tribal group, got very confused while solving the questionnaire. One group had a problem in drawing the axis and a couple of groups had a problem in determining day and night. One group extended only the given rays and showed day on less that half of the earth and night on the remaining part. All the groups kept confusing the day-night line (terminator) with the axis line. Students were not able to understand which view was depicted in the diagram. So when I asked where would a certain part of the earth come after some time, some students showed another point on the perimeter as if it was a top view and the axis was at the mid point. After seeing the chaos in the classroom, I drew the diagram on board parallely with the students, guiding them through the solution. The following hints were provided while students were solving the questionnaires:
Hint 10.1: Check the axis-ecliptic angle.
Hint 10.2: Extend the rays to decide day night.
Hint 10.3: Remember the earth is spherical, not flat.
Hint 10.4: Rotate the spherical earth in mind to determine the parts which will be in light or in darkness for all 24 hours.
Hint 10.5: (Question 2): Complete the second diagram, do not change the direction of the axis; it is in the direction of the Pole Star.
Hint 10.6: Are the answers of the first and second question the same? What is the difference?
Hint 10.7: What are the seasons in India in each of the diagrams?

The following confusions were noted down at the time of collaborative problem solving:
1. Although students extended the parallel sun-rays given in the diagram, the sun-rays tangential to the earth which define day-night were not drawn in 5 out of 30 diagrams (Figures 4.30b & 4.30c).
Out of 30 diagrams, the angle of inclination of the axis was incorrect in 7 and the equator was incorrectly inclined in 4 diagrams; either because of a mistake in angle

measurement or because the axis was drawn by guesswork without measuring the angle. In 11 diagrams, the equator was extended outside the earth.

In 2 out of 30 diagrams, the orientation of the human being to be drawn on the equator was incorrect.

2. Confusion between line of axis and line of day-night separation (Figure 4.30b). Students were told to draw line of axis longer than the diameter, to draw a curved arrow near the axis to show direction of rotation and name all the parts (axis, day, night) to avoid confusion. Some students still considered line of axis of rotation same as line of day night (Figure 4.30b). In 5 (out of 30) diagrams, the line of day-night was extended outside the perimeter of the earth similar to the line of axis of rotation. In 3 diagrams (out of 30) the direction of rotation was not shown near the axis of rotation.

3. Although students drew lines parallel to the equator which would show which part will go at which place after 12 hours, students found it difficult to determine which part will be in darkness throughout the day or throughout the night. In total 10 out of 30 diagrams, these parts were not coloured symmetrically (Figure 4.30d), some of these were coloured only on either side of the axis. Another mistake in the colouring occurred when students did not understand exactly how much part will be either in light or in darkness. In 15 diagrams only the upward or downward curves were coloured (Figure 4.30c)and in 4 diagrams, complete cones were coloured (Figure 4.30e). (Some of the tribal students did not understand the mode of motion of the earth, they though it as if the pole is at the centre and circumference as equator). These difficulties were related to comprehending the motion represented in diagram and simulating the mental model according to specified motion.

Questionnaire 11: Day-night on earth and North-South elevations of the sun in the two hemispheres at the time of equinox

In Questionnaire 11, the earth was shown in the orbit as seen from the plane of the ecliptic and the sun was supposed to be outside the plane of paper, exactly in 'front' of the earth. Students were not asked to add anything in the diagram, but they were asked questions similar to those in Questionnaire 10. Although Questionnaire 11 was similar to Questionnaire 10, it was bit difficult to imagine spatially, because the sun was out of the plane of the paper.

The following hints were given:
Hint 11.1: Show the direction of rotation of earth (diagram was drawn on board).
Hint 11.2: Label North Pole, South Pole, Axis, equator, Northern hemisphere, Southern hemisphere, Day, Night.

Students faced the following problems while solving Questionnaire 11:
1. Rural students guessed correctly where the sun wold be in Questionnaire 11, but they were not sure. So almost all the groups confirmed it with the teacher. Some of them were hesitant to say that there will not be any blue colour. This shows the habit of answering only stereotypical questions.
2. Even after drawing correct answers to first few questions in Questionnaire 11, a few students answered conclusive questions wrongly. They were hesitant to say that there is neither winter nor summer anywhere at the time of the equinox. This might mean that students are not able to exploit limiting case analysis. They could not anticipate that there will be a neutral position between the transition from winter to summer and vice versa.

The following mistakes occurred while solving Questionnaires 10 and 11:
1. In a total of 13 cases, the rays which define the terminator were not drawn.

In the fourth question, students were given six statements to judge as true or false. The data for this question for one of the groups is not available, so the number of groups who attempted these question is recorded as 14. Remarkably and unfortunately, after solving a questionnaires which addressed the occurrence of seasons, 7 out of 14 of the groups stated that seasons occur due to change in distance between the earth and the sun. Four groups (not necessarily same) did not agree that in December, it is winter in the Northern hemisphere, same number of groups thought that it never gets dark on some parts on the earth, and could not identify that the inclination of the axis in the given diagram had changed, which was an error. Three groups did not agree that it is winter in the Southern hemisphere when it is summer in the Northern hemisphere. None of the groups made a mistake in judging two of the statements: ‘Polar region are lit for six months and dark for the remaining six months. (True)’ and ‘In the polar regions, the earth takes more then 24 hours to move around itself’ (False).

4.4 Pedagogic sequence Part III: The sun-earth-moon system

Part III of the intervention consisted of about 10 sessions of teaching followed by 6 sessions for administration of 5 post-tests and post intervention interviews. The sequence of concrete models, gestures-actions and diagrams in Part III is given in Table 4.5. The first two sessions were devoted to solving Homework sets 4 and 5 and revision (explained in Section 4.5). The first activity in Table 4.5 was in continuation of Homework set 4, in which students pointed and traced the acute, obtuse and right angles in the room (CM19, G32). Homework 6 addressed some facts about the moon (that is a satellite of the earth, its dimensions, etc.) and by solving it in the class, these facts were recalled and some common misconceptions (such as, there is a deer on the moon or the moon is made of silver) were refuted. All the activities thereafter were related to the sun-earth-moon system and explanations of phenomena related to the moon.

Table 4.5: Pedagogic sequence for Part III: The sun-earth-moon system

Context or Concept	**CM: Concrete Model/ *Teaching aid*** **G: Gestures and actions** **D: Diagram/ *Visual representation on paper*** XX: Category absent
Angle	**CM19**. Objects in the room **G32**. Pointing and tracing acute, right and obtuse angles in room, finding out parallel lines. XX

We see only one face of the moon	**CM20**. The earth-moon system **G33**. Only rotation, Only revolution, Both rotation and revolution together. **D31**. *Photograph of the moon and the earth-moon system* **D32b**. Earth from above North Pole (D9b) + moon + orbit of the moon + explanatory elements (Figure 4.31)
Observable phases (calendar)	XX XX **D33**. *Photographs of the full, gibbous, half and crescent moon* **D34**. Observable phases (Figure 4.32)
Phases of moon and eclipses	**CM21**. A ball mounted on a long stick and a strong light source **G34**. Rotating the ball around one's head in tilted orbit, with a strong light source on one side. **D35**. Explanatory diagram for phases ((D32b) + parallel sun-rays + explanatory elements) (Figure 4.33)
Phases of moon	XX **G35**. Replace the ball by friend and watch friend's face. XX
Tilt in the moons orbit explains why there are no eclipses on all full and new moon nights	**CM22**. A ring or a cycle wheel, *Ball* **G36**. Showing tilt of moon's orbit by moving extended arm around (with or without ball in the hand). **D36a**. Sun-earth system as seen from the plane of equator (D23a) + Moon's orbit making angle of 5° to ecliptic. (palm gesture to indicate that the orbit could be tilted in any plane; not necessarily in the plane perpendicular to the board) (Figure 4.34)
Phases of moon and eclipses	XX **G37**. Moving around a friend considering one's head as the moon and the friend's head as the earth, simulating tilt of orbit to ecliptic. **D37a, b**. Lunar(a) and solar(b) eclipses by parallel rays (Figure 4.35), **D38**. *Photograph of the earth at the time of Solar eclipse*
The sun-earth-moon system	XX **G38**. Moon moving around the earth while earth moving around the sun **D36b**. D23b + orbit of the moon (Figure 4.34)

Moon takes 2 extra days to complete the orbit with respect to the sun than with respect to the background sky	XX **G39**. Moon moves around the earth while the earth moves forwards (considering the earth's orbit to be almost straight and the sun to be very far away). **D39**. *D32b + earth forwarded by 30° by the time the moon completes one revolution*
Connection between apparent motion of the moon and indigenous months and *Nakshatras* (Calendar)	XX **G40**. Moon moving around the earth against the background of stars behind (Arrangement similar to G29). **D40**. D32b + background stars

After solving the homework sets in the classroom students were given a questionnaire to solve in groups. This questionnaire was based on the content taught in Part I and II and mainly served as revision (See Appendix B.6).

The students were shown photographs of the moon and the earth-moon system which they could instantly identify. To recall the basic facts about the moon an information chart was pasted in the classroom (Appendix E). A ball was attached to the stand of the globe to prepare a model of earth-moon system (CM20); the ratio of sizes of the earth to the moon were roughly preserved, although the earth-moon distance was not true to scale. Students were shown this model and asked to identify differences between this model and the real system. Students came up with several differences, similar to those listed in the case of the model of the sun-earth system (Subsection 4.3.2).

The revolution of the moon around the earth was shown to the students using this model. In the beginning the students mimicked the basic model of the earth-moon system, i.e., rotation and revolution of the moon around the earth. This action also explains why we see only one face of the moon, and demonstrates the falseness of the common belief that a particular half of the moon is always in darkness (G33). Although a similar gesture had been carried out in Part II of the intervention to explain simultaneous rotational and orbital motion of the earth (G22) this apparently simple motion turned out to be a tricky one for students to perform. At first when asked to perform it students would only do the revolution. So they were asked to first only rotate, in which they noticed that their field of view should change during rotation. Then they were asked to only revolve, in which case, they found that the field of view does not change. Next they performed the two motions in portions of 90°, in which their body rotated by 90° when they completed a quarter of the revolution, so that their one side (conveniently, the face) remained always towards the earth. The gesture was followed by an explanatory diagram (D32b; Figure 4.31). Note that D32b is meaningful only if accompanied by explanatory dialog, which is more or less true for many other explanatory diagrams.

Next we addressed phases of the moon, the most prominent phenomenon in the night sky. Students had been asked to keep a record of observations of the moon for a single night and of phases of the moon for one month, in the charts provided to them (Appendix C). Most students failed to keep regular notes, but because of their general observations and those during the intervention, they were aware that the shape of the moon remains the same overnight and they knew about the periodic changes in shape of the moon. After showing them photographs of the full, gibbous, half and crescent moons (D33), students were asked to read aloud the Marathi names of the phases (*tithi*) from the calendar. The shape of the moon was drawn on the blackboard on each *tithi* and the pattern of phases and its time period was clarified (D34; Figure 4.32). Information was given about the indigenous calendar such as, Marathi months are named after the *Nakshatra* in which the full moon is found, and days are counted according to phases of the moon (*tithi*) (See Appendix G.2).

To observe phases of the moon, students were asked to move a ball attached to a long stick around them against a bright source of the light (CM21, G34). If the light source is in the plane of orbit, one observes lunar and solar eclipses instead of a new and full moon. Then students were told that the orbit was slightly tilted so that they were able to observe the new and the full moon. The explanatory diagram of the phases of the moon was constructed on the blackboard with the help of students (D35; Figure 4.33). We insisted that students should draw the rays to determine the terminator for the moon and the earth to understand that half of the moon (and the earth) is always lit, and the terminator is always perpendicular to the sun-rays, and hence it remains parallel to itself in all positions of the moon. Students were told that half of the moon will be seen from the earth, and were asked to draw the shape at each position. They were also asked to predict the time at which the moon will rise and set in each phase.

In the action for visualizing the phases of the moon, the face of the student acting as the moon denoted the lit part and the hair denoted the dark part of the moon. Thus in this action the student acting as the moon always faced the direction of sun rays (G35). The student who was the earth observed how much of the moon's face (i.e. its lit part) was visible. Although this action is at variance with the correct motion (as explained in G33), it was useful to 'see' the phases in terms of the quarter, half and three fourths of the face. G35 had an advantage over G34 (where the moon was played by a lit ball), since the outline of a face is clearer to see than the line of illumination on a ball, the latter being not very sharp in the diffuse light of a room.

Students were told that the moon's orbit makes an angle of 5° with the ecliptic while carrying out G34. The tilted orbit oriented in different directions with respect to the sun-earth line was shown by orienting a large ring (or a cycle wheel, CM22) in different ways. Students were asked to show the tilt of orbit in different orientation by moving an extended arm around (with or without a ball in the hand) to configure and distinguish the situations at the time of lunar and solar eclipse and full and new moon (G36). The angle between the orbit of the moon and the ecliptic was shown in the diagram of the sun-earth-moon system as seen from within the ecliptic (D36a; Figure 4.34).

To explain the eclipses of the moon and the sun, and the phases of the moon, together, an additional feature was added to G33: instead of revolving in the horizontal plane, the moon lowered and raised her head appropriately to take account of the tilt in her orbit (G37). In this motion the earth was able to see, instead of a lunar and solar eclipse respectively, the full moon (fully lit face of a friend) and the new moon (fully dark face of the friend, on the same side as the light). In this motion the tilt of the moon's orbit could be conveyed, from the viewpoint of the earth, and of the moon. Students then repeated this gesture to enact the orientation of the orbit at the time of the lunar and solar eclipses. The eclipse situations were drawn on the blackboard (D37; Figure 4.35) and the photograph of the earth during the solar eclipse was shown (D38).

The model of the sun-earth-moon system was enacted (G38) to communicate simultaneous motions of the earth and the moon which further led to G39. The sun was stationary. The earth rotated 7 times and moved forward slightly in her orbit while the moon completed a quarter of its revolution and rotation. The diagram of the sun-earth-moon system was drawn from two orthogonal perspectives (above the North Pole and within the ecliptic) (D36b; Figure 4.34).

The next, more difficult, step was to explain why the synodic month is longer than the sidereal month (G39). The moon completes one revolution around the earth in 27 days against the background stars (due to which in the Indian calendars the sky is divided into 27 *Nakshatras*, star-patterns in the lunar path sometimes called 'lunar mansions'), yet the phase cycle (revolution according to the sun, due to which a month in the Indian calendar is of roughly 30 days) is of 29.5 days. Conveying this idea to students only through a diagram is difficult because of the two simultaneous and interrelated motions that need to be shown. The student acting as the earth, which was stationary in the previous three gestures, now has to move slowly, to take account of her revolution around the sun. Suppose we start our observation on the full moon night when the angle between the sun, earth and the moon is 180° and the moon is seen in *Ashwini Nakshatra* against the background of stars (the role of the background stars is played by some fixtures in the wall). The moon comes back to its original position with respect to this star-background, that is in the *Ashwini Nakshatra*, in around 27 days. But by that time the earth has moved forward a little, and the moon has to catch up with the earth by covering some extra distance to arrive at the position of full moon, that is, to again subtend the sun-earth-moon angle of 180°. The tilt of the orbit was not important to understand the observation that the duration of the phase cycle is more than the time required for the moon to come back to its original position with respect to the background stars.

Thus each gesture (G33, G35, G37 & G39) conveyed a specific aspect of the complex motion of the moon against the sun-earth system (analyzed in Subsection 5.2.1). The diagram to represent the simultaneous motion of the earth and the moon and the effective path of the moon was was not drawn in the classroom, but space to draw the diagram was provided for the related question in the Post-test-5. Students did try to represent their explanation through a diagram, and hence the diagram is numbered (D39; Figure 7.22) in Table 4.5.

Finally, students were asked to study the calendar to understand the connection between the apparent motion of the moon and the indigenous months and *Nakshatras*. Students saw that the moon changes its *Nakshatra* each day. They were told that there were 27 *Nakshtras* because the moon takes 27 days to complete one revolution. The motion of the moon around the earth was acted out with students standing in a circle each representing one *Nakshatra*, and they predicted which Solar and Lunar *Nakshatra* and Marathi month was going on. The corresponding diagram was drawn on the board (D40). This last part however was dealt with in a rush due to lack of time.

4.5 Homework

Daily homework during the intervention

During Part II and III of the intervention students were given a daily 1 page homework sets which included spatial tasks such as paper folding, mental rotation, etc.. The spatial tasks were not directly related to astronomy, but we hoped that these exercises would help students practice their spatial abilities for use in the classroom situations. The original tasks and their translations are provided in Appendix D. Most of the students solved this homework regularly and insisted on getting the home-work sheet if they had missed a class on the previous day, which indicates that students enjoyed solving this homework.

Homework between two parts

A total of 6 homework sets were provided in the period between two parts of the intervention (Appendix C). Homework sets 1, 2 and 3 were given in the gap of 5 months between Part I and Part II of the intervention. It was found in the first part of the intervention that students' understanding of the world map was inadequate, so whenever a place, country or a continent was named, for example, if it is noon in India, what time it will be at North America? they could not quickly imagine the position of North America in relation to India on the globe. Homework set 1 addressed students' unfamiliarity with the world map and also revised the content taught in the first part. It dealt with the earth, equator, tropics, poles, their positions in the map of the world and the name of countries in which they lie, directions, axis of rotation, explanation of apparent motion of the stars due to rotation of the earth, shadow of a pillar due to light sources at different position, and some general information about the observable night sky.

The second homework set was given to refresh concepts in geometry which were necessary to learn elementary astronomy. It included problems on the concepts which they had already learnt but were not proficient with, such as, parallel lines, angles, circle and its properties such as radius, diameter, perimeter etc., and concepts which they had learnt in Part 1 such as axis of rotation and dimensions of space.

The third homework set dealt with measurement. It was seen in Part I of the intervention that many students were not familiar with units of measurement of length, which added to the difficulty of conveying the vastness of astronomical distances. The minimum distance in elementary astronomy that we refer to is the radius of the earth, which is taken on an average to be 6400 Km. Students had no idea how much a kilometer is, so we gave a homework set on units of length, area and volume, which also helped reemphasize the concept of 1, 2 and 3 dimensions. The problems began with small numbers and then went on to address the perimeter, volume and the mass of the earth.

In astronomy, ratios play an important role in comprehending distances and other quantities. When the quantities are too large (or too small) it is often easier to think in terms of multiples of a known quantity. Powers of 10 make numbers especially easy to handle. Students from Grade 8 were found to be neither proficient with handling powers of 10, nor with calculating ratios of large numbers. So three problems on calculating ratios were given at the end of Homework set 3 which however very few students could solve. Recall that Part II of the intervention included an activity of plotting the distances in the inner solar system (G27).

Homework set 4 included geometrical problems on some concepts which were required for understanding of astronomy, such as, parallel lines, angles and geometry of a circle. Students were also asked to orally solve arithmetical problems (on multiplication, division and powers of 10), to prepare them to calculate ratios of the sizes and distances in the solar system.

Homework set 5 was based on astronomical content taught in Part II, mainly on the shape of the earth, its orbit and its representation from different perspectives. There were questions on local time, and on the parallel ray approximation.

Students were given a table to note their observations about the moon over a single night. They were asked whether the position, shape and the colour of the moon changes overnight and, if yes, what were the changes etc. that they observed. Then they were asked to find some facts about moon from their textbook such as, dimensions, distances their rations of the sun, earth and the moon. Students were also asked to answer whether the moon rises and sets at the same time every day by studying the calendar. They were asked to judge whether the given statements were true or false which contained some common alternative conceptions and statements about the moon.

The homework sets included considerable visual (diagrammatic) content. Students were either asked to draw the diagrams or answered questions based on a given diagram. The homework sets are provided in their original form in Appendix C). Although the gap between the parts of the intervention was long, many students completed the homework sets, which were evaluated before the next part of the intervention and the results used in planning of the classroom sessions to come.

4.6 Prerequisites

Understanding of models in elementary astronomy builds upon some basic knowledge of concepts, facts and procedures from science, mathematics and geography. These prerequisites, which were not met in the majority of students, had to be addressed during the intervention through homework assignments and class discussions.

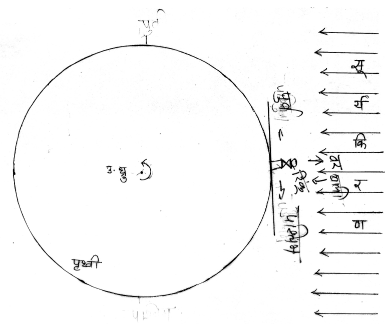
Science: Properties of light and ray diagrams are taught in science. Using ray diagrams in identifying shadows in common situations is often considered to be intuitive. Students also learn in school to draw ray diagrams for eclipses. However, we found their understanding of these eclipse diagrams was quite inadequate. The diagrams were simply learnt by rote. Diagrams of shadows formed by point sources and by parallel rays were addressed during the intervention. We suggest that students need practice in drawing ray diagrams for shadows from different kinds of sources (point, parallel ray, extended source). Interpreting the consequences of shadows and using geometrical optics in experiments e.g. inferring the position and kind of source from the shadow, using Eratosthenes diagram to find radius of the earth, etc. should be required exercises in science.

Mathematics: Basic mathematical operations are needed to deal with large sizes and distances, for which knowledge about powers of ten and operations involving them are useful. Sizes, distances and masses being beyond imagination, they are often understood and remembered in terms of ratios. Some of these ratios such as Astronomical Units and Solar masses are used as formal units in advanced astronomy. Grade 8 students were found to be not competent with calculating ratios.

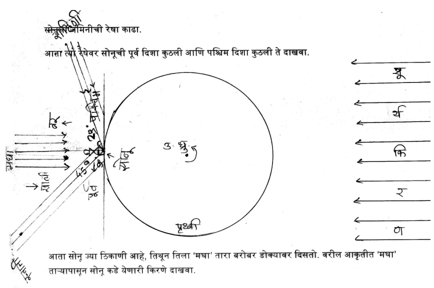
Concepts in geometry such as parallel lines, angle and geometry of a circle are taught in school, but several students were either not competent in these or could not apply them in the astronomical context. Placing geometrical concepts in the astronomical context is a good exercise for both astronomy and geometry. Other geometrical concepts such as dimensions of space, their units of measurement, and geometry of a sphere, were found to be prerequisite, but these concepts were not taught in school. Understanding of the inverse relation between distance and apparent size (solid angle subtended) was also found to be crucial. Even a two dimensional understanding of these ideas would help in making intuitive inference in three dimensional situations.

Geography: Knowledge about locations of the continents and some countries on the world map is useful to refer to different locations around the globe. Knowledge about time zones, seasons and weather conditions in different geographical regions is also helpful.

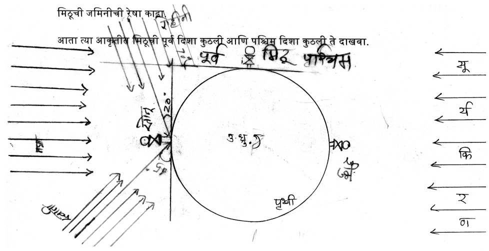
The pedagogy helped in refining our conjecture and in determining the key criteria that diagrams should possess to be helpful for students. These two results are presented in Chapter 5.



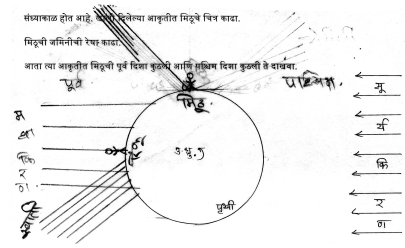
(a) Absolute East and West (on upper and lower side of the earth) and incorrect East-West of the horizon (erased) by rural boys' group



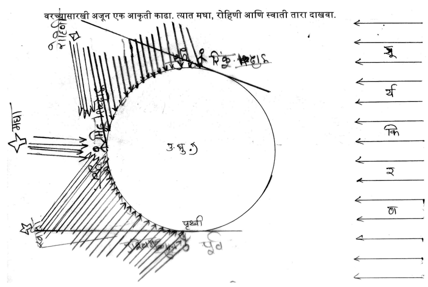
(b) Correct response to Questionnaire 5 by a group of rural boys



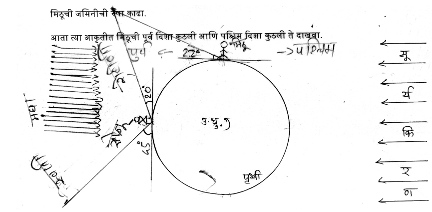
(c) Correct response to Questionnaire 7 by rural girls. Notice that the 70° angle is measured on the horizon of Mithu, but not at the point of his legs



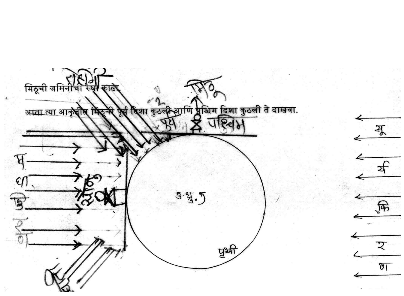
(d) A group of tribal boys did not draw the horizon



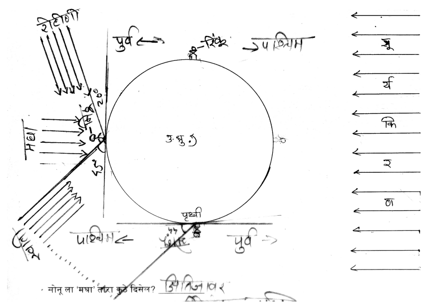
(e) A response by tribal boys. The sun-rays are drawn parallel, but without measuring the angle with Mithu's horizon. Notice the slanted horizon of Rinku



(f) A group of rural boys drew divergent rays from star *Rohini*

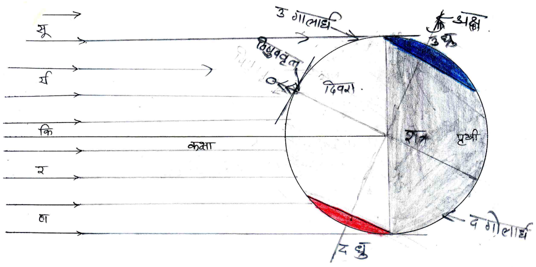


(g) Parallel rays in approximate direction drawn by a group of tribal boys

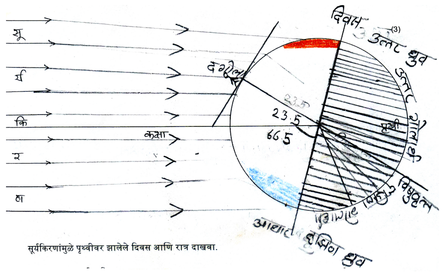


(h) Correct response to Questionnaire 8 by a group of rural boys

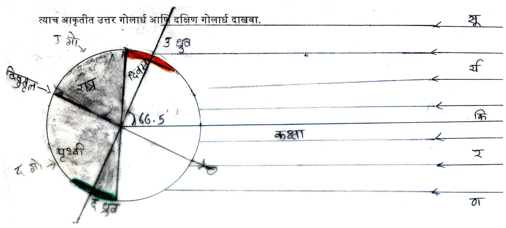
Figure 4.29: Responses to Questionnaires 5-8: Correlating global cues with local directions and angles of elevations; time differences



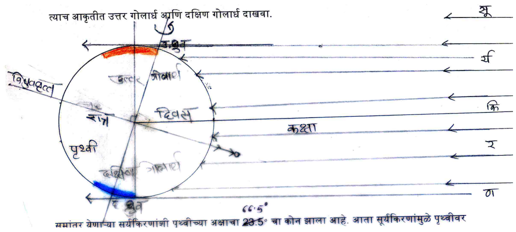
(a) Correct response for the winter equinox by a group of rural girls



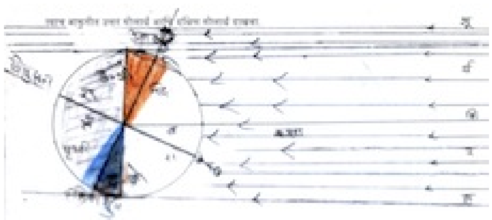
(b) A group of rural girls confused between terminator and the axis of rotation



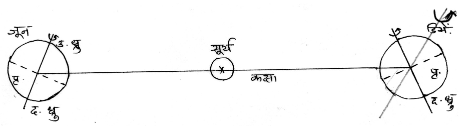
(c) A group of rural boys coloured upward or downward curves



(d) A group of tribal boys could not determine the Polar regions



(e) A group of tribal boys coloured complete cones



(f) After stating that the given diagram is incorrect, 7 groups corrected it.

Figure 4.30: Responses to Questionnaire 10-11: Seasons (solstice and equinox)

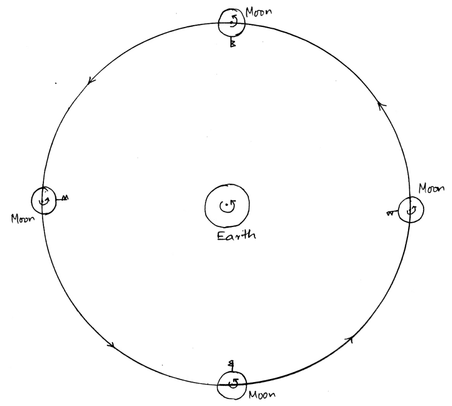


Figure 4.31: The earth-moon system: We see only one face of the moon (D32b)

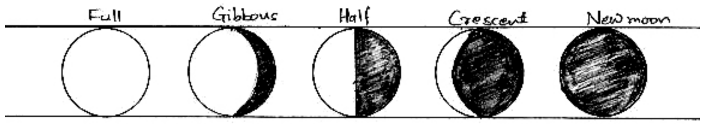


Figure 4.32: Pattern of changes of the phases of the moon (D34)

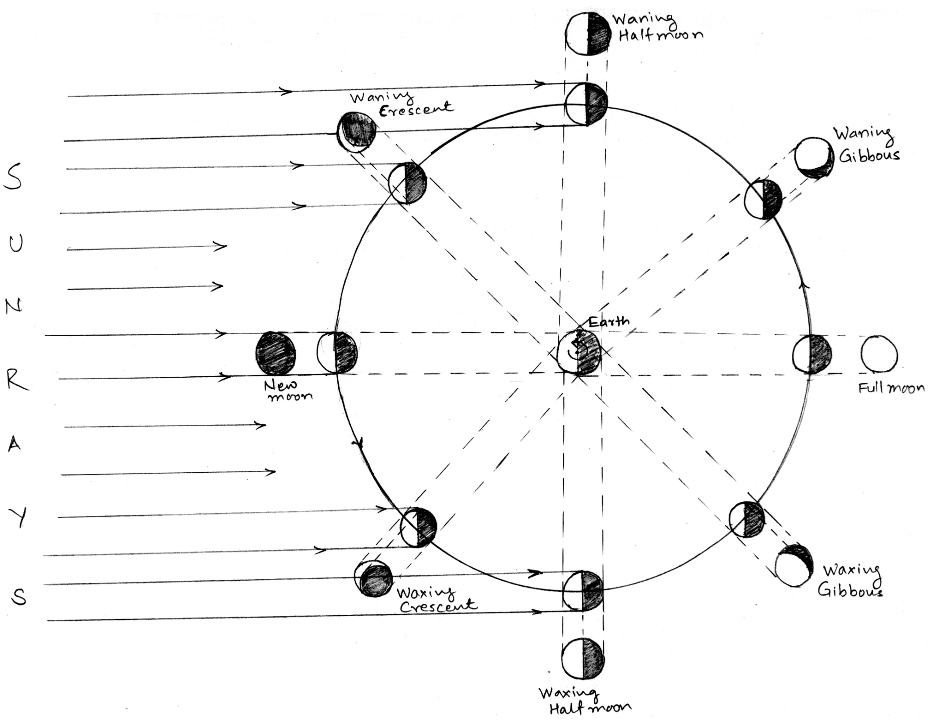


Figure 4.33: Explanation of occurrence of phases of the moon (D35)

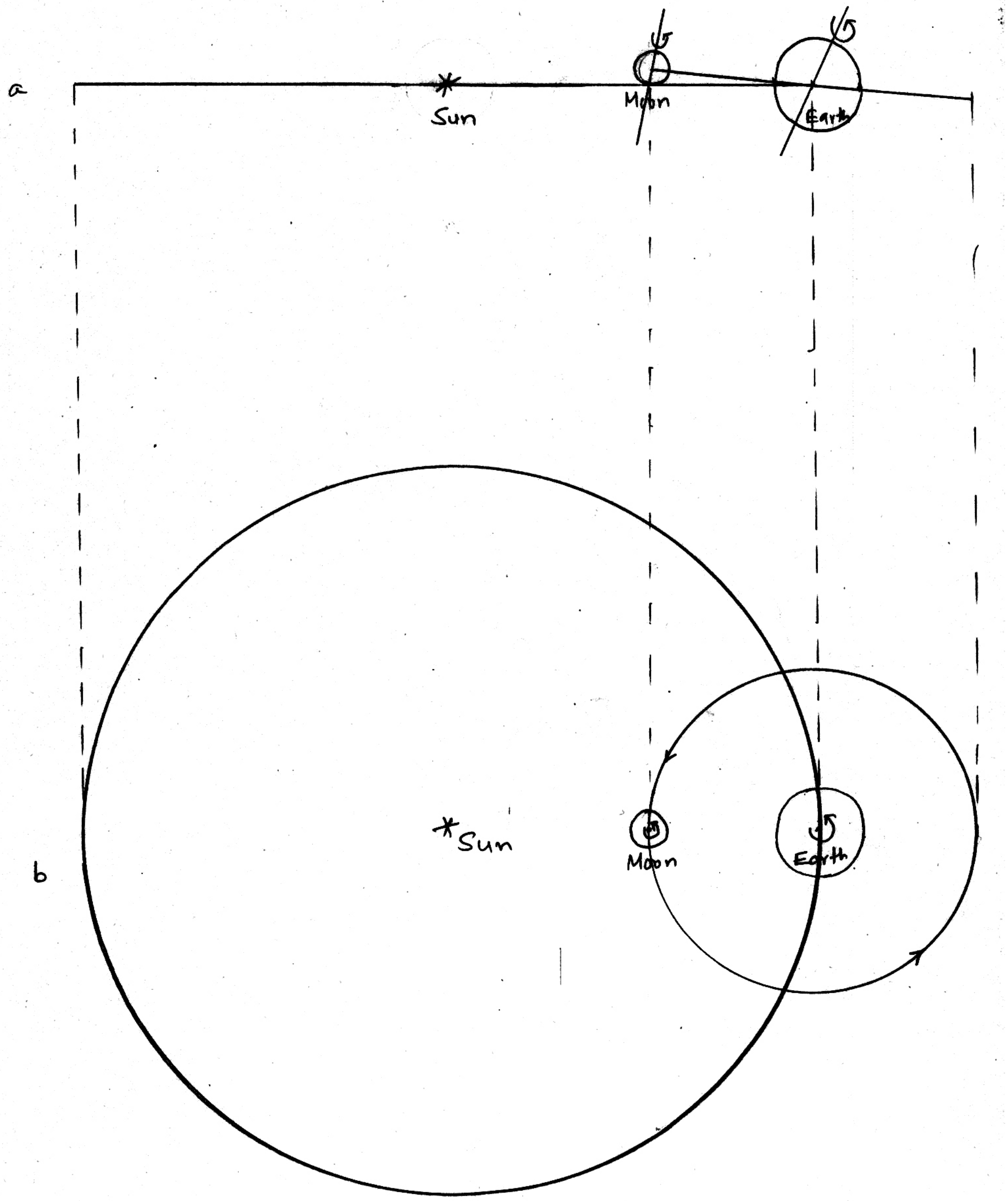


Figure 4.34: The sun-earth-moon system represented from two different perspective (D36-a: From within ecliptic, b: From above North Pole)

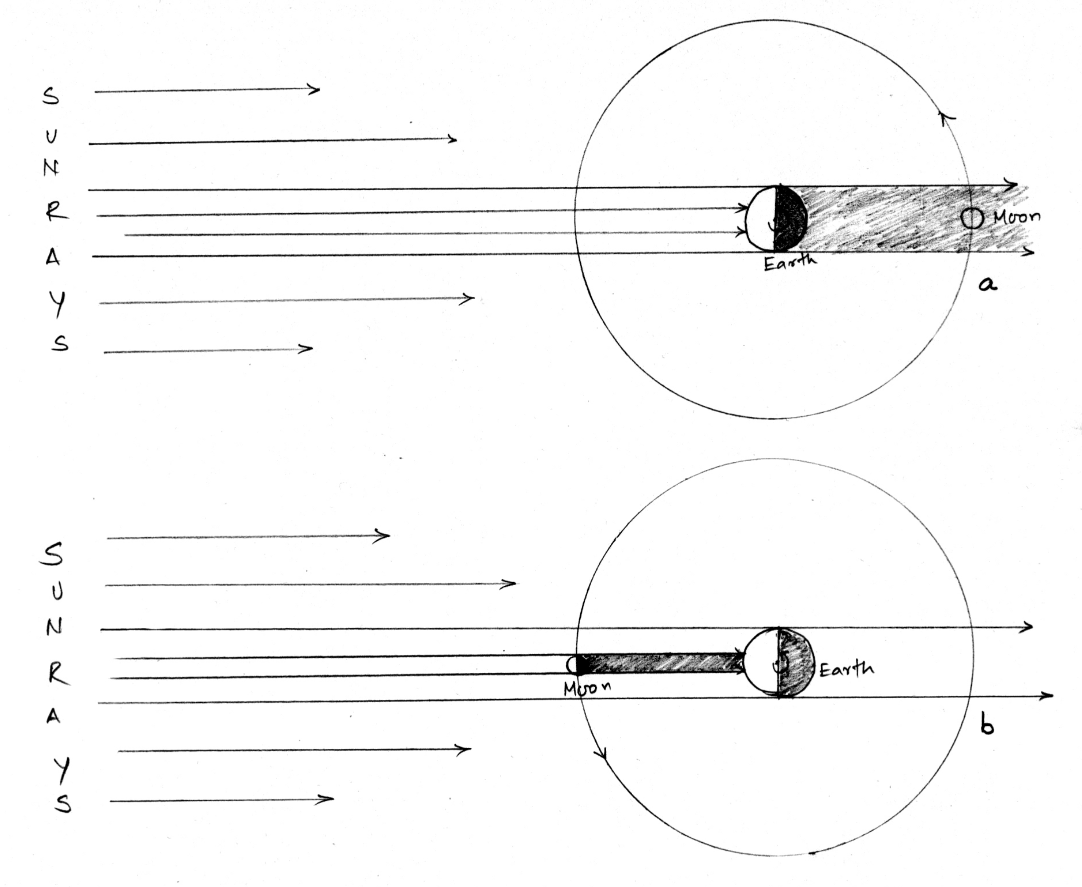


Figure 4.35: Approximate explanation of eclipses using parallel rays (D37a: Lunar eclipse, b: Solar eclipse)

Chapter 5

Analysis of Spatial Tools

Our research conjecture (Subsection 3.3.4) and hence our pedagogical intervention (Chapter 4) was based on the use of concrete models, gestures, actions and diagrams as spatial tools. In this Chapter, we first summarize the details of concrete models used in the intervention (Section 5.1). Then we analyze our designed pedagogical gestures according to the functions they served in the pedagogy and students' spontaneous gestures according to their types and frequency (Section 5.2). Finally, in Section 5.3 we analyze diagrams according to criteria developed for the pedagogical diagrams and students' diagrammatic responses. The coding of concrete models (CM), gestures and actions (G) and diagrams (D) has been introduced in Chapter 4. Please refer to Tables 4.1, 4.2 & 4.1 for descriptions and specific numbers assigned to the Concrete models, Gestures and Diagrams.

5.1 Concrete models and concrete experiences

The most frequently used concrete model was the Globe. The instances of the use of Globe can be seen in Table 4.1 in Chapter 4. A small globe was given to each group of students while solving problems and two large globes (30 cm. diameter) were always available in their classroom (Figure 5.1a). Using the Globe as a geosynchron (Section 4.2) could explain several phenomena such as day-night, local time for different locations of the earth, shadow of a person at that point, apparent motion of the sun and the stars, and the stationary position of the Pole Star (Figure 5.1b). A small round fruit and a tooth-pick was used for a similar purpose while enacting an episode from the play 'Life of Galileo' (Brecht, 1947). A rotating chair was also used to explain the changes in apparent motion of the sun in the same play. A small disk was used along with a doll human figure standing on the globe to suggest that although the horizon is drawn as a line in the diagrams, it actually denotes a cross-sectional view of a circular horizon.

(a) Urban students handling globe during guided collaborative problem solving (CM2)

(b) Setting un the geosynchron in the tribal school (CM11)

Figure 5.1: Globe (CM2) was extensively used during the intervention

In Part II of the intervention (Section 4.3) a sun-earth model was prepared using a candle as the sun and a small globe as the earth (Figure 4.19). A pulley was used at the joint of the wire connecting the sun and the earth so as to keep the inclination of the axis constant. In Part III of the intervention a model of the earth-moon system was prepared using a small ball as the moon and the globe. Students were asked to list the difference between the models and the real system when these models were introduced for the first time (Chapter 4). This helped avoiding possible mis understanding as many of the characteristics of the real system (real sizes, distances, and other physical properties) came up during the discussion.

Concrete models of real systems, such as a globe (CM2), the sun-earth system (CM16) and the earth-moon system (CM20) were presented along with their photographs D3, D22 and D31 respectively. Some realistic aspects of the system get represented through photographs and some get represented through concrete models. Thus these two media together give realistic physical details, whereas the temporal (motion) and other conceptual aspects are better represented through gestures-actions and diagrams (see Subsections 5.2 and 5.3).

A small ball was used as the moon to accompany two of the gestures. A ball was attached to a thin rod and students were asked to rotate it round themselves across a strong source of light to observe the phases (G34). G36 was performed to communicate the angle between the ecliptic and the moon's orbit by moving an extended arm around (with or without a ball in the hand). When the direction of the sun-rays was specified, different situations lead to either a new-moon and full-moon or to the solar and lunar eclipses.

A gnomon was given to students to plot the shadows every day. A model of three orthogonally perpendicular axes was used to teach the Cartesian co-ordinate system in three dimensions and was linked to other concrete experiences such as finding a house in a town, or specifying location of an object in the classroom for the given co-ordinate system.

For the activity of plotting scaled distances on the ground we used a marble as the earth (CM18). All the students prepared their own astrolabe and used it for measuring angles. Different objects were rotated in different fashions to identify the axis of rotation. Different objects in the surroundings were used to demonstrate measurement of length, area, volume and angle, along with measuring tools (scale, protractor) to study their units. Cardboard cut-outs were used to create shadows and beams of different shapes and to study the changes in the shadows by moving those cutouts (projections). A bangle, bucket and other objects with a circular rim were observed and drawn from different perspectives to understand that the circle looks like an ellipse when viewed at an angle, and like a line when viewed edge-wise.

5.2 Gestures and actions

This Section is based on Padalkar and Ramadas (2010).

5.2.1 Designed pedagogical gestures

Table 5.1 lists 40 groups of gestures and actions (body configurations) aimed at illustrating a set of spatial concepts. These were metaphorical or iconic gestures (see Subsection 2.7.6) designed to communicate specific spatial content to help students construct a dynamic mental model. The order of gestures is aimed at progressively introducing complexity in the model, and follows the order of teaching for the most part (same as that in Tables 4.1, 4.2 & 4.5). Some gestures were carried out as an activity or a part of activity. As seen in Table 5.1, some of these were not 'gestures' but 'actions' during activities which gave kinesthetic feedback. Some were whole body actions performed by individuals or groups, while others were performed in the presence of concrete props or diagrams. Video clips linked with Table 5.1 are at http://web.gnowledge.org/pedagogic-gestures/.

Table 5.1: Gestures and actions in our pedagogy

G No.	Gestures and Actions	Purpose	Static/ Dynamic	Type of linkage	Stand-alone
Part I: Round rotating earth					
1	Tracing star patterns by fingers/ hands.	Ph. I.	S	G-D	N
2	Directions in local environment by extended arm; Angles estimate by fist/ palm and arm	Space I.	S	G-D	Y
3	Moving hands with palms open to show sphere.	Model I.	S	CM-G	Y
4	Moving arm with open curved palm to show half sphere of the earth coming out of the blackboard, imagining circle as circumference of the earth and other half sphere inside the black board.	Model I.	S	G-D	N
5	Holding or imagine to be holding a very small to a very large ball and observe the change in curvature on palm and then arm.	Model I.	S	CM-G-D	Y

6	Rotating objects and body parts and identifying axis of rotation.	Space I.	D	CM-G-D	Y
7	Index finger pointing inside or outside, perpendicular to the diagram (D9a: Figure 4.5b).	Model I.	D	G-D	N
8*	Sitting on a rotating chair to see occurrence of day-night.	Model I. (Ch.Ori.)	D	CM-G	N
9*	Assuming apple to be the earth, and radially attached tooth-pick as a human. Rotating the apple around the axis passing through its stem to see day-night.	Model I. (Ch.Ori.)	D	CM-G-D	Y
10	**a.** Showing a vertical index finger in horizontal circle in front of blackboard (or in half circle, with axis as center) (D9a: Figure 4.5a) **b.** Moving a horizontal index finger in a vertical circle around a point on the blackboard (D9b: Figure 4.5b)	Model I.	D	G-D	N
11	Down: pointing index finger towards center of the earth. Up: pointing index finger away from center of the earth North: Towards North Pole (D11a; Figure 4.12). South: Towards South Pole (D11a; Figure 4.12a).	Model I. (Ch.Ori.)	S	CM-G-D	N

12	East: Orienting orienting one's self parallel to the North-facing person in the diagram so that the right hand indicates East in the diagram, OR find the direction of motion of the earth (West to East) with right hand thumb rule. East is indicated by the direction of curl of the fingers (G13). West: Opposite to East (Figure 4.12b)	Model I. (Ch.Ori.)	S	CM-G-D	N
13	Gesture of thumbs-up. In (D9: Figures 4.5a & 4.5b) align thumb in the direction of axis and pointing towards the North Pole, then curl the fingers to show the direction of earth's rotation (or revolution)(West to East).	Model I.	D	CM-G-D	N
14	Shadow created by fingers/ parts of the body/ whole body	Ph. I.	S	CM-G-D	Y
15	Tracing path of light-beam/ ray by open palm (representing wave front) / finger on board.	Model I.	D	G-D	N
16 (2)	One student becomes the earth, another student (or object) becomes the sun. Mark the objects around in egocentric frame (front/ back/ left/ right). Observe how the field of vision and positions of objects changes due to rotation from right to left.	Model I. (Ch.Ref. Frame)	D	CM-G-D	Y
17	Move the stretched hand in vertical or inclined half circle from East to West. Inclination towards North or South depending upon whether one imagines herself in the Southern or Northern hemisphere.	Ph. I.	D	G-D	Y

18	Fix a point vertically overhead on the ceiling and check whether its position changes while rotating around the vertical body-axis.	Model I. (Ch.Ref. Frame)	D	CM-G-D	Y
Part II: Sun-earth system					
19	Measuring 1mm to few meters by using body parts.	Space I.	S	CM-G-D	Y
20	Rotating hand from 0°to 180°.	Space I.	D	CM-G-D	Y
21	Length: walking Area: flat palm Volume: Filling up	Space I.	S	CM-G-D	Y
22 (2)	Only rotation (facing changes); only revolution (facing does not changes); 1 rev + 1 rot; 1 rev+ 2 rot; 1 rev + 4 rot; imagine 1 rev + 365 rot.	Model I. (Ch.Ref. Frame)	D	G	Y
23*	Drawing ellipses using 2 nails: A series of diagrams which give kinesthetic feedback.	Model I.	D	G-D	N
24*	Making circle, ellipse and line by joining palm.	Space I.	S	G-D	Y
25*	Observing loop made by thumb and index finger (or other objects) from top, side and oblique view.	Space I.	S	CM-G-D	Y
26*	Show axis tilt by forearm bent at elbow.	Model I.	D	G-D	Y
27	Find out ratios of distances considering an earth of diameter 1cm and plot them on the ground.	Model I.	S	CM-G	Y
28 (10)	Each student becomes one planet and revolves around the student who is the sun, taking account of the relative speeds.	Model I. (Ch.Ref. Frame)	D	CM-G-D	Y

29 (30)	One student becomes the sun, another becomes the earth and revolves around the sun. All other students become different *Nakshatras* representing a star background. Students predict which Marathi month and which solar *Nakshatra* is on, depending upon the position of the earth.	Model I. (Ch.Ref. Frame)	D	G-D	Y
30	Put your hand above hot lamp (or in rain) in different orientation, to sense that collection of heat (or water) depends on angle of incidence.	Ph. I.	S	G-D	Y
31	Trace a semicircle with a stretched arm making different angles with horizon depending upon the season.	Ph. I.	D	G-D	Y
Part III: Sun-earth-moon system					
32	Pointing and tracing acute, right and obtuse angles in room, finding out parallel lines.	Space I.	S	CM-G-D	Y
33 (2)	Only rotation, Only revolution, Both rotation and revolution together.	Model I. (Ch.Ref. Frame)	D	CM-G-D	Y
34	Rotating the ball around one's head in tilted orbit, with a strong light source on one side.	Model I. (Ch.Ref. Frame)	D	CM-G-D	Y
35 (2)	Replace the ball by friend and watch friend's face.	Model I. (Ch.Ref. Frame)	D	G	Y
36	Showing tilt of moon's orbit by moving extended arm around (with or without ball in the hand).	Model I.	D	CM-G-D	Y
37 (2)	Moving around the friend considering one's head as the moon and the friend's head as the earth.	Model I. (Ch.Ref. Frame)	D	G-D	Y

38 (3)	Moon moving around the earth while earth moving around the sun.	Model I.	D	G-D	Y
39 (2)	Moon moves around the earth while the earth forwards (considering the earth's orbit to be almost straight and the sun to be very far away).	Model I. (Ch.Ref. Frame)	D	G-D	Y
40 (30)	Moon moving around the earth against the background of stars behind (Arrangement similar to G29).	Model I. (Ch.Ref. Frame)	D	G-D	Y

Key for Table:

Number in the bracket in the first column (G No.) indicates the Number of students involved in that gesture or action. If no number is specified, the gesture is to be carried out individually.

Purpose

Space I.: Gestures used for 'Space Internalization'

Ph. I.: Gestures used for 'Phenomenon Internalization'

Model I.: Gestures used for 'Model Internalization'

Ch.Ori.: Change of Orientation

Ch.Ref. Frame: Change of Reference Frame

Type of Linkage

CM-G: Gestures follow 'Concrete Models'

G-D: Gestures lead to 'Diagrams'

CM-G-D: Gestures follow 'Concrete Models' and lead to 'Diagrams'

Stand-alone Y: Gesture can be done in absence of concrete model or diagram

N: Gesture has to be done in presence of concrete model or diagram

Static/ Dynamic

S: Gesture conveys a static property

D: Gesture conveys a dynamic property

Gesture numbers marked with an asterisk were done at a different point in the sequence, but they are placed in Table 5.1 where they are thought to be more appropriate.

Typically, the teacher performed a gesture along with or after introducing a concrete model, and students were asked to imitate the gesture. Students were then asked to perform similar gestures for slightly different conditions. Then the same gesture was performed along with a diagram or leading up to a diagram. For example, the direction of rotation of the earth was shown by the direction of curl of fingers while aligning the right-hand-thumb with the axis near the North Pole (G13). The direction thus determined was shown to be consistent with the 'West to East' direction as identified by an earlier gesture (G12). Then students were asked to determine the direction of rotation of the earth for different orientations of the globe and for diagrams of the earth from different perspectives (Figure 4.5).

The number in the first column in Table 5.1 gives the placement of the gestures or actions in our pedagogic sequence. The second column describes the specific gesture or action. The third column, 'Purpose', is derived from the 'mental model - gesture - phenomenon' link of our conjecture (Subsection 3.3.4). It is further explained in Subsection 5.2.1 (Purpose of the gestures). The fourth column of the Table 5.1 specifies whether the gesture communicates a static or a dynamic property of the system. The last two columns, labelled 'Type of linkage' and 'Stand-alone', are derived from the 'concrete model - gesture - diagram' link in our conjecture (Subsection 3.3.4). These two columns are further analyzed in Subsection 5.2.1 (Gestures as a link between concrete models and diagrams).

Besides these deliberately designed gestures, many fleeting metaphorical and deictic gestures occurred spontaneously during teaching as part of natural communication, which are not listed in Table 5.1. Of the deictic gestures used in the pedagogy a small number, which were designed to convey significant information (G7, G10, G15 & G32 in Table 5.1) are considered in the analysis of pedagogical gestures.

Figure 5.2 summarizes the classification of gestures according to their purpose and whether they convey a static or dynamic property, along with the number of gestures in each category.

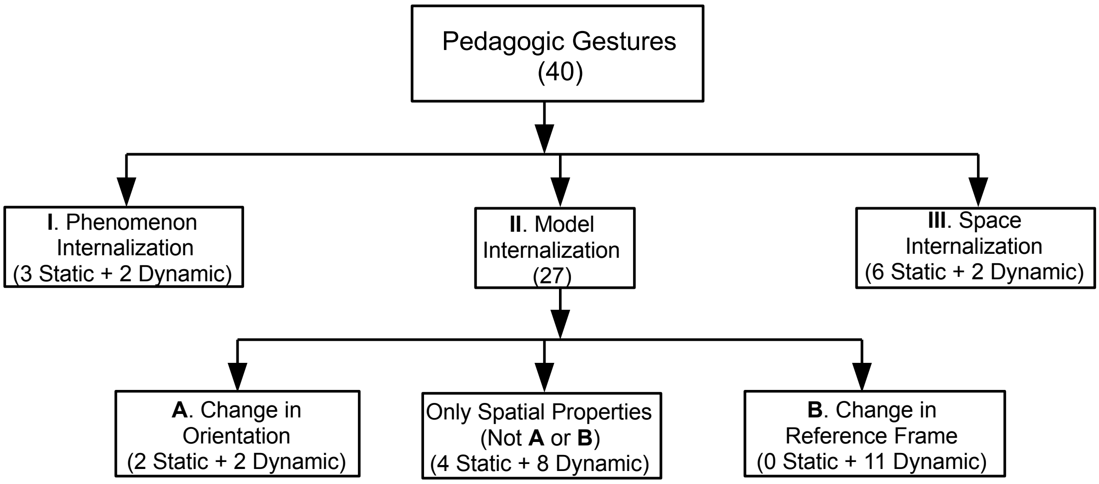


Figure 5.2: Tree-diagram for types of pedagogical gestures derived from columns 3 (Purpose) and 4 (Static/ Dynamic) of Table 5.1.

Purpose of the gestures

The ‘purpose’ of the gestures, i.e. its intended function in the ‘mental model - gesture - phenomenon’ link of our conjecture, is specified in column 3 of Table 5.1. All of the gestures were meant to facilitate the internalization of spatial and temporal properties. Spatial properties in relation to the SEM system could be derived from first-hand observation of a phenomenon from the earth (Ph.I.), or they could be inherent to the relevant astronomical model (Model I.). Through a set of supporting activities, we also addressed some general (Euclidean) properties of space which were not specific to this system (Space I.).

I. Internalizing the Phenomenon (Ph.I.): Five out of the 40 (G1, G14, G17, G30 & G31) types of gestures were meant to enable internalizing a phenomenon. Three of them illustrated static or almost-static properties, as in mimicking or tracing star patterns with configurations of fingers and hands (G1), casting shadows using parts of the body in different orientations (G14: Figure 5.3), and using the palm to detect changes of heat intensity with orientation (G30).

The other two of the five types of gestures were dynamic, illustrating motion

Figure 5.3: Casting shadows using parts of body (G14)

of the sun or the stars across the sky (G17: Figure 5.4 & G31). These motions, sometimes done in the presence of concrete models of the globe or geosynchron (Padalkar and Ramadas, 2008b; Monteiro, 2006), related immediate observation to imagined observations, in one case from different latitudes, and in the second case to observations in different seasons.

(a) (b) (c)

Figure 5.4: Tracing path of the sun (G17)

The expectation motivating these gestures was that they would help students, while observing the phenomenon to internalize it, or achieve 'ownership' of it, through their body configurations. In the case of dynamic phenomena (relating to motions in the sky), learning of these body motions in turn would enable later enactment in the absence of that phenomenon. Repeated observations and enactment would, we hoped, help students understand and internalize the patterns in the phenomenon, for example, the path of the sun over the day from East to West at different latitudes (G17), and how this path moves North or South over the year (G31). When done in the presence of concrete models, these gestures could also help connect the phenomena with the models.

II. Internalizing the Model (Model I.): Twenty seven out of 40 gestures were meant to facilitate internalizing the scientific models. The spatial properties of the models to be internalized are, the round earth (G3, G4 & G5), axis of rotation of the earth (G7 & G10), direction of rotation (G13: Figure 5.5a) and revolution (G23, G26 & G27) of the earth, motion of the moon (G36 & G38) and transition of light (G15).


(a) Direction of rotation and revolution of the earth (G13)


(b) Showing axis tilt by forearm bent at elbow (G26)

Figure 5.5: Gestures facilitate internalizing spatial properties of models

The pedagogy included three sets of gestures to show the roundness of the earth: to connect it with the shape of the globe (G3), and reconcile this roundness with the flat diagram on blackboard or paper (G4) on the one hand, and the apparently flat visible portion of the earth on the other (i.e. how curvature decreases as the radius increases, to show why the earth appears flat to us) (G5).

Three sets of gestures were designed to show the axis of rotation of the earth and its tilt with respect to the ecliptic plane (the axis of the earth makes an angle of 23.5 with the ecliptic) (G7, G10 & G26: Figure 5.5b). These gestures, when done in combination with diagrams, helped link the model of the rotating earth with diagrams of the earth drawn in different orientations.

Of the model-related gestures six illustrated predominantly static properties of the system. The other 21 sets of gestures illustrated dynamic properties, which constitute the major source of learning difficulties in astronomy. The aim of these gestures and actions was to assimilate the abstract models of the system (e.g. the round rotating earth, etc.) into one's internal mental model. Although, concrete external models were used with some of these gestures, other gestures were completely independent of concrete models, while in all others the aim was, as a consequence of internalization, to make the concrete models ultimately dispensable. In addition to internalization of spatial properties of model, two further types of tasks were involved here:

A. Change of orientation (Ch.Ori.): Changing one's heading in imagination presents great difficulty even in simple everyday contexts, and kinesthetic feedback helps significantly in performing such tasks (Klatzky et al., 1998). Thus we frequently encouraged students to partially orient themselves in the direction in which the person in a diagram (or problem) was standing on the earth.

Four sets of gestures had to do with specific changes of orientation, starting with 'Up' and 'Down' with respect to the earth (G11). Two sets arose in an enactment of an episode from the play 'Life of Galileo' by Bertolt Brecht (Brecht, 1947) (G8 & G9). Another set was enacted in the presence of a globe and/or a diagram of the earth, and it illustrated, besides 'Up' and 'Down', the directions, North, South, East and West (G11 & G12). These gestures were also meant to help link the concrete model with a diagram of the earth.

B. Change of reference frame (Ch.Ref. Frame): A large subset (eleven) of model-related gestures were meant to facilitate a change of reference frame (G16: Figure 5.6, G18, G22, G28, G29, G33, G34, G35, G37, G39, G40). In the context of mental models, two 'frames of reference' are identified: an intrinsic (or egocentric) frame of reference, in which the viewer is inside the model, and an extrinsic (or allocentric) frame in which viewer is outside the model. In the extrinsic frame it is relatively easy, for a middle-school or older child, to imagine one model from different perspectives. But it is extremely difficult to change one's frame from an extrinsic/allocentric to an intrinsic/ egocentric frame. The further task of moving from one intrinsic frame to another, e.g., imagining the view alternatively from the earth or the moon, is even more demanding. The allocentric-egocentric transformation, which calls for a high level of visualization, often results in an inability to connect the external model to the observed phenomenon. We found group gestures to be a good way to make this transformation. When persons replace the objects in the model by themselves, they see the system from ‘inside’, which helps the allocentric to egocentric transformation. To facilitate anthropomorphic models we designed group configurations and actions involving humans forms (G16, G22, G33, G35, G37 & G39). We felt that if the students enacted these anthropomorphic situations, it may help them to form mental representations which would be useful in the visualization, even in the absence of actual situations or (later) the gestures.

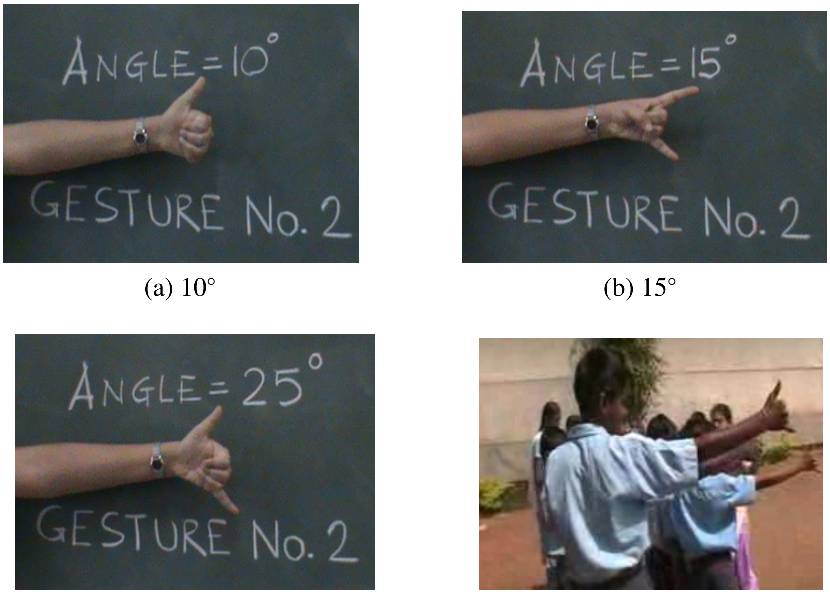
(a) (b)

Figure 5.6: Pairs of students performing a gesture for day-night (G16)

Ten out of 40 gestures / actions were done either in pairs (G16, G22, G33, G35, G37 & G39), triads (G38) or in larger groups (G28, G29 &G 40). All were done for the purpose of internalizing the SEM model, and nine of them served to enact the changing of frame of reference. Thus, group gestures were most important in model internalization and changing frame of reference.

We designed different group gestures to visualize different phenomena, though concerning the same system. For example, classes of phenomena namely, visibility of only one face of the moon, phases, eclipses and inconsistency between sidereal and synodic month, could be explained using the SEM model, with only two people, one acting as the moon and another as the earth, but each with different actions (G33, 35, 37 & 39 as explained in Section 4.4). Although verbal explanation provided in Section 4.4 is long, the actions involved are simple enough that students could do them without much trouble. Thus specific aspects of a complex motion could be expressed in a simple and natural manner, through a series of actions.

III. Internalizing Euclidian Space (Space I.): Eight of the 40 groups of gestures were aimed at internalizing properties of three dimensional Euclidean space through appropriate configurations of the body. Six of them convey static properties and two convey dynamic properties of space. They encompass length and displacement (G19), area and volume (G21), angles (G2: Figure 5.7, G20 & G32), rotations (G6), and shapes of trajectories (G24 & G25). Specific and common units of measurement were also appropriated with the help of gestures.



(a) 10° (b) 15°

(c) 25° (d) Students estimating angles

Figure 5.7: G2: Angle estimation by palm

Summary of ‘Purpose’

The classification of the gestures in Figure 5.2 shows that most (27 out of 40) gestures served the purpose of ‘Model internalization’ (Model I.), compared with eight meant for ‘Space internalization’ (Space I.) and five gestures meant for ‘Phenomenon internalization’ (Ph.I.). This according to us is a possible basis for designing gestures for teaching astronomy. Use of gestures might be most important in model internalization for the following reasons:

1. Astronomical models, due to their vast scale, are not accessible to direct perception. Scaled concrete models, gestures and diagrams are the only way to understand them.
2. Out of 27 gestures which serve to internalize the model, 11 are useful in changing the frame of reference. In other words, the person who replaces the earth can observe the phenomenon in a rotating frame. Thus these gestures are not only useful for internalization of dynamic aspect of the model, but they are the most accessible and perhaps unique medium through which we can change an allocentric (or extrinsic) frame of reference to an egocentric (or intrinsic) one. This is an important function of gestures, in astronomy, making explanations immediately evident without any formal means of reasoning.
3. From Table 5.1 and Figure 5.2 we see that, out of 27 gestures used in model internalization, 21 are meant to convey a dynamic aspect of the model. Following the phenomenon is easier since we concentrate on only one body and follow its motion, and that motion is perceivable. But comprehending this motion requires keeping track of the objects over long time scales, not an easy task. Gestures provide natural and effective ways to add dynamism to both concrete models and diagrams. They are important in internalizing dynamic aspects of phenomena, and play a vital role in internalizing dynamic aspects of the models.Thus the major function of gestures was to convey dynamic aspects of the phenomenon, model, or of space. Out of 40 gestures, 25 conveyed dynamic aspects of either phenomenon or model or space (Figure 5.2).

Gestures as a link between concrete models and diagrams

The columns 'Type of linkage' and 'Stand-alone' in Table 5.1 exemplify the 'concrete model - gesture - diagram' link of our conjecture. Table 5.2, derived from these two columns of Table 5.1, summarizes the number of gestures in our scheme which follow concrete models and/or lead to diagrams, and those which are necessarily done in the presence of concrete models and/or diagrams.

As seen in the last column of Table 5.2, there are 11 gestures which have to be performed (at first, necessarily) either in the presence of concrete models or in the presence of diagrams. For example, using the right hand thumb to decide direction

Table 5.2: Use of gestures to connect concrete models to diagrams derived from columns 5 (Type of linkage) and 6 (Stand-alone) of Table 5.1.

Type of linkage	From Concrete Models (CM-G)	From Concrete Models and to Diagrams (CM-G-D)	To Diagrams (G-D)	Total
Gestures necessarily done in presence of CM or D	2	4	5	11
Gestures which follow from CM or lead to D	1	15	11	27
Total	3	19	16	38

of rotation of the earth (G13, Table 5.1) makes sense only if it is done along with the globe or a diagram to show its orientation. These gestures thus fill up the meaning that is missing in the concrete model or in the diagram.

The remaining 29 gestures are possible to do on their own but, as seen in Table 5.2, they can in a natural way follow a concrete model (1) or lead to a diagram (11) or both (15). These examples demonstrate that gestures can be used to link concrete models of systems to their diagrams. Two gestures (G22 & G35 in Table 5.1), which were used for changing the frame of reference, were exceptional in that they were not naturally linked to either concrete models or diagrams. Note however that the gestures involved one more person, who provided a visual cue for that gesture.

5.2.2 Students' spontaneous gestures

Students' spontaneous gestures were observed within a naturalistic classroom setting with students working in mixed ability groups of three. Over the course of five classroom sessions these groups solved a graded sequence of problem tasks (Subsection 4.3.3). As explained in Subsection 3.5.5 the video data were recorded during guided collaborative problem solving. Video data on spontaneous gestures was collected only for two groups of three students, one group of three boys (TB1, TB2, TB3) in the tribal classroom (TB group) and a group of three girls (RG1, RG2, RG3) in the rural classroom (RG group). The camera was placed one meter away at a slightly higher level than the heads of the students. Each group contained one student with relatively high pre-instruction scores and better engagement in the classroom. The aim was not to identify representative groups nor to draw comparison between the two selected groups but to analyze the types of gestures. The duration of this video data was 263 minutes for the TB group and 231 minutes for the RG group. The detailed description and overall qualitative analysis of all students' responses during these sessions is presented in Subsection 4.3.3.

In the video analysis our interest was primarily in gestures, specifically those that were related to the content of the problem-solving tasks. This was not a comprehensive discourse analysis, as due to circumstances of language and sociocultural context (see description of sample in Section 3.4), there was very little verbal interaction between the students. Added to this the unfamiliar nature of the subject matter and lack of exposure to problem solving in general, may have resulted in students' low confidence in expressing their ideas verbally. Their utterances were thus brief and sometimes apparently disconnected, consisting of whispers, mutters, and suggestive words, often difficult to decipher in a noisy classroom. Under these circumstances gestures may have provided an especially useful tool for their communication. For these reasons, and because our interest was not in the logical process of argumentation (description / explanation / dispute etc.), the analysis of videos focused mainly on gestures, specifically those in the 'deixis', 'metaphoricity', and 'iconicity' categories, i.e., excluding the social interactivity categories (Section 2.7). The existing classification schemes however needed some modifications to take account of spatial information that is conveyed by gestures in science and astronomy.

These content related gestures occurred against a background of continuous physical activity. Students constantly moved their hands and bodies, picked up relevant and irrelevant tools such as pencils, scale, eraser, etc., dropped one of these, bent down to pick it up, and so on. They also often scratched their heads, noses and other parts, touched each other to seek attention, sometimes continuously hitting the pencil on paper while apparently lost in thought. In interactions they used body-language to show their agreement (nodding), dissatisfaction (looking away and not paying attention), questioning, showing urgency of the task (vigorous motion), etc., all involving gestures and postures of the whole body. Their level and pattern of activity changed in occasional interaction with other groups and with the teacher, yet they remained continuously active and involved in the task.

Coding of video data was done by the author after which the author, along with her thesis advisor, reviewed about 17% of the data spread over all of the five sessions. These video segments, totaling 85 minutes and selected to include the relatively rare but important instances of metaphoric gestures, were watched by both of us together. Though there were no cases of disagreement over already coded gestures, occasional additional gestures were noted during the review, particularly when simultaneous gestures occurred in a group. Taking a conservative view, the numbers of gestures recorded here give a lower bound rather than a maximum limit, though we are reasonably confident that the actual numbers are not very much higher than the given numbers.

Types and rates of students' gestures

Table 5.4 gives the total number of gestures, rate of gesturing, and the number of occurrences of different types of gestures within each of the groups RG and TB. The categories of students' gestures in Table 5.4 and Figures 5.8 and 5.9 build on but go beyond existing classification schemes (McNeill in (Radford et al., 2009), (Roth, 2000; Goldin-Meadow, 2006a)) (Subsection 2.7.6). The category of 'deictic gestures' includes all those gestures which involve pointing, usually on a diagram or text on paper, but also occasionally towards the blackboard or the teacher. We found our students using a large variety of deictic gestures, many of which had spatial significance, which we included in a new category, 'Deictic spatial', which (as explained later) was distinct from the 'Metaphoric' category. Thus we modified and expanded the 'deictic' category on the basis of empirical observations from our data. Further we found that the 'Orientation change' gestures, which were introduced in our pedagogy, did not fit into the existing categories, hence we created a new category to include these. The names of these categories of students' gestures and abbreviations used for them in Table 5.4, Figure 5.8 and Figure 5.9 are given in Table 5.2.2 and are further explained in '**Types of gestures and content of task**'. Figure 5.8 plots the student-wise rate of each type of gesture, i.e., the number of that type of gesture occurring per minute, for each student in the TB and RG groups. The categories of students' spontaneous gestures are derived from their observed features, in contrast to the categories of designed gestures which were based on their purpose in pedagogy.

Table 5.3: Category numbers, types of students' spontaneous gestures and their abbreviations used in Table 5.4, Figure 5.8 and Figure 5.9

Category No.	**Type of gesture**	**Abbreviation**
1	Simple Deictic	
1a	*Deictic point*	*D pt*
1b	*Deictic multiple point*	*D mult pt*
2	Deictic spatial	
2a	*Deictic line*	*D ln*
2b	*Deictic multiple line*	*D mult ln*
2c	*Deictic circular*	*D circle*
2d	*Deictic simultaneous point*	*D simult pt*
2e	*Deictic simultaneous line*	*D simult ln*
3	Other Deictic	
3a	*Deictic portion*	*D portion*
3b	*Deictic instruc*	*D instruction*
4	Metaphoric	Metaphoric
5	Iconic	Iconic
6	Orientation change	Ori ch

Taken together, Table 5.4 and Figure 5.8 show the relative frequencies of different types of gestures, as well as the distribution of these gestures within each group of students. The rate of gesturing was higher in the TB group as compared with the RG group with the exception of TB3, who had the lowest rate of gesturing. Thus variability within the group of three students appeared to be higher in the TB group than in the RG group (Figure 5.8). It is interesting that RG1 and TB1, who carried out the most number of content related gestures within their group, performed outstandingly in the post-tests, and their interview performance at the end of the intervention was amongst the best in their cohort.

Table 5.4: Total number of spontaneous gestures used by students (Session-wise)

		Session 1		Session 2		Session 3		Session 4		Session5		Total	
No.	Gesture Type	Parallel Rays		Shadows		Rotating Earth		Star-month		Seasons			
		RG	TB	RG	TB†	RG	TB	RG†	TB	RG	TB	RG	TB
	Time (min.)	50	57	56	80	64	62	5	8	56	56	231	263
	Total no. of gestures	39	149	112	133	178	258	15	40	223	159	547	739
	Average gestures/ student/ min.	0.26	0.87	0.67	0.83	0.93	1.39	1.5	1.67	1.33	0.95	0.87	1.1
1a	D pt	15	71	43	56	83	74	7	8	96	76	224	285
1b	D mult pt	1	26	7	26	45	62	5	17	53	40	111	171
2	D Spatial	16	14	53	16	36	67	2	13	61	27	168	137
2a	*D ln*	*12*	*6*	*37*	*9*	*19*	*32*	*0*	*1*	*33*	*21*	*101*	*69*
2b	*D mult ln*	*0*	*6*	*15*	*5*	*10*	*8*	*1*	*0*	*27*	*6*	*53*	*25*
2c	*D circle*	*1*	*2*	*1*	*2*	*5*	*20*	*1*	*10*	*1*	*0*	*9*	*34*
2d	*D simult pt*	*1*	*0*	*0*	*0*	*2*	*6*	*0*	*2*	*0*	*0*	*3*	*8*
2f	*D simult ln*	*2*	*0*	*0*	*0*	*0*	*1*	*0*	*0*	*0*	*0*	*2*	*1*
3a	D portion	0	0	0	0	0	4	0	0	0	5	0	9
3b	D instruc	0	2	0	3	0	0	0	0	11	0	11	5
4	Metaphoric	7	36	9	32	3	31	0	1	1	11	20	111
5	Iconic	0	0	0	0	4	5	1	1	1	0	6	6
6	Ori ch	0	0	0	0	7	15	0	0	0	0	7	15

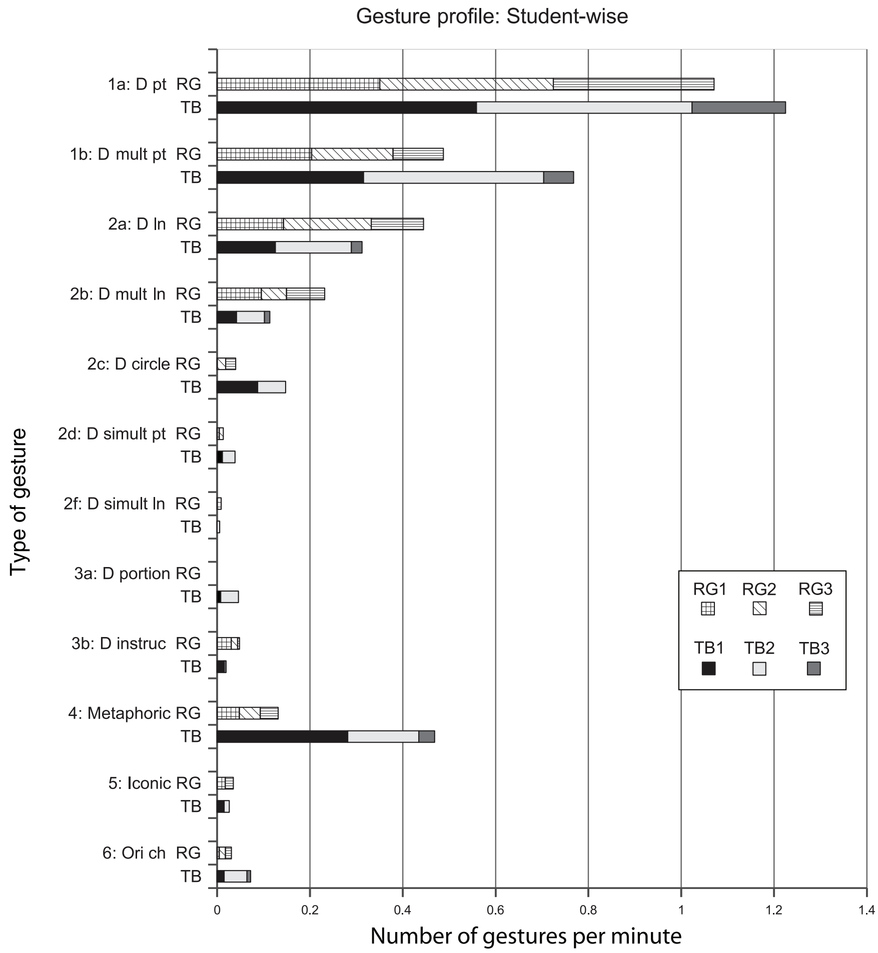
RG = Rural Girls, TB = Tribal Boys

† Only two students were present in these sessions.

Types of gestures and content of task

Since the profile of use of gestures over the different gesture types was similar in the two groups, we collapsed the data for all the six students to plot Figure 5.9, showing the total rate per student per minute of each type of gesture, for each of the five problem solving sessions. The categories of gestures and their use in different sessions is given below:

1. Simple Deictic gestures: The most frequent type of gestures in both TB and RG groups were deictic (pointing) ones, using a finger (or palm or tools such as a pencil or ruler) to point to parts of the text or of the diagram on paper (Category 1a in Table 5.4 and Figures 5.8 and 5.9). For example, in the RG group in first



Rate of gesturing of individual students: TB1=1.59, TB2=1.49, TB3=0.35; TB average = 1.1 gestures per minute; RG1=0.97, RG2=0.90, RG3=0.74; RG average = 0.87 gestures per minute.

Figure 5.8: Type of spontaneous gesture used by students Versus Rate of use of that gesture for each student (Rural girls: RG1, RG2, RG3; Tribal boys: TB1, TB2, TB3)

two sessions on 'parallel rays' and 'shadows' (106 minutes), out or 151 recorded gestures, 136 were of the deictic type. Of these, 95 were done by finger, 26 by hand, and 12 used an instrument such as ruler or pencil. Three of these 'deictic' gestures used 2 fingers, 2 hands and 2 arms each (Figure 5.10a).

Most of the deictic gestures were simple deictic ones consisting mostly of 'Deictic point' (Category 1a). A common variation of this gesture was to point to mul-

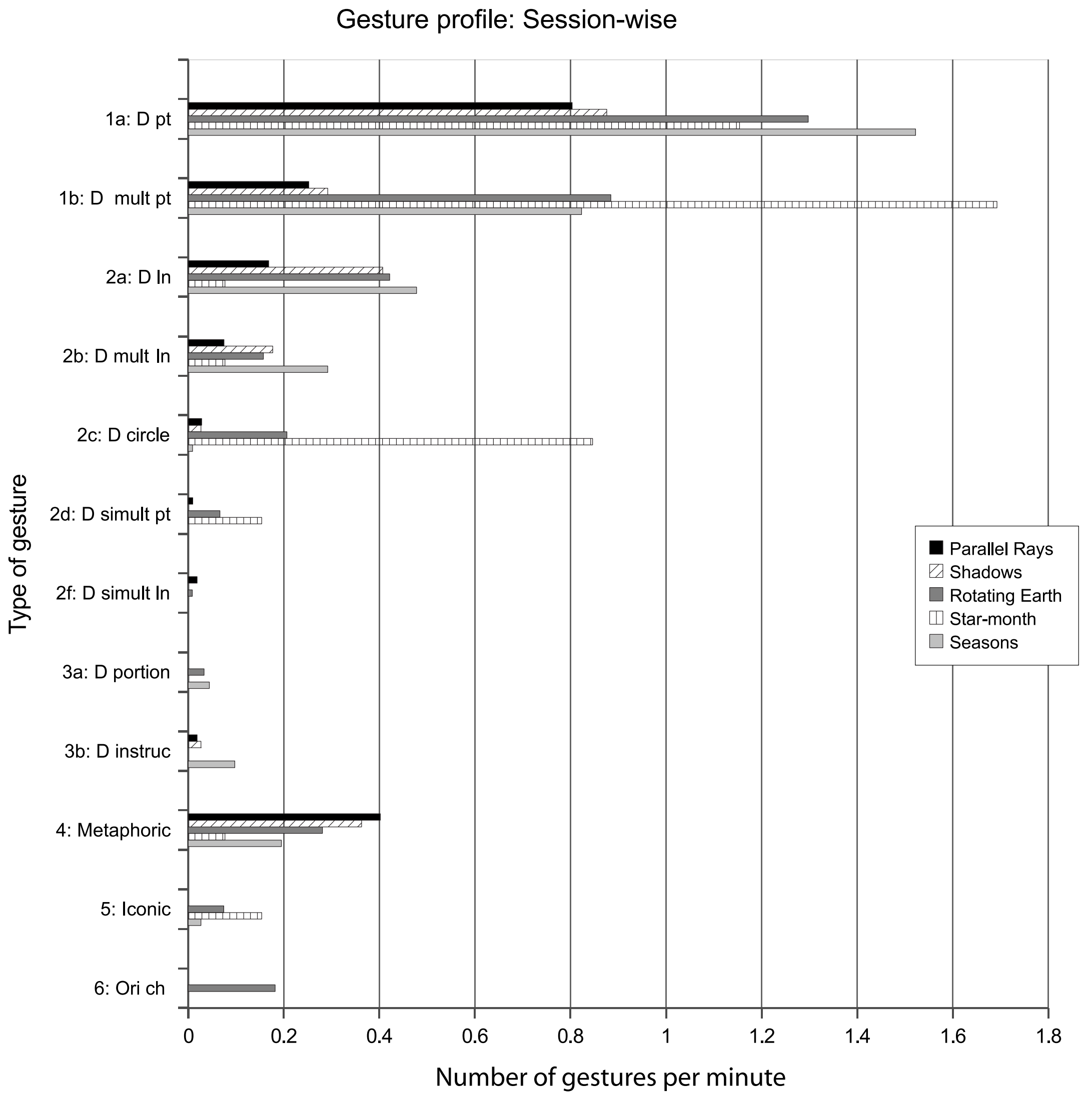


Figure 5.9: Type of spontaneous gesture used by students Versus Rate of use of that gesture in each session.

tiple points on paper (Category 1b, 'Deictic multiple point'). This gesture occurred in the course of reading, while pointing to successive portions of the text, in which case it had temporal significance (in McNeill's system, (Radford et al., 2009)), or while successively pointing to parts of the diagram, in which case it may have had both temporal and spatial significance.

Figure 5.9 shows that over successive sessions the number of 'Deictic point' gestures increased, with the exception of Session 4 (Star month). It may be that more difficult tasks encouraged more pointing gestures. Session 4 had problem tasks in which 'Deictic multiple point' was natural to use for showing several constellations around the sun-earth system. In fact these gestures were used preferentially in Session 4 (see Figure 5.9).

(a) Deictic gesture: Tribal boys pointing on questionnaire

(b) Iconic gesture: A rural girl performing right hand thumb gesture (G13) to determine the direction of rotation of the earth

Figure 5.10: Examples of students' spontaneous gestures

2. Deictic spatial gestures: The next most frequent category was 'Deictic spatial' (Category 2), in which the finger or pencil followed one line, or more than one lines in succession ('Deictic line' and 'Deictic multiple line', 2a & 2b), an arc or part of a circle or a whole circle ('Deictic circular', 2c), or two or more simulations points or lines ('Deictic simultaneous point' and 'Deictic simultaneous line' 2d & 2e). The latter two were used in rare cases, when students were referring to parallel lines or simultaneous rays.

Category 2 gestures appeared to convey spatial properties such as length, orientation or direction of a line or ray. Sometimes they stood for an element in diagram such as, a ray or several rays of light, the axis, equator, orbit, etc. They also could show motion such as rotation, revolution, or transition of light and simultaneous transition of rays. These attributes might ordinarily describe 'Metaphoric' gestures, hence 'Deictic Spatial' gestures may lie on the borderline of 'Deictic' and 'Metaphoric' gestures. They are classified here as 'Deictic' because, they involved pointing and were invariably made on paper. In comparison with ‘Metaphoric’ gestures, they carried less meaning in themselves and could in principle have been translated into speech, had the speaker wished to do so. However they did reflect students’ process of thinking, particularly when they traced a proposed shape aimed to lead towards a solution of the problem, rather than an existing shape on paper. The frequent occurrence of ‘Deictic spatial’ gestures may therefore be seen as support for the ‘mental model - gesture - diagram - phenomenon’ links that were part of our research conjecture.

Several types of ‘Deictic spatial’ gestures occurred informally in our teaching. Our set of designed gestures (Table 5.1) contained four in the ‘Deictic spatial’ category (G7, G10, G15 & G32), of which G10 and G15 were used spontaneously by students. G10, showing motion of the earth for the axis in the given diagram, which is a version of ‘Deictic circular’, was used in Session 3 (0.08 times per minute for RG and 0.32 times per minute for TB), where the tasks were based on the rotation of the earth. G15 (in Table 5.1, tracing ray diagrams) was used in all of the sessions. Session 2 (Shadows), Session 3 (Rotating earth) and Session 5 (Seasons) involved problem tasks in which light rays were necessary to be drawn respectively to locate a shadow, to identify angle of a particular star above the horizon and to find out lit and dark parts of the earth. Figure 5.9 shows that ‘Deictic line’ and ‘Deictic multiple line’ gestures were in fact used most often in Sessions 5, 3 and 2. Similarly, the ‘Deictic simultaneous line’ was used only in Sessions 1 and 3, in which pairs of lines and beams of light were to be drawn. These examples further confirm our expectation that students’ gestures would be closely connected to the content of the task.

Exact interpretation of deictic gestures was not feasible, especially when the pointing was done on the diagram, since (although the paper was visible) the focus of the camera was on the student and not on the paper. At a gross level however, it was possible to characterise the purpose of the above deictic gestures as: **1.** to avoid referring to something each time by word, **2.** to refer to something whose name is less familiar or unknown, **3.** to communicate the position, orientation, or shape of an existing, or proposed, portion of the diagram, **4.** to compare the drawn diagram with another diagram (either drawn for an earlier question or on rough paper), **5.** to suggest corrections to the diagram ("not this way, but this way"), and **6.** to plan (for self as well as in the group). 'Deictic simple' and 'Deictic spatial' thus constituted the first two most frequent types of gestures, playing varied and important roles in the process of communication in solving spatial tasks in astronomy.

3. Other deictic gestures: Category 3a 'Deictic portion' refers to a gesture showing part of text or diagram on paper using the thumb and index finger. This gesture occurred rarely and was more akin to a style adopted by a couple of students, to refer to the text or relevant part of a diagram, without necessarily carrying any specific spatial significance.

Deictic gestures of first three categories (1, 2a - 2f and 3a), which make up the largest fraction of the total gestures, were done on paper. Category 3b 'Deictic instruction' on the other hand, refers to pointing towards an instruction or a hint written on the board by the teacher, or occasionally directly pointing to the teacher to refer to her hints or instructions. The 'Deictic instruction' gesture did not relate to any specific content but referred to whatever hint happened to be written on the board. Figure 5.9 shows that the largest number of 'Deictic instruction' gestures occurred in Session 5, in which problems were based on the newly taught content of seasons, and hence teacher interventions too occurred frequently.

4. Metaphoric gestures: 'Metaphoric gestures' (Category 4) formed the fourth most frequent type of gestures. Their distinguishing feature was that they were performed in the air and, unlike spatial deictic gestures, did more than merely serve to trace parts of the text or diagram on paper. A second characteristic that distinguished metaphoric gestures from the 'Deictic spatial' category was that, although often accompanied by speech, they carried in themselves significant meaning that was not easily expressible in words. Two instances of spontaneous metaphoric gestures were: two palms inclined to the vertical to denote the tilt of the earth's axis with respect to the ecliptic plane, and a flipping movement of the palm to denote formation of a shadow of a vertical object on a horizontal plane.

Metaphoric gestures formed the predominant component of our designed pedagogical gestures, yet students' spontaneous metaphoric gestures differed considerably from those used in our pedagogy. Firstly, the students' gestures were fleeting, not bold, well-defined and elaborated, as had been the practice during the teaching. Secondly, they occurred in chunks, spread over a minute or two, yet each gesture was done very quickly, typically within a fraction of a second. Thirdly, the students' gestures expressed discrete aspects of the model, for example, rays and beams of light, or individual objects such as the sun, earth or ground, rather than whole models as they were taught, for example, the rotating earth, or formation of shadows.

Fourthly, most of the metaphorical gestures happened to be not addressed to fellow students in the group, but were done in the presence of the teacher, or in response to the teacher's questions to the entire class. Though these gestures may have been a direct result of the teacher's earlier efforts to encourage gestures, they appeared spontaneous enough that other interpretations are possible. The teacher's interventions occurred mainly when a conceptual formulation was needed, or further explanations were called for: situations that might have been especially facilitated by metaphorical gestures. Another possibility is that, while for communication with fellow students, subtle oral or gestural hints sufficed, in communicating with the teacher, students needed to be more explicit, so that the teacher understood their explanation, or became convinced of their competence with the concept.

Finally, several of the metaphoric gestures in our pedagogy included whole body actions or were done in groups of more than one student: none of these were seen spontaneously in students.

Table 5.4 shows that the average number, of all types of gestures taken together, per student per minute, actually increased over the sessions (except for a slight decrease in the last session). Yet Figure 5.9 shows that the incidence of metaphoric gestures decreased from Session 1 to Session 5 (except for Session 4). This may imply that students used more gestures with more difficult content but in order to use metaphorical gestures they needed better expertise, or more familiarity with the content. A parallel might be drawn with verbal communication, where an expert may use fewer but more precise words than a novice to communicate the same content.

5. Iconic gesture: Strikingly enough, the only iconic gesture in the pedagogy for determining direction of rotation of the earth ('Right Hand Thumb Rule', G13 in Table 5.1) also turned out to be useful for problem solving (Category 5). Students spontaneously used this gesture while solving problems which required the direction of rotation of the earth in Session 3 (0.06 times per minute in RG and 0.08 times per minute in TB) and in Session 5 (0.05 times per minute in RG); and while solving problems based on the revolution of the earth in Session 4 (0.2 times per minute in RG and 0.13 times per minute in TB) (Figure 5.10b).

6. Gestures for orientation change: Another type of pedagogical gestures that were spontaneously adopted by students was the 'Orientation change' gestures (Category 6). Specifically G12 in Table 5.1 was used in Session 3 (0.11 times per minute in RG and 0.24 times per minute in TB). These gestures do not fit into any of the categories in the classification schemes currently used in the literature (McNeill in (Radford et al., 2009)), (Roth, 2000; Goldin-Meadow, 2006a). The reason is that all the current schemes consider exclusively the communicative aspect of gestures, whereas in the 'Orientation change' category we have gestures with no necessary communicative purpose: the primary purpose of performing this gesture is to facilitate an imagined change in orientation. Many researchers believe that gestures are not only tools for communication but they play an important role in thinking and reasoning, and continuous effort are made to find evidence for this claim (Goldin-Meadow, 2006a; Hegarty, 2005). The 'Orientation change' gestures are strong candidates to provide support for the above claim.

In summary, students freely and spontaneously used gestures many of which followed the patterns introduced in the pedagogy and were consistent with the requirements of the problem situations.

As explained in the Conjecture (Subsection 3.3.4) and in the Pedagogic Sequence (Chapter 4) our gestures were designed to lead towards depicting the models or the phenomena in the form of schematic diagrams. We will next analyze the diagrams that were used in teaching and then analyze the students' diagrams, based on criteria formulated for this purpose.

5.3 Diagrams

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 about shapes and sizes of the bodies in the solar system and their respective distances and patterns of motion, which help to explain visible astronomical phenomena. Considering the frequent usage of visual representations in astronomy in general and the significance of the visual-spatial properties of the heliocentric model in elementary astronomy in particular, students should be exposed to as many types of visual representations as possible and should learn the skills to comprehend them. Schematic diagrams being foremost among visual representation in our pedagogy, are analyzed in this section. Other visual representations of potential use in conveying content in elementary astronomy such as photographs, graphs, etc., were not analyzed.

Subsections 5.3.1 analyzes the functions of diagrams and Subsection 5.3.2 outlines the characteristics that make them effective as a pedagogical tool. Subsection 5.3.3 analyzes students' diagrams before and after intervention to assess the effects of a diagram-centered pedagogy. (These Subsections are based on (Padalkar and Ramadas, 2011)).

5.3.1 Types of diagrams in astronomy

We have classified diagrams in elementary astronomy into three functional types:
1. Diagrams representing a 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) (Examples: D4, D9, D10, D23, D32, D36 from Tables 4.1, 4.2 & 4.5). They have the following characteristics:

i. A particular perspective (for three dimensional to two dimensional 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 the comparison with sizes of celestial bodies, these diagrams cannot be drawn to scale.

Figure 5.11 is an example of diagrams representing a mental model of the sun-earth system from three different perspectives. It is a projection view which shows motion using arrows, and it is not drawn to scale.

2. Diagrams representing a phenomenon or patterns in the phenomenon (over many days) show view as seen by an observer (usually) on the earth, and record either observed position or shape (Examples: D1, D15, D30, D34 from Tables 4.1, 4.2 & 4.5). Such diagrams may be drawn over 12 hours (e.g. to identify the pattern of motion of the sun, moon or stars over a day or night), or 30 days (e.g. 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). Spatial as well as temporal elements need to be included in them. 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 5.12).

3. Diagrams providing explanations or predictions include an argument, and generally require a change of reference frame from allocentric to egocentric (Examples: D6, D7, D11, D13, D14, D16, D18, D27, D29: Figure 5.13, D32, D35, D37, D39, D40 from Tables 4.1, 4.2 & 4.5). 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, in the following ways:

i. Explanatory diagrams require selection of a preferred point of view.

ii. They include only relevant parts and elements of the model.

iii. They include additional elements or transformations.

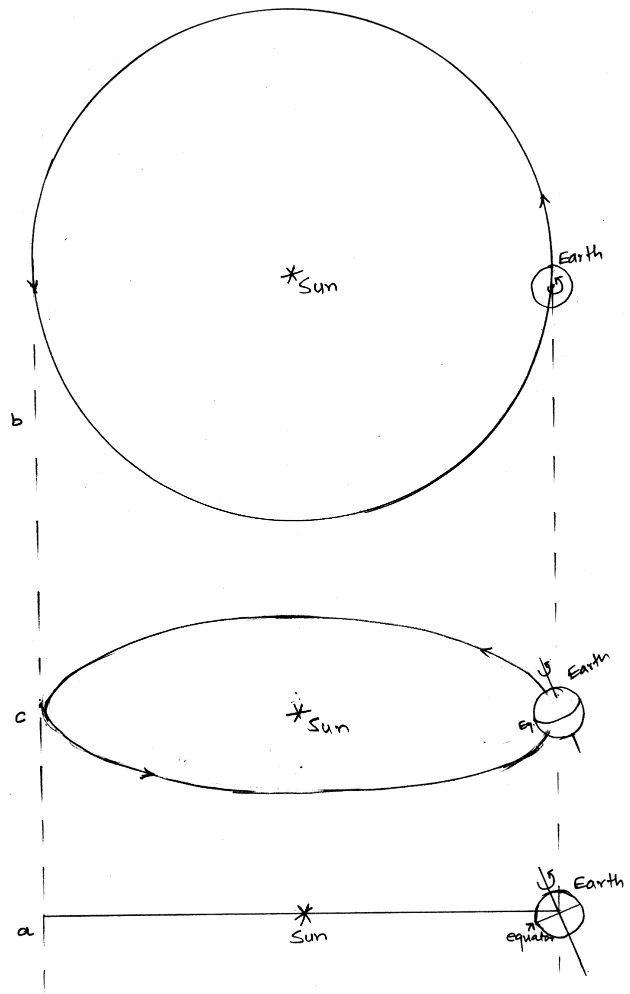


Figure 5.11: The sun-earth system from three different perspectives (D23; a: as seen from within ecliptic, b: oblique view, c: as seen from above North Pole)

Identification of the relevant elements of a model and choosing a suitable point of view may make explanatory diagrams difficult to construct.

This broad classification may be applicable also to diagrams in advanced astronomy, all of which (in our experience) represent either phenomena, or models or, explanations which join models with phenomena.

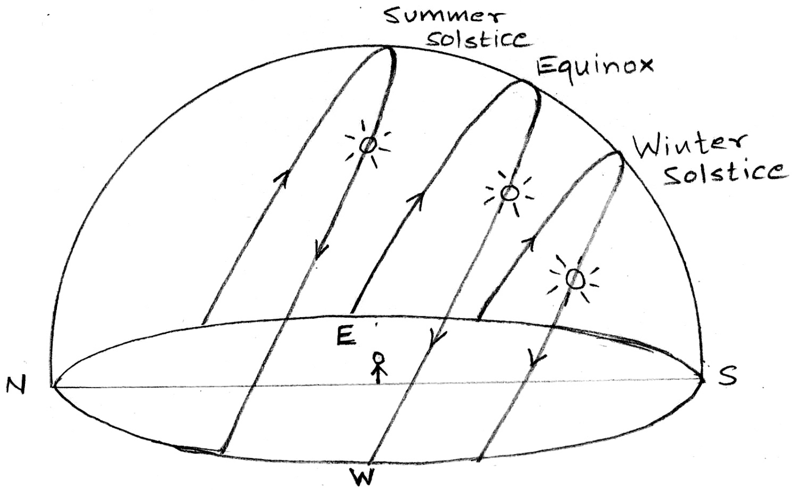


Figure 5.12: Changes in the path of the sun over a year on the tropic of cancer

5.3.2 Characteristics of our pedagogical 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 (Section 5.2), spatial tools which were expected to help students construct a mental model and meaningful diagrammatic representations.

2. Interactivity: Students are generally not equipped with the skills for constructing schematic diagrams. During our pre-intervention testing and intervention, we found that students cannot draw a complete diagram on their own. They need continuous scaffolding until they achieve a mastery over both the subject matter as well as the diagrammatic medium. In place of giving a readymade diagram (which usually the case in textbooks) it is better if a diagram evolves in front of the students. In this way, students can become familiar with the process of construction of a diagram, and the transformable nature of diagrams can also get manifested during the process. In our pedagogic sequences, the diagrams were made interactive in the following two ways:

i. *Diagrammatic dialog in classroom*: Diagrams were drawn on the black board through the joint efforts of teachers and students. A teacher would ask one of the students in the class to draw a particular element of the diagram. If s/he drew it incorrectly another students would come to the board and correct it. The teacher would continue to provide instructions and hints and would draw it herself if only if the students could not draw that particular element or if any new or crucial elements were to be drawn. Thus the entire diagram would be constructed jointly by students and teacher, with an accompanying dialogue involving observations, concrete models, gestures, and actions.

ii. *Providing skeletal diagrams*: We know from previous work that providing students with skeletal diagrams enables them to work within an abstract context and results in more explanatory, in place of descriptive, responses (Ramadas and Driver, 1989). 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. Students in each group discussed the problems, negotiated the solutions on rough paper, and finally wrote and drew their consensus solutions. Skeletal diagrams and step-wise instructions were provided and students had to complete the construction of a diagram to draw the inference asked in the problem. The original Marathi questionnaires for guided collaborative problem solving are given in Appendix B.

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 5.11, the top view represents the directions of the earth's rotation and revolution and the correct shape of its orbit, whereas the side view 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, not only in Indian school textbooks but also in most otherwise good 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, the angle of a celestial body above the horizon and finally, to take a projection so as to view what the observer must be seeing. Extending the rays until they touch the surface allows one to see a consequence (e.g. 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 5.12). Rays 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 explanatory diagram for occurrence of seasons (D29: Figure 5.13 in Section 4.3) for example, we have assumed that the sun-rays are parallel, the horizon in 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.

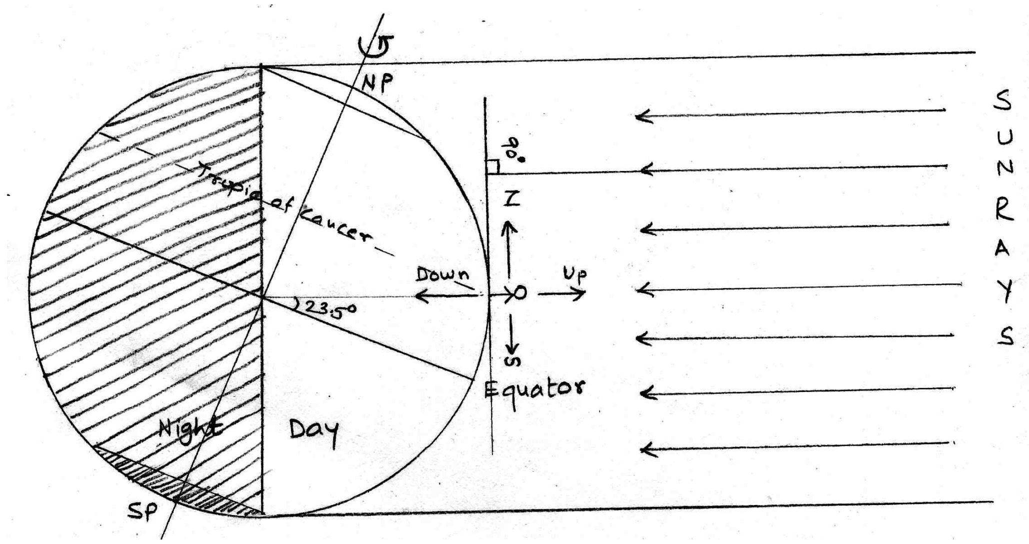


Figure 5.13: Apparent position of the sun for a person on the tropic of cancer on the day of summer solstice

5.3.3 Assessment of students' diagrams

Of the four characteristics discussed above, the first two, 'integration' and 'interactivity' have to do with classroom interactions, and results on them are presented in Section 5.2 and Subsection 4.3.3. The second two, 'transformability' and 'presence of explanatory elements', can be seen directly in diagrams. We now assess these two characteristics in diagrams drawn by students from different grades: 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 total number of possible diagrams where that component could have been shown (percentage of diagrams which included that component out of total number of required diagrams). A * next to any value in the Tables indicates a significant difference (by pair-wise z test) between that value and the one in the row below it in Tables 5.5 - 5.7 or column to the right of it in Tables 5.8 & 5.9.

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 5.5 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.

Table 5.5: Percentages of total diagrams, irrelevant diagrams and diagrams which contain realistic details out of total number of diagrams.

Grade	*No. of diagrams*	Percentage of diagrammatic responses	*No. of diagrams*	Percentage of incorrect diagrams	*No. of diagrams*	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

* Denotes that the difference between that value and next one in the same row is significant at $p<0.05$.

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.

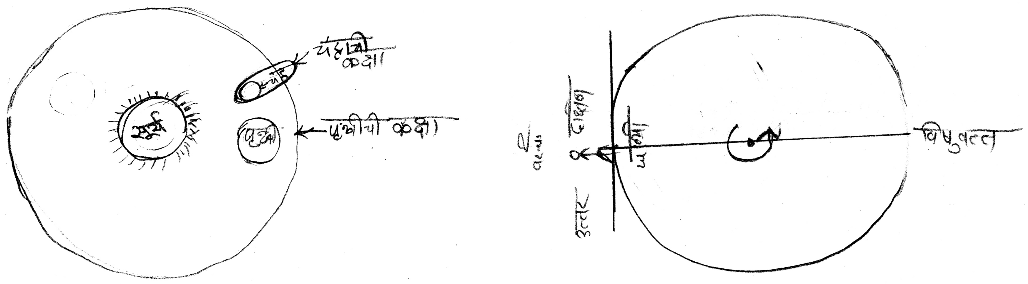
i. Coherency: the relation between different elements (rotational axis, poles, equator, orbits) of the system (whether the axis is perpendicular to equator, whether the sun is inside the earth's orbit). An example of diagram with model coherency "incoherent diagram" is Figure 5.14a where both the earth 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 5.14b the equator is drawn from the plane of ecliptic and the axis is drawn from above the North Pole. Figure 5.14a 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.

The percentage of diagrams showing coherency and perspective consistency are shown in Table 5.6. If a diagram contained only a single element or no element, then neither coherent nor consistency could be determined hence these diagrams are omitted from Table 5.6.

Table 5.6 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



(a) Student's diagram of the sun-earth-moon system shows incoherency in elements (the earth and the moon are not in their orbits and the moon's orbit is not around the earth)

(b) Student's diagram of the earth from 'within the plane of the ecliptic' shows inconsistent perspective (the equator is drawn from the plane of ecliptic and the axis is drawn from above the North Pole)

Figure 5.14: Examples of students diagrams showing incoherency in relations among elements and perspective inconsistency

Table 5.6: Percentage of diagrams with coherent model, indeterminate model coherency, coherent perspectives, and indeterminate perspective coherency out of total possible diagrammatic responses

Grade	*No. of diagrams*	% 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

* Denotes that the difference between that value and next one in the same row is significant at $p<0.05$.

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 model coherency and perspective consistency as well as model incoherency and perspective inconsistency.

After identifying the key criteria to judge the diagrams, we found is a need to develop a more specified scheme to evaluate students diagram which will take account of number of elements drawn in the diagram while deciding the coherency between the elements and perspective consistency.

An important feature of mental models is that they are dynamic and can be simulated or 'run' to draw inferences (Hegarty, 1992). Representing of motion in diagrams is a means of rendering them dynamic and thus 'transformable'. Table 5.7 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)

Table 5.7: Percentage of diagrams in which axial and orbital motion was shown

Grade	No. of students	*No. of diagrams*	% of diagrams in which motion is not shown (a)	% showing axial motion (b)	*No. of diagrams (orbital)*	% showing 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

* Denotes that the difference between that value and next one in the same row is significant at p<0.05.

Table 5.7 shows that the percentage of diagrams showing motion, either axial or orbital, was not significantly different in Grades 4 and 7. Only 4 and 3 students respectively represented the rotation of the earth in Grade 4 and Grade 7 respectively. 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. 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 (notation used in the intervention).

iv. Other (e.g. ring).

Students from Grade 4, Grade 7 and the Grade 8c used only the last notation, which is ambiguous and less economic. Most of the students in Gr8t (more than 30%) used the Axis + curved arrow.

Table 5.7 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. However it may be a result of the extensive treatment of orbital motion in Grade 7. 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.

Explanatory elements

Three elements were identified as those which help explanations (see Subsection 5.3.2): horizon, local directions and parallel rays. Students were required to draw horizon and local directions in three diagrams. The results are in Table 5.8. Since none of the students from Grade 4 and Grade 7 drew the 'horizon' and 'local directions', their percentages are not listed. In Question 1 in Table 5.8, students had to draw the earth, human beings on it, and the horizon and local directions for two of those human beings (Question no. 2 in Test 4, Appendix B.4). 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 (Question no. 9 in Test 4, Appendix B.4). 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 (Question no. 11a in Test 4, Appendix B.4). 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 diagram was required to be drawn from a specific perspective.

In Question 3 (Table 5.8) 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 in the North. Only 1 student from the comparison group drew the horizon and 3% students drew the North-South directions.

Table 5.8: Percentage of students who drew the 'horizon' and 'local directions'

Q. No.	Question	Horizon		Local directions		
	No. of students	Gr8t *55*	Gr8c *76*		Gr8t *55*	Gr8c *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

* Denotes that the difference between that value and next one in the same row is significant at $p<0.05$.

Parallel rays: Students were required to draw parallel rays in 6 questions (Table 5.9). Five of these questions (Questions 2-6) were not given to Grade 4 students, and two (Questions 2 & 3) were not given to Grade 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 required to draw parallel sun-rays to determine both the terminator and the angle of the sun above the horizon.

Table 5.9: Percentage of students who drew 'parallel rays'

No.	Question *No. of students*	Gr4 *88*	Gr7 *59*	Gr8t *55*	Gr8c *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

* Denotes that the difference between that value and next one in the same row is significant at $p<0.05$.

From Table 5.9 we see that percentage of students who drew parallel rays for Questions 1, 3 and 4 is significantly higher in the treatment group than in the comparison group. Although average percentage of students who drew parallel rays in Questions 1-3 is similar in Grades 4, 7 and 8t, Grades 4 and 7 students were required to explain only only the first question, and the textbook diagram for for this situation contains parallel rays. Grade 8 students were required to draw parallel rays from the Pole Star and to explain seasons. Percentage of students who drew parallel rays to explain seasons was significantly higher in the treatment group than the comparison group. However, only one student from the treatment group and none from the comparison group drew parallel rays from the Pole Star, which shows the difficulty in learning to use parallel ray approximation in the case of stars.

To summarize, the 'concrete model-gesture/action-diagram' conjecture was found to be useful in the design of our pedagogy. In our pedagogy, concrete models were used flexibly, were made out of materials which were easily available and could be easily replaced by other material. For example, a model of three axes could be made out of chop sticks, or pencils or wooden twigs. Models used to revise concepts in geometry were concrete objects in the surrounding, or those that students could recall (e.g. rail-tracks for parallel lines), which helped place abstract concepts in a concrete context.

Designed pedagogic gestures was a novel attempt. These gestures brought out the dynamic three dimensional nature of phenomena, models and diagrams. Change of reference frame and change of orientation are functions unique to gestures and actions. We found that students also used such gestures. Although students' gestures were not as elaborate as pedagogic gestures, they were closely related to the content of discourse.

Difficulties in students' diagrams had to do with representing relations in a coherent fashion, maintaining a single perspective and representing motion. Students' diagrams also lacked explanatory elements and contained irrelevant elements representing realistic details. However, conscious efforts to make students aware of these factors and extensive practice in drawing improved the quality of their diagrams.

Chapter 6

Assessment of Astronomical Knowledge: Observations and Facts

Out of the five pre and post tests, analysis of the first three tests (Observations, Textbook Facts and Indigenous Knowledge) is presented in Sections 6.1, 6.2 & 6.3 respectively. Analysis of Tests 4 and 5 (The Sun-Earth Model and The Moon) is presented in Chapter 7. The percentages of correct (C.) and incorrect (W.) responses in each grade ware tabulated for each question (N.R.= No response). Responses similar in kind are grouped together and where possible, arranged in order of their frequency in the Tables. Response numbers in bold denote the correct (or expected) responses or aspects of the diagrams. Gr4, Gr7 and Gr8t refer to Grades 4, 7 and the 8-treatment group. 'N' denotes the total number of students in the corresponding Grade who attempted that test. Gr8c refers to the Grade 8-comparison group. Rural, tribal and urban samples are combined to find the percentages, since (at this granular level) no consistent pattern was found in the responses of these three samples. Overall differences between these samples are summarized in Section 7.5.

Pairwise z tests between two successive columns (Grade 4 and Grade 7, Grade 7 and Grade 8 for the treatment group, and the treatment group and the comparison group) were carried out for each category of response, as explained in Subsection 3.5.5. A * next to any value in the Tables indicate a significant difference between that value and the value in the column to the right of it in the same row.

Significance of difference between percentages of two kinds of responses is not calculated. However, where we found such comparisons insightful, we have noted them, though these comparisons are qualitative no statistical significance is implied in them.

6.1 Test 1: Observation

The ‘Observation test’ aimed to investigate students’ breadth of observations relating to everyday astronomical objects and events, the quality of these observations and students’ knowledge about terms used in observational astronomy. A total of 173 answer scripts were analyzed from students of Grade 4, 7, 8-treatment group and 8-comparison group (Table 3.3). The original test is given in Appendix A.1.2 and its English translation in Appendix A.1.1. In most of the questions students were first asked whether they had seen a particular astronomical object or event. If yes, they were asked to name the instances or describe them. A few questions which did not fall under this general pattern are explained in the subsections that follow.

Analysis of the ‘Observation test’ is divided into 4 subsections each related to a group of different astronomical objects and events. In Subsection 6.1.1 we discuss responses to questions testing general observations (Question nos. 1 & 12). In Subsection 6.1.2 students’ observations about the sun and day-night are discussed (Question nos. 2, 3 &5). Subsection 6.1.3 concerns objects and events in the night sky such as planets, stars and shooting stars (Question nos. 4, 6, 7, 8, 9 & 10). Subsection 6.1.4 exclusively discusses students’ observation about the moon (Question no. 11). Table A.2 shows correspondence between the subsections below and the original question numbers.

6.1.1 General observations

Two questions were related to general observations. One was a free response question asked at the beginning of the test to initiate students’ thinking, and another was asked at the end to check whether students were aware of the reference frame in which all their observations are embedded.

Free response question

Students were asked to list the objects seen in the sky in the appropriate column of a Table marked ‘Morning’, ‘Both’, ‘Night’ (The Marathi word for ‘Morning’ is used because the colloquial Marathi word for ‘day’ is ambiguous. It may mean ‘day-time’ as well as a ‘24 hours day’ which includes night). This question was meant to test general observational ability and to prepare students’ mind-set for the tests in astronomy.

All students (except one in Grade 7 in the tribal sample) could list the objects seen in the sky. Their responses (in percentages) are classified and summarized in Table 6.1. Correct time for each response (M: morning, N: night, B: both) is indicated in bracket in front of the response. Responses indicated in the correct time are listed in the ‘Timing correct’ column and those in the wrong time are listed in the ‘Timing wrong’ column. ‘XX’ in the ‘Timing wrong’ column indicate that the particular response can never be wrong since those objects are seen during both day-time and night.

This being the first question in the first test, students were not primed to the astronomical context. Even then they gave large number of astronomical responses. Perhaps students notice and/ or recall astronomical objects more than other objects in the earth’s atmosphere. It may also indicate a level of interest in astronomical objects and event. In any case this shows that astronomical world must be a subject of students’ interest and curiosity.

A total of 36 kinds responses were given, out of which 31 could be characterized as correct responses. Out of these 31 kinds, 17 responses were objects in the space (or events such as eclipses/ shooting star) (Response nos. 1-9 are the frequent among them). The remaining 14 were objects on the earth (Response no. 10-18). Responses related to astronomical objects or events were more frequent than objects/ events in the earth’s atmosphere. Out of 1644 responses, roughly 61% related to astronomical objects and 27 % to objects in the earth’s atmosphere. The remaining 11% responses were invalid such as Sky ($\sim$ 5%), Sunshine ($\sim$ 2%), Objects on the earth or the earth itself ($\sim$ 2%), Moonlight ($\sim$ 2%), Darkness ($\gtrsim$ 1%).

From Grade 4 to Grade 7 to Grade 8, students’ focus shifted from objects in

Table 6.1: Percentage of students who cited particular objects seen in the sky (Question no. 1)

No.	Grade *N*	Gr4 *87*		Gr7 *62*		Gr8t *52*		Gr8c *72*	
	Timing	**C.**	W.	**C.**	W.	**C.**	W.	**C.**	W.
	Objects in Space (Correct time)								
1	Sun (M)	97	1	92	3	96	19	99	0
2	Moon (B)	98	XX	95	XX	100	XX	97	XX
3	Stars (N)	40	3	50	7	73	4	83	1
4	Chandanya (N)	24*	1	33*	2	12	2	0	0
5	Name of a star (N)	1*	0	7	0	4	0	1	0
6	Rockets	12*	XX	3	XX	12	XX	4	XX
7	Planets (N)	29	5	25*	5	65*	4	21	0
8	*Nakshatra* (N)	4	1	10	0	10	6	3	0
9	Other correct responses	3*	0	24	0	20*	2	0	0
	Objects in the earth's atmosphere								
10	Clouds (B)	55*	XX	79*	XX	35	XX	26	XX
11	Plane (B)	60*	XX	26	XX	23	XX	39	XX
12	Birds (B)	61*	XX	35*	XX	14*	XX	35	XX
13	Kite (B)	1	XX	3	XX	2	XX	10	XX
14	Helicopter (B)	2	XX	2	XX	2	XX	4	XX
15	Rainbow (M)	2	0	0	0	0	0	0	0
16	Dust particles (M)	0	0	2	0	0	0	3	0
17	Smoke (M)	1	0	2	0	0	0	0	0
18	Electric light (B)	0	0	3	0	2	0	0	0

* Denotes significant difference at $p<0.05$ between that value and the corresponding value for the Grade level to its right in the same row.

the earth's atmosphere to astronomical objects. The percentages of three most frequent responses of the objects in the earth's atmosphere (Response nos. 10, 11 & 12) were significantly less in Grade 7 students than in Grade 4 students, and in two of the cases (Response nos. 10 & 12) they further decreased after treatment. Significantly more number of students in treatment group correctly responded after the intervention that some planet (or a particular planet) can be seen in the night sky, and the credit might be attributed to the night sky gazing sessions.

'Other correct responses' (Response no. 9) included Jupiter, satellite, galaxy, shooting star, asteroid, solar eclipse and lunar eclipse. Some rare responses given by less than 1% (less the 3 students) were: balloon, rain, firing, solar system, artificial satellite, *Rashi*.

Qualitatively we see that in the list of correct responses, the objects which are bigger (Sun, moon, clouds; Response nos. 1, 2, 10) or more frequently seen (Response nos. 3, 11; i.e. stars, airplanes[1]) are listed more often than smaller/ less-frequently-seen objects; which is but natural. However, all these responses may not be derived from observations. Fifteen percent of the total (1644) responses related to objects which either could not have been seen or identified by students (e.g. Galaxy, rocket), or were rarely seen or avoided to be seen because of cultural strictures (e.g. eclipse).

Almost all the students repeated the answers in two or all three columns (e.g. Writing 'moon' in columns 'Morning', 'Both' and 'Night') (Response no. 2). We have counted every response only once, and if it was written in one correct column and one wrong column (e.g. the 'sun' in both 'Morning' and 'Both' column) we counted it only in the correct column.

Reference frame for observations

All our observations from the earth are essentially embedded in a frame of reference that is defined by the local horizon (Subsection 4.2.4). Yet, most textbooks do not address the concept of 'horizon' in the context of astronomy, although the word (*'kshitij'* in Marathi) is sometimes known to students from literary or poetic contexts.

Three questions were asked to find out what students know about the horizon and whether they have seen it:
i. What does 'horizon' mean?
ii. From where have you seen the widest horizon?
iii. What was the shape of the horizon?
Percentages of students' responses on these questions are summarized in Table 6.2.

[1] In the Kolhapur area, where the rural and tribal schools are located, the nearest airport is a small one, with only one daily airplane. Most of the planes which are seen are of small size i.e. flying high up

Table 6.2: Percentage responses to questions related to 'horizon' (Question nos. 12 i, ii, iii)

Grade (*N*)	What does 'horizon' mean?			Location from where biggest horizon is seen			Shape of horizon		
	% **C.**	% W.	% N.R.	% **C.**	% W.	% N.R.	% **C.**	% W.	% N.R.
Gr4 (*87*)	0	2	98	0	0	100	0	0	100
Gr7 (*62*)	0*	0*	100*	0*	0*	100*	0*	0	100*
Gr8t (*52*)	74*	8*	18*	58*	8*	34*	66*	2	32*
Gr8c (*72*)	31	0	69	28	0	72	14	4	82

* Denotes significant difference at p<0.05 between that value and the one below it in the same column.

The correct responses to the question 'what does 'horizon' mean?' include the following:

1. Sky touches land

2. Point up to which we see

3. Line of ground (Marathi translation of this phrase "*Jaminichi resha*" was often used in the classroom)

The locations reported by students from where they had seen the widest horizon were: seashore, (playing) ground, mountain, terrace, and farm. The responses for shape of the horizon were: round and line. A few students drew a picture, usually of a wavy irregular line (Figure 6.1).

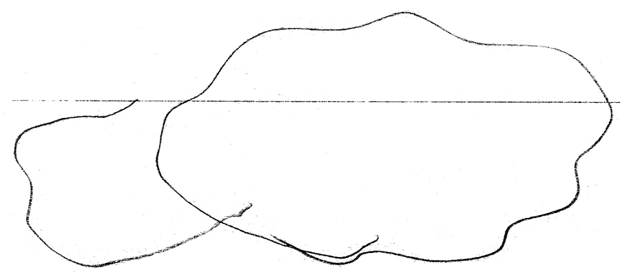


Figure 6.1: Picture of horizon by a Grade 8 (treatment group) rural girl

Table 6.2 shows that students in Grades 4 and 7 had no idea of the meaning of the term 'horizon'. Post intervention (in Grade 8), 74% students in the treatment group could correctly write the meaning of the word 'horizon', 58% responses mentioned an acceptable location from where they might have seen the widest horizon and 66% responses cited an acceptable shape of the horizon. The corresponding percentages for the comparison group were significantly lower: 31%, 28% and 14%.

The treatment group thus performed significantly better than the comparison group in all these three questions. Interestingly in the comparison group most of the correct responses come from tribal students, which may mean this particular class had been exposed to this concept perhaps through some experience common to that class.

6.1.2 The sun and day-night

In the second question students were asked to write a description of and give some information about the sunrise and sunset. The question was asked to investigate what students know about sunrise and sunset, to check whether they have really observed the sunrise and sunset and if they have, what are their observations.

How many students have seen the sunrise and sunset?

Students were asked whether they have seen the sunrise and sunset. The percentages of students who responded that they have seen the sunrise and the sunset are summarized in Table 6.3.

Taking all samples together, we see from Table 6.3 that:
In Grade 7 and Grade 8c more students responded that they have seen the sunset than those who said they have seen the sunrise[2]. In the treatment group, the percentage of students who have seen the sunrise in the pre-test is significantly greater then that in pre-test.

[2]Statistical significance across the columns is not marked in the Table.

Table 6.3: Percentage of students who responded that they have seen the sunrise and the sunset and the correct directions of sunrise and sunset (Question nos. 2 i, iv, vii & ix)

Grade	No. of Students *N*	Whether seen		Direction of	
		Sunrise	Sunset	Sunrise: East	Sunset: West
Gr4	*87*	87	86	76*	76*
Gr7	*62*	76*	95	89	95
Gr8t	*52*	91	94	93	94
Gr8c	*72*	78	93	94	94

* Denotes significant difference at $p<0.05$ between that value and the one below it in the same column.

How many students know the direction of sunrise and sunset?

Students were asked to name the direction of the sunrise and sunset. Table 6.3 shows that the percentages of students who correctly stated the direction of the sunrise and the sunset increased from Grade 4 to Grade 7 and then seems to have saturated. The percentage of students who stated the correct direction of sunrise and sunset is almost same for post-test of the treatment group and the comparison group, which shows that students would have learnt these facts in the regular course, even without intervention.

How many students know that the direction of the sunrise and the sunset slightly changes every day?

Systematic observations are required for noticing the changes in the directions of the sunrise and sunset and the pattern of these changes, particularly in the tropical regions where variations in direction of sunrise and sunset are relatively small. On the positive side, the fact of change in path of the sun towards the North from winter to summer and towards the South from summer to winter is taught to students in the Geography textbooks of Grades 6 and 7. The winter solstice is also celebrated as a festival "*Makar Sankranti*". In two different questions students were asked whether the time of sunrise and sunset remains the same every day or it slightly changes. The percentage of correct responses is summarized in Table 6.4. As expected, the percentage of younger children who have noticed the changes in the direction of sunrise and sunset is quite small (in Grade 4, 26% and 33% respectively). The percentage of correct response has increased from Grade 4 to Grade 7 for both sunrise and sunset and has further increased from Grade 7 to Grade 8 in the treatment group. However the percentage of students who responded that the direction of the sunrise and the sunset changes every day is almost same in post-test of the treatment group and the comparison group which shows that our intervention had little effect for this observation, which may have been learnt probably through school intervention.

Table 6.4: Percentage of students who responded that the direction and time of the sunrise and the sunset changes every day (Question nos. 2 v, vi, x & xi)

Grade	No. of Students *N*	Changes in direction of		Changes in time of	
		Sunrise	Sunset	Sunrise	Sunset
Gr4	*87*	26*	33*	25*	31*
Gr7	*62*	44*	50*	65*	66*
Gr8t	*52*	76	70	93*	91
Gr8c	*72*	76	69	72	89

* Denotes significant difference at p<0.05 between that value and the one below it in the same column.

Dose the sun rise and set at the same time every day?

As remarked above with regard to variation in direction, the variation in the time of sunrise and sunset too is less dramatic in tropical places (here, about two hours maximum). Although getting dark earlier in winter may be a noticeable phenomenon, noticing the changes in the time of sunrise and finding out the pattern of these changes may not to be easy for younger students. On the positive side, the geography textbook of Grade 6 mentions that the durations of days and nights vary during seasons and in Grade 7 the textbook explicitly mentions that the time of sunrise and sunset changes over the year. The local calendars, also mark times of sunrise and sunset. Students were asked whether the time of the sunrise and the sunset remains the same every day or are there slight changes. The percentages of correct responses are tabulated in Table 6.4. As expected, the percentage of the students who responded that the time of the sunrise and sunset changes every day is small in Grade 4 (25% and 31%), but has increased to about 65% by Grade 7. The percentage of correct responses in the treatment group has further increased in the post-test to more than 90%, more than the percentage of correct responses given by the comparison group (roughly 80%) suggesting that the majority of students learnt the relevant fact in the normal course.

More than 90% of students in the treatment group answered this question correctly. While explaining occurrence of seasons, the intervention included a session on tabulating timings of sunrise and sunset, and plotting their graphs to see variations in day-light. The reason behind the changes in timings was also addressed through a diagram which students were asked to construct during one of the guided collaborative problem solving sessions. However, although students were encouraged to note the position of the sun at different times of the day, observation of the sunrise and the sunset were directly not carried out in the presence of teacher as a part the intervention. A well designed set of observations of sunrise and sunset should be included in future interventions.

Does the sun come overhead every day?

In the tropical region, the sun at noon remains fairly close to the zenith. The non-zero shadows at noon are indirect evidence that the sun is not exactly at the zenith, but such reasoning requires good observational and inferential skills. For these reasons we expected that most of the students would not know that the sun is not overhead every day. Table 6.5 gives the percentage of correct and incorrect (wrong) responses to the question 'Does the sun comes overhead every day?[3]'.

Only about 3% students in Grade 7 responded in the pre-test that the sun does not come overhead every day. On the other hand, almost 84% students responded that the sun does come overhead every day. The percentage of correct responses increased to about 34% in the post-test and the percentage of incorrect responses dropped to 55%. The percentage of both correct and incorrect responses in the comparison group is similar to that of the treatment group in the pre-test. Although

[3]The word in Marathi is '*Dupaar*' which refers to the times of noon and afternoon and is popularly related to the idea of the overhead sun.

Table 6.5: Percentage of students who correctly said that the sun does not come overhead every day and who incorrectly responded that the sun does come overhead every day (Question no. 2 xiii)

Grade	*N*	The sun doesn't come overhead every noon	The sun is overhead at every noon
Gr4	*87*	52*	41*
Gr7	*62*	3*	84*
Gr8t	*52*	34*	55*
Gr8c	*72*	4	75

* Denotes significant difference at p<0.05 between that value and the one below it in the same column.

many students could not respond correctly in the post-test, the treatment group is significantly better than the comparison group. Surprisingly, about 52% Grade 4 students responded correctly that the sun does not come overhead every noon, more than the percentage of correct responses in Grade 7 and Grade 8 in the treatment group. The reason remains unknown, but most likely Grade 4 students randomly responded either 'yes' or 'no', and there is no way to tell it since justification or evidence for their response was not asked.

Qualitative observations of the sun

Two questions called for qualitative observations about the sun. In one, students were asked to describe the rising sun (Question no. 2 ii) and in another they were asked to list differences between the sun at noon and the setting sun (Question no. 2 xii). In a separate question they were also asked to list three differences between day and night (Question no. 5). These three questions together constitute the qualitative observations of the sun, which are summarized below.

a. Description of the rising sun: Nine kinds of responses were provided by students, which are tabulated frequency-wise in Table 6.6.

Students' responses can be classified into 3 basic categories:

1. Sensory (Visual + physical)

Colour of the sun (Response no. 1)

Brightness or intensity of light (Response nos. 4 & 5)

Table 6.6: Percentage students who gave particular descriptions of the rising sun (Question no. 2 ii)

No.	Description of the Rising sun *N*	Gr4 *87*	Gr7 *62*	Gr8t *52*	Gr8c *72*
1	Colour based response	53*	80	79*	61
2	Shape based (round/circle) (partially correct)	31*	7	19*	0
3	Size based (Big)	5	10	4	6
4	We can see the rays	4	7	2	8
5	Rays are mild	1	3	0*	10
6	Comes up	0*	7	4	0
7	Rises from East	4	0	2	0
8	Hot	1	0	2	1
9	Human centric response	2	2	0	7
10	Other incorrect responses	6*	0	2	0
11	No response	7	2	4*	31

* Denotes significant difference at $p<0.05$ between that value and the one to its right in the same row.

Heat and temperature (Response no. 8)

2. Spatial

Shape of the sun (Response no. 2)

(Apparent) size (Response no. 3)

(Apparent) motion (Response no. 6)

Position (Response no. 7)

3. Human centric (Response no. 9)

From Table 6.6 we can see that colour-based responses (Response no. 1) are most common in all grades. In general, sensory responses (Response nos. 1, 4, 5 & 8) are more frequent than responses based on spatial information. Differences between pre and post tests were not significant.

Some uncommon and unusual responses given by less than 1% students: small (may be confusion between less bright and small), less hot, rays are inclined (2% only in post-test of the treatment group), we can see the sun (2 students in the comparison group), time of sunrise (between 6 to 7). Responses such as 'the sun rises in the East', 'the sun is hot while rising' and other irrelevant responses are counted in ‘Other incorrect responses’ (Response no. 10).

b. Difference between setting sun and sun at noon: In another questions, students were asked to list three differences between the setting sun and the sun at noon. Students’ responses and their frequency distribution is given in Table 6.7.

Table 6.7: Percentage students who gave particular differences between the sun at noon and the setting sun (Question no. 2 xii)

No.	Difference between setting sun and sun at noon	Gr4	Gr7	Gr8t	Gr8c
	N	*87*	*62*	*52*	*72*
1	Intensity of light: less rays (light)/ strong rays (light)	62*	40	49	42
2	Colour: red/ white	43	42*	68*	38
3	Position of the sun: West (side)/overhead	15	24*	55*	25
4	Heat of the sun or sun-rays: Sun (rays) not too hot / hot	2*	27	23	24
5	Heat (general): less heat/ more heat	14	19	8	11
6	We can view the sun/ we can’t	1	13	8	15
7	Apparent size: bigger/ smaller	1*	15	6*	0
8	Time : 6 / 12 noon	6	10	4	1
9	Heat (specific objects): road, land, air, etc. Cold / hot	0*	11	4	1
10	Temperature of the sun: less temp of the sun/ more temp of the sun	9	5	0	0
11	Other correct	2	2*	15*	0
12	Human centric responses	8	16*	4	11
13	Other incorrect responses	44*	6	4	8
14	Unorganized	26	27	15	15

* Denotes significant difference at $p<0.05$ between that value and the one to its right in the same row.

Again, the responses can be classified into 4 (3 in the earlier scheme and 1 new: temporal) categories:

1. Sensory (Visual + physical)

Intensity of light (Response nos. 1, 6)

Colour of the sun (Response no. 2)

Heat and temperature (Response no. 4, 5, 9, 10)

2. Spatial

Position of the sun (Response no. 3)

Apparent size (Response no. 7)

3. Temporal: Time of these two events (Response no. 8) and

4. Human centric (Response no. 12)

Response based on intensity of light (Response no. 1) is the most frequent, unlike the earlier question where the colour based responses (Response no. 1 in Table 6.6) were most frequent. In the sub-category 'Intensity of light' there were two kinds of responses: those which directly mention that the intensity (or sometimes angle of incidence - the latter were particularly present in the post-instruction test) of light or rays (Response no. 1) and indirect responses such as 'we can view the sun in the evening but not in the afternoon' (Response no. 6). Whether we can see the sun depends upon the intensity of the sun-rays. Thus the response of the second kind is a consequence of the first. But students who gave the second kind of response might not have developed the concept of intensity of light (as a scientific or common-sensical quantity) and may treat it as a qualitative personal experience. Therefore these two responses are tabulated separately.

Colour based responses (Response no. 2) are the second most frequent responses for this question. Both brightness and colour are visual properties. Thus, responses based on visual properties are more common than spatial and temporal responses.

Four kinds of responses fell under the sub-category 'Heat and temperature'. In the 'heat of sun or sun-rays' kind of response (Response no. 4), students responded that the sun is (or sun-rays are) hot in the afternoon and in 'temperature of the sun' kind (Response no. 10) they responded that the temperature of the sun is less while it is setting and is more at the noon. Both these responses represent two closely related misconceptions: that the sun actually emits more heat at noon or the sun's temperature is actually more in noon than evening. Responses of the 'Heat (general)' kind (Response no. 5) do not specify what exactly is more hot but from the construction of the sentence we can assume that students are talking about weather. This therefore is not an incorrect response, but is incomplete. Responses of the 'Heat (specific objects)' explicitly mention that at noon, the road or land is hot and hence the feet burn, or the weather is hot so they feel tired (Response no. 9). Note that students were asked to list the difference between setting sun and the sun at the noon, but these responses are about general physical conditions at that time, besides they are more like personal experiences, not yet detached to form an abstract generalization.

The percentage of position based responses (Response no. 3) is more than double in Grade 8 students in the treatment group than that of Grade 7 students in the pre-test and that in the comparison group.

There were few responses which were contradictory to the correct responses. They were considered incorrect because some of them might represent genuine misunderstanding, but some may have resulted from careless writing, and there is no way to distinguish between these possibilities. For example, 2% students in Grade 4, 2% in Grade 7 and 3% in the comparison group responded that the sun is red in the afternoon and white (or yellow) while setting (opposite to Response no. 2). (Perhaps since red is hotter than yellow, the sun may be red in the afternoon?). Two percent of students in Grade 7 and 3% in the comparison group responded that there is less light at noon and more light in the evening. Three percent of students from the comparison group responded that it is hotter in the evening and less hot in the afternoon. Two percent of Grade 7 students responded that the size of the sun is smaller in the evening and bigger at the noon and 2% of Grade 7 students responded that the sun is overhead in the evening. We were completely mystified by these responses.

Responses which were not presented as clear contrasts were classified as 'Unorganized responses' (Response no. 14) but were given a half mark in scoring and have been counted in finding the percentages of other categories of responses. Some of them were entries only on the one side with a contrasting point missing, and some were long descriptions where the job of finding contrasts was left to the evaluator.

c. Difference between Day and Night: In another question, students were asked to list three differences between day and night. Students' responses are summarized in Table 6.8. They can be categorized as:

1. Sensory (Visual + physical)

Presence/ Intensity of light (Response nos. 1, 4)

Presence of celestial objects in the sky (sun, stars, planets and moon) (Response nos. 2, 3, 5, 11 & 13)

Colour of the sky (Response no. 6)

Heat and temperature (Response nos. 7, 9, 10)

2. Biological (Response no. 8)

3. Human centric (Response no. 14)

Spatial and temporal responses were not present for this question.

Table 6.8: Percentage students who gave particular differences between day and night (Question no. 5)

No.	Differences Between Day and Night *N*	Gr4 *87*	Gr7 *62*	Gr8t *52*	Gr8c *72*
1	light/ no light (dark, moon-light, star-light)	68	79	68	65
2	Sun/ no sun	52*	71	74	64
3	Stars are not seen/ seen	39*	60	70	60
4	We can see/ cannot see	8	13	21	19
5	Planets are not seen/ seen	5	3*	23*	3
6	Blue sky/ black sky	7	11	2	4
7	Heat (general): Hot/cold	0*	6	8	8
8	Biological (photosynthesis)	2*	11	4	0
9	Heat (specific objects): Road, air, land hot/ not hot	3	5	0	3
10	More temp/ less temp	8	2	0	0
11	Planets not seen/ seen	3	0	0	0
12	Other correct	3	2	6	1
13	Moon is seen/ not seen	47	37	32	46
14	Human centric (People, living beings work (awake)/ sleep)	7	16	8	17
15	Other incorrect	22*	8	8	8
16	Unorganized	14	13	8	13

* Denotes significant difference at $p<0.05$ between that value and the one to its right in the same row.

Responses based on the intensity of the light are most frequent. Under the first sub-category ‘Presence/ intensity of light’ are, first, direct responses about amount of light, such as there is light in daytime and no light, or dark, or small amount of light by moon or by stars, in the night (Response no. 1). Secondly some students responded that we can see things around us in the day and cannot see things around us or we need artificial light in night (Response no. 4). The second kind of response is a consequence of the first kind (whether the light is present or not) but is more like a personal experience, and hence qualitatively different from the first.

Out of the five kinds of responses under second sub-category ‘Presence of celestial objects in the sky’. The most frequent ones were based on presence of the sun and the stars. The third frequent response, that the moon cannot be seen in the sky during day but can be seen in the night, was classified as incorrect since the sighting of the moon in the day-sky is fairly common. The least frequent response in this category was sighting of planets.

Colour-based responses for difference between day and night (Response no. 6) were less frequent compared with the earlier two questions on the sun.

Responses based on plant life (e.g. related to photosynthesis), birds (e.g. fly for food in daytime) and other animals are categorized as ‘Biological responses’ (Response no. 8). These were unrelated to astronomy but were scientifically correct. Responses based on human activities (Response no. 14) were classified as ‘incorrect response’ since they were fairly self-evident mundane statements.

Unorganized responses are those not written in terms of contrasts, or in which the contrasting points did not match (Response no. 16). They were more like a description or points in jumbled order. These students were perhaps not familiar with such question or they had not organized their knowledge into ‘comparing and contrasting’ situations, which happens to be a most useful meta-cognitive strategy.

Sunlight and Shadows

Students’ understanding of the relation between sunlight and shadows was probed through a question which required them to deduce the shadow of a pole on the ground from the position of the sun in the sky (Question no. 3). Four sub-questions each with a snapshot-diagram representing four successive situations included four diagrams of a pole on a horizontal ground at four different times (morning, noon, evening and night). Each sub-question required students to draw three related factors:

a. Depict the position (within a range) of the hands of the clock during the given period of the day (Morning, Noon, Evening, Night): this was to confirm their understanding of the time of the day.

b. Draw position of the sun at the given time: relate the position of the sun with the time in the clock (quantification of observations). Inadequacy in drawings may have been a consequence of conceptual difficulty (not understanding the systematicity in pattern of movement of the sun) or drawing difficulty (not knowing how to draw a cross-sectional diagrams).

c. Draw the correct shadow for corresponding position of the sun: This was to probe whether students can use ray diagrams and for those who cannot, what kinds of diagrams do they produce to draw the shadow? By Grade 7 students are exposed to ray-diagrams in the context of astronomy (though they have not been taught to draw ray diagram in systematic manner yet; there is a chapter on 'Light' in Grade 8 with more details in Grade 9). Drawing ray-diagrams in a simple (but unfamiliar) situation is one of the most important skills they would require while learning elementary astronomy.

Responses to these three sub-questions are tabulated in Tables 6.9, 6.10, 6.11 & 6.12 respectively.

a. Depiction of time in the clock: If the time shown in the clock was between 6 to 9 for morning, 12 to 3 for noon, 4 to 7.30 for evening and 7 to 4 for night, it was classified as a correct response, otherwise it was incorrect.

Table 6.9: Percentage of correct and incorrect timings for Morning, Noon, Evening, Night, and average percentage of correct and incorrect responses (Question no. 3 i)

Grade (*N*)	% Correct responses					% Incorrect responses				
	Morn.	Noon	Eve.	Night	Average †	Morn.	Noon	Eve.	Night	Average †
Gr4 (*87*)	89	85	75	76	81	6	5	14	8	8
Gr7 (*62*)	90	100	85	79	89	10	0	10	8	7
Gr8t (*52*)	83	91	79	58	78	6	0	4	0	2
Gr8c (*72*)	85	93	81	43	75	6	0	8	4	5

†statistical significance was tested only for these columns and no differences between grades were found.

No significant differences was found in the percentages of correct responses among different grades. Most of the students had a good understanding of time shown by a clock.

b. Position of the sun at a given time: Table 6.10 summarizes the percentages of correct and incorrect positions of the sun in the sky at four different times: Morning (Morn.), Noon, Evening (Eve.), and Night.

Table 6.10: Percentage of correct and incorrect responses for position of the sun at Morning, Noon, Evening and Night (Question no. 3 ii)

Grade (*N*)	% Correct responses					% Incorrect responses				
	Morn.	Noon	Eve.	Night	Average †	Morn.	Noon	Eve.	Night	Average †
Gr4 (*87*)	78	32	43	52	51	14	57	48	47	42
Gr7 (*62*)	74	73	53	68	67*	19	26	44	31	30*
Gr8t (*52*)	89	89	89	89	89*	9	9	9	8	9
Gr8c (*72*)	68	81	64	69	71	17	13	29	29	22

†statistical significance tested only for these columns
* Denotes significant difference at $p<0.05$ between that value and the one below it in the same column.

If we assume that all students by Grade 7 know that the sun goes from one side of the sky to another within a day, about 30% students cannot represent it by drawing a cross-sectional diagrams. The percentage of average (over all four conditions) correct response in the post-test is higher than in the pre-test and in the comparison group.

Table 6.11 summarizes the percentage of students who correctly labeled East and/or West in their diagram to specify the direction in which the sun is seen in the morning and evening. The percentage of students who specified East-West in their diagram is quite low.

c. Draw the correct shadow for the corresponding position of the sun: Students in Grade 7 are not exposed to drawing ray-diagrams for simple situations such as daily shadows. Table 6.12 summarizes the average (over morning, noon and evening) percentages of each kind of response to represent a shadow of the stick. The categories are not mutually exclusive.

Table 6.11: Percentage of students who correctly mentioned East-West in their diagram to specify the position of the sun (Question no. 3 ii)

Grade	*N*	Morning	Noon	Evening	Night	Average †
Gr4	*87*	14	7	11	2	9
Gr7	*62*	3	0	3	2	2
Gr8t	*52*	8	6	8	4	6
Gr8c	*72*	4	1	3	0	2

†statistical significance tested only for this column and no differences were found.

Figure 6.2 depicts the students' progress from Grade 4 to Grade 7 and from pre-test to post-test on 5 aspects: the 'Position of the sun' (from earlier question, Table 6.10), correct ray diagram and parallel sun-rays for drawing the shadow and two correct representations of the shadow ('Line on land' - conventional shadow; Response no. 7 and 'Darkened shadow'; Response no. 8).

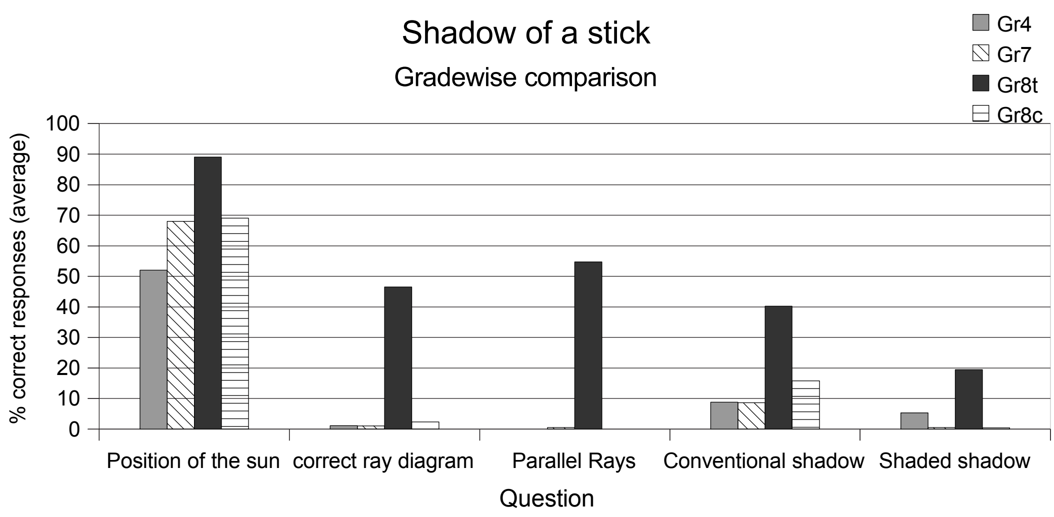


Figure 6.2: Grade-wise percentages of correct responses for the position of the sun, correct ray diagram, parallel sun-rays, conventional representation of shadow (Response no. 7) and shadow darkened (Response no. 8).

Table 6.12 shows that only 1% students from Grade 4 and Grade 7 in the pre-test could draw the correct ray diagram for shadow of the stick (Response no. 1). This percentage increased to 47% in the post-test, which suggest that a good number of students had learnt to draw simple ray-diagrams. The corresponding percentage in the comparison group is 2% (despite the fact that ray diagrams are involved in science and geography textbooks in Grade 8). About 63% students in Gr8t attempted to draw ray-diagrams in the post-test (Response no. 2 & 3), and 55% of them drew parallel sun-rays. The percentages (of Response nos. 1, 2 & 3) from the pre-tests and the comparison group suggest that most of the students in these groups did not even attempt to draw ray diagrams and drew the shadow by guesswork. This suggests that shadows might not have been understood as precise effect of obstruction of light. About 17% Grade 4 students (and 8% Grade 7 students in the pre-test) drew the sun and the shadow on the same side (Figure 6.3h). Also, a few students from Gr4, Gr7 and Gt8c drew a shadow which was not connected to the stick (e.g. Response no. 11: line parallel to stick; see Figure 6.3f). None of the students from the treatment group made the latter mistake in the post-test.

The increase percentages of two correct representations of shadow (Response no. 7: Line on the land; see Figure 6.3c, and Response no. 8: Darkened/shaded shadow; see Figure 6.3d) increased after intervention and are greater in the treatment group than in the comparison group. The percentages of two incorrect responses dropped after intervention (Response no. 10 & 11). The percentage of picture-like representation of shadow (Response no. 13) is more in Grade 4 than in Grade 7.

While drawing shadow for noon, if the sun is exactly overhead, one can correctly chose not to draw shadow (Response no. 18). It is important to note here that in post-test some students took efforts to represent their understanding in different ways instead of just skipping to draw the shadow. For example, some students indicated that the shadow is exactly below stick and some explicitly wrote that the shadow will be little towards North or South at exact noon.

6.1.3 Planets, stars, constellations and other night sky objects

In this subsection, we report findings about students' observations of celestial bodies in the night-sky. In three different question students were asked whether they have seen a planet (Question no. 4 i), any of different *Rashis* and *Nakshatras* (Ap-

Table 6.12: Percentage of response in each category for the shadow of the stick (Question no. 3 iii)

No.	Responses for shadow (average of morning, noon & evening) *N*	Gr4 *87*	Gr7 *62*	Gr8t *52*	Gr8c *72*
1	Correct ray diagram	1	1*	47*	2
2	Parallel sun-rays / only one relevant ray	0	1*	55*	0
3	Divergent rays	0	0*	8*	0
4	Shadow on opposite side of S	47	45	63	48
5	Shadow and S on same side	17	8	2	4
6	Shadow not connected to stick	8	12*	0*	11
	Representation of shadow				
7	Shadow: Line on land	9	9*	40*	16
8	Shadow: Darkened	5	1*	19*	0
9	Other correct	1	2	1	3
10	Shadow: Tilted in air	16	19*	4*	24
11	Shadow: Line parallel to stick	8*	22*	1	6
12	Shadow: Line joining tip to stick and land	18	10	3	5
13	Shading on ground	14*	3	3	9
14	Shading (hatching) adjacent to stick	0*	6	3	10
15	Shaded smaller triangle	4	1	3	5
16	Shadow: Parallel to ground	7	4	0	1
17	No shadow	0	4	5	0
18	No shadow (correct at noon)	10	17*	4	13
19	Other incorrect	9	8	1	2
	Responses for shadow at night				
20	No shadow	10	20	27	21
21	Shadow drawn	20	9	3	7
22	No response	2	3	1	5

* Denotes significant difference at $p<0.05$ between that value and the one to its right in the same row.

pendix G.2) (Question no. 7) and a shooting star (Question no. 8 i). The percentages of students in each Grade who reported that they have seen a particular object are given in Table 6.13.

Table 6.13: Percentage of students who reported that they have seen a planet, a *Rashi* or a *Nakshatra* and a shooting star (Question nos. 4 i, 7 and 8 i)

Grade (*N*)	Planets	Shooting Star	*Rashi/ Nakshatra*
Gr4 (*87*)	55	28	10
Gr7 (*62*)	61*	42*	15*
Gr8t (*52*)	81*	68	76*
Gr8c (*72*)	51	51	4

* Denotes significant difference at p<0.05 between that value and the one below it in the same column.

Planets

There is significant increase in the percentage of students who have seen a planet in the treatment group from the pre-test to post-test. The percentage of Grade 8 students who responded that they have seen the planets is significantly less in the comparison group than that in the treatment group.

As a continuation of this question, students were further asked to name the planets which they have seen (Question no. 4 ii). Nine correct (Response nos. 1-9) and 4 kinds of incorrect (Response nos. 10-13) responses were provided by students (Table 6.14). Incorrect response included 'the moon' 'the sun' or 'name of a star'. In Marathi, out of seven of days of week, five are named after 5 planets: Tuesday (Mars), Wednesday (Mercury), Thursday (Jupiter), Friday (Venus) and Saturday (Saturn). Of the remaining two days, Sunday (*Raviwar*) is named after the sun and Monday (*Somwar*) may refer to the moon, though the appellation '*Som*' for moon is rarely used). Some of the students seem to have generalized that all the names of days of the week are named after the planets and thus cited *Som* and *Ravi* (or the sun) as names of planets (Response nos. 10, 11). Responses such as names of other celestial bodies ('stars', 'constellations', 'clouds', 'planet', 'satellite', 'asteroid' (Marathi names for satellite (*Upagraha*) and asteroid (*Laghugraha*) are compound words which include the suffix '*graha*' which means planet)), names of directions, and some irrelevant names such as 'Ploton', 'Newton' and 'Plague' fell under the category 'Other incorrect responses'. Table 6.14 summarizes the percentages of students who gave each kind of response and the average number of correct and incorrect responses per student for each Grade.

Table 6.14: Percentage of students in who gave particular response as a name of planet (last 5 responses are incorrect) (Question no. 4 ii)

No.	Name of Planet *N*	Gr4 *87*	Gr7 *62*	Gr8t *52*	Gr8c *72*
1	Mercury	43	58	49*	19
2	Venus	45	48	62*	21
3	Earth	25	29*	13	13
4	Mars	29	39	49*	25
5	Jupiter	40	60	47*	22
6	Saturn	45	55	60*	19
7	Uranus	9	10	19*	7
8	Neptune	8	15	25*	8
9	Pluto	14*	31	26*	3
10	Som	6*	16*	2	4
11	Sun/ Ravi	11	11	6	10
12	Moon	7*	19	8	15
13	Name of a star	1	0*	15*	0
14	Other	9	10	15	7
15	Average correct/ student	2.57	3.44	3.51	1.38
16	Average incorrect/ student	0.34	0.56	0.45	0.36

* Denotes significant difference at p<0.05 between that value and the one to its right in the same row.

The percentages of two correct (Response nos. 5 & 9) and two incorrect (Response nos. 10 & 12) responses increased from Grade 4 to Grade 7. Interestingly, the percentage of students who named the earth as one of the planets is less in both Gr8t and Gr8c than in Gr7 (Response no. 3). The percentage of students who incorrectly responded ‘Som’ as name of planet decreased from the pre to the post-test (Response no. 10), but it was also low in the comparison group. Students from the treatment group were exposed to names of stars during the intervention. Fifteen percent students from Gr8t gave a name of a star as a name of a planet in the post-test, but none in the pre-test and comparison group made this mistake (Response no. 13). The percentage of 8 out of 9 correct responses is more in Gr8t than in Gr8c (Response nos. 1, 2 & 4-9).

In response to this question, we assumed that students would respond yes if they had actually seen that object in the sky. However, we found that students named the planets which are not easily seen (such as Mercury, Neptune, Uranus, Pluto). When asked about this observation (while they were solving the test) students responded that they had seen these planets in the book or on the television. We asked therefore to specify whether they had actually seen the planet or they had learnt about it from some other source, or if they had seen the picture of it, to specify the source. But this post-hoc addition to the question resulted in most of the students specifying the source where they have seen the picture of the planet, so exactly which planets they actually had seen and which were seen in pictures remained unclear. The percentages reported in Tables 6.13 & 6.14 are of the students who responded that they had seen the planets (either actually or in the book). Table 6.15 summarizes the percentage of students from each class who reported that they saw a picture of the planet (not the actual planet).

Table 6.15: Percentage of students who reported that they have seen the planets only in picture (Question no. 4 ii)

Grade *N*	Rural *119*	Urban *83*	Tribal *72*
Gr4	0	29	20
Gr7	0	33	0
Gr8t	38	33	19
Gr8c	12	67	29
Total	12*	32*	19

* Denotes significant difference at $p<0.05$ between that value and the one to its right in the same row.

From Table 6.15 we can see that the percentage of students who have seen a picture of a planet is highest in urban sample, perhaps because the urban sample has maximum exposure to other sources of knowledge such as books and media.

Stars

Four questions were asked to probe students' observations about stars (Question nos. 6, 8, 9 & 10). In Question no. 6 students were first asked whether they had ever tried counting the number of stars seen in the sky (Question no. 6 i), if they had, what was the number? (Question no. 6 ii). In the same question, students were asked to describe the stars (Question no. 6 iii). We expected that students might mention the different brightnesses (or sizes) and colours of the stars and also their apparent motion in the sky overnight. They might also mention of different constellations and changes in them seen at different times of year and the changes in visibility of the stars according to change is phases of the moon (more of stars seen on new moon nights and fewer on full moon nights), or weather, etc.. In continuation students were asked to name the stars which they could identify (Question no. 6 iv).

Response nos. 1-5 in Table 6.16 refer to the first two questions which were not part of the tests for the rural and tribal samples for Grade 4 and Grade 7 before intervention. Therefore N=45 for Gr4 and N=18 for Gr7 for Response nos. 1-5. Across-grade comparisons for these questions are therefore less reliable.

From Table 6.16 we can see that a few students (16 to 25%) responded that they tried counting stars (Response no. 1), while most (84 to 74%) reported that they never counted the stars (Response no. 2). Yet many students responded to the number of stars, saying that the stars are uncountable, infinite, many, thousands or very high numbers (Response no. 4). These responses might have come through the experience of looking at a sky full of stars on a dark night. Only few students gave specific numbers (Response nos. 3 & 5).

As a description of the stars, 8 kinds of correct responses were given (Response nos. 6, 7, 9-14 Table 6.16). These responses fall under the following categories:

1. Sensory (Visual)

Brightness (Response nos. 6, 10)

Colour (Response no. 7, 8)

2. Spatial

Apparent size (Response no. 11): some students reported that the stars are actually big but they are very far, therefore look small.

Pattern (Response no. 12)

Position (Response no. 13)

3. Number (Response no. 9)

4. Human centric (Response no. 16)

Temporal Responses were absent.

Table 6.16: Percentage of students for 4 sub-questions regarding number, description and names of stars (Question no. 6)

No.	Response *N*	Gr4 *45*	Gr7 *18*	Gr8t *52*	Gr8c *72*
	Have you ever counted stars?				
1	Yes	16	17	19	25
2	No	84	83	79	74
	What is the number?				
3	Correct (20<N<2000)	2	0	4	13
4	Infinite/ Many/ Thousands/ Crores (considered partially correct)	58*	89*	47*	21
5	Incorrect (8<N or N>2000)	13	6	9	13
	Description of stars (*N*)	*87*	*62*	*52*	*72*
6	Shine/ Twinkle/ Give light	48	53	40	46
7	Colour (White/Silver)	20	16	8	14
8	Wrong colour	0	2	0	0
9	Uncountable/ Infinite/ Many	17	24*	6	8
10	Some are bright, some faint	0*	8	19	17
11	Apparent size (small)	0*	26*	8	6
12	Some are in group some are single	0	2*	15	7
13	Pole Star always to North	0	0	4	0
14	Other correct responses	9	5	11*	1
15	Other incorrect responses	10	6	13	4
16	Human centric responses (good/ beautiful)	3*	18*	4	11
	Names				
17	Pole Star	1*	16*	57*	10
18	Sun	16	10	9	17
19	*Shikari-tara / Vyadha* (Sirius)	8*	0*	43*	6
20	*Bramharhiday* (Capella)	0	0*	17*	0
21	*Agasti* (Canopus)	6	0	6*	0
22	*Magha* (Regulas)	0	0	6*	0
23	*Swati* (Arcturus)	0	0	4	0
24	*Chitra* (Spica)	0	0	2	0
25	Other correct	0	0	4	0
26	Other incorrect	34*	19*	57*	31

* Denotes significant difference at $p<0.05$ between that value and the one to its right in the same row.

Although there are no consistent trends across the grades, the variety of responses are interesting. Students in the post-test gave responses such as, ‘some are in pairs', 'self luminous', description of one of the constellations (e.g. three stars in Orion), 'direction can be found using stars' and 'calendars are created using stars'. Other correct responses from students from other groups include 'round', 'scattered all over the sky', 'some are close some are far' and a picture of an asterisk (Response no. 14). Other incorrect responses included 'they reflect sunlight / lit by moonlight / not self-luminous', 'look like birds', names of other celestial bodies such as planets and incorrect responses about the Pole Star (e.g. Fixed at South, biggest, rises in the West before all other stars) (Response no. 15).

Students from the treatment group know names of more number of stars, since none of the students in Grade 4, 7 or the comparison group could name stars other than the Pole Star, the sun, Sirius and Canopus. Other correct responses given by students in post-test are: Deneb, *Agranad* (Achernar), *Abhijeet* (Vega). Other incorrect names included names of constellations, planets and zodiac signs (Response no. 26). Note that the percentage of incorrect responses increased after intervention and is greater than that in the comparison group. Thus after intervention the students knew more names of celestial objects but it is difficult to draw any conclusion regarding their observational ability.

In Question no. 8, students were asked whether they had seen any of the *Rashi* (zodiac signs) or *Nakshatras* in the sky and were asked to list the ones which they could identify. The percentages of the students who reported that they have seen the zodiac signs and *Nakshatras* are tabulated in Table 6.13. According to Table 6.13, there is significant increase in the treatment group from the pre to post-test and between Grade 8 students in the treatment and the comparison group.

The word '*Nakshatra*' is technically used only for those constellations through which the moon passes, but sometimes ambiguously it is used for other constellations also. The average number of *Nakshtras*, *Rashis* and constellations cited per student are given in Table 6.17. Here again, we cannot be sure that students could actually identify those *Nakshatras* and *Rashis*. For more discussion see Subsection 6.3.2

Question no. 9 was designed to probe whether students are aware that the stars do not remain at the same place all over the night and their position as seen at the same time each night also changes over the days. In this question, students were

Table 6.17: Average number of *Nakshatras, Rashis* (zodiac signs) and constellations per students (Question no. 8 ii)

Grade	*N*	*Nakshatra*	*Rashi*	Constellations
Gr4	*87*	0.01	0.14	0.01
Gr7	*62*	0.16	0.55	0
Gr8t	*52*	1.77	0.53	0.13
Gr8c	*72*	0	0.04	0

given a diagram of three stars seen from window, and told that the picture depicts the sky seen from the window of a house at 10 o'clock yesterday. The questions posed were:
i. Will the same sky be seen at 4 o'clock in the morning?
ii. Will the three stars remain at the same place?
iii. Will the same sky be seen at the same time after one month?

The first two questions are similar in intention, and meant to cross check students' responses to make sure that they had not randomly written 'yes' or 'no' (most of the other questions which required 'yes' / 'no' responses were followed by descriptive answers). The percentages of correct and incorrect responses are given in Table 6.18. Inexplicably the percentage of students who responded that the sky

Table 6.18: Percentage of responses for questions related to apparent motion of the star over night and over months (Question no. 9)

No.	Response	Gr4	Gr7	Gr8t	Gr8c
N		*87*	*62*	*52*	*72*
	Same sky over night?				
1	No	84*	60*	89*	58
2	Yes	14*	39*	9*	32
	Stars at same place?				
3	No	80	66	68	63
4	Yes	16	29	28	28
	Same sky after 1 month?				
5	No	54	68	75	58
6	Yes	43*	27	23	22

* Denotes significant difference at $p<0.05$ between that value and the one to its right in the same row.

changes over night decreased from Grade 4 to Grade 7. However it increased after intervention and is more in the treatment group than in the comparison group.

Relatively more Grade 4 students have not noticed that the night sky changes over the year (Response no. 6).

The last question related to stars was asked to probe whether students correctly know the reason of why the stars are not seen in the daytime (Question no. 10). They were asked the following three sub-questions:
i. Are the stars in the sky in daytime?
ii. Have you ever seen the stars in daytime?
iii. Explain your answer.

Students were expected to respond that the stars are present in the sky during daytime but they have not seen the stars during daytime. The stars are not seen during the day because sunlight is too bright. (Data for urban students from Grade 4 and Grade 7 are not available. Therefore, N=42 for Gr4 and N=44 for Gr7).

Table 6.19: Percentage of responses for the explanation of why stars are not seen during day (Question no. 10)

No.	Response *N*	Gr4 *42*	Gr7 *44*	Gr8t *52*	Gr8c *72*
	Are stars present in the sky during daytime?				
1	Yes	17	32*	55	51
2	No	81	68*	42	46
	Can stars be seen during daytime?				
3	No	93	95	83	89
4	Yes	5	5	6	7
	Reason				
5	Sunlight	5*	25*	55	44
6	Other incorrect	7	11	4	13

* Denotes significant difference at p<0.05 between that value and the one to its right in the same row.

From Table 6.19, the percentage of students who correctly responded that the stars are present during daytime increased from the pre-test to post-test (Response no. 1), but the corresponding percentage in the comparison group was similar. Most of the students (83%-95%) responded that the stars are not seen during day time (Response no. 3). Remarkably, some students (3% rural students in Grade 4 and

12% rural students in the treatment group in post-test) responded that they have seen the stars in daytime during solar eclipse, which is counted in correct responses (Response no. 4).

Finally, very few (5%) Grade 4 students know the correct reason for the absence of the stars in the sky during daytime. The percentage of Grade 7 students who correctly wrote the reason is higher than in Grade 4 and has increased in the post-test, but again is not significantly higher than the corresponding percentage in the comparison group (Response no. 5). Thirty-three percent of the urban students from the treatment group incorrectly reported the 'Earth's motion' as a reason in the post-test. Other incorrect responses include responses such as 'heat', 'stars go behind cloud or sky', 'stars are very far', 'change in their position', 'might have got bigger or smaller' (Response no. 6).

Shooting stars

Question 7 asked whether students have seen a shooting star and if yes they were asked to describe it. From Table 6.13 we saw that only 28% students in Grade 4 responded that they have seen a shooting star. The percentage of students who have seen the shooting star increased (from 42% to 68%) between the pre-test to post-test.

Students' descriptions of a shooting star are summarized in Table 6.20. Shooting star is called *Tut-ta tara* in Marathi ('a star that breaks off from its position and falls' (Response no. 6). Other correct responses (Response no. 7) included 'it vanishes', 'brighter', 'burning', 'made up of stone, soil, ice, etc.', 'it is not a star but a big stone from comet's tail', 'self luminous' , 'makes a crater'. These origin or explanation-based responses such as latter four (not exactly visual descriptions, but nonetheless correct responses) are mostly found in the post-test. Other incorrect responses included 'falls down slowly', 'spreads colour everywhere' (Response no. 8).

Students' responses fell under the following categories:

1. Sensory (Visual + physical)

The responses such as colour-based responses such as 'white' or 'golden'

Table 6.20: Percentage of each kind of response as description of a shooting star (arranged from most to least frequent) (Question no. 7 ii)

No.	Response	Gr4	Gr7	Gr8t	Gr8c
	N	*87*	*62*	*52*	*72*
1	Goes fast	6	13	15	22
2	(Appears) Bigger (than a star)	2	6*	30	18
3	Falls down/ Goes from one place to another	11	16*	0	0
4	(Apparently) Has a tail or Peacock-tail (pis-ara)	0	2*	17*	1
5	Looks like a line	0	0	2	3
6	Breaks	5	5	0	0
7	Other correct	6*	21	32*	4
8	Other incorrect	9	8	9	10
9	Human centric	3	8*	0	3

* Denotes significant difference at $p<0.05$ between that value and the one to its right in the same row.

were a few and are counted in ‘other correct responses’ (Response no. 7).

2. Spatial

Motion (Response no. 1, 3)

Apparent size (Response no. 2)

Shape (Response nos. 4, 5)

3. Human centric (Response no. 9)

Temporal and quantitative (number) responses were absent.

There was no clear trend across the Grades in the set of correct responses. The percentage of human centric responses (such as ‘beautiful’ and ‘fulfills a wish’) decreased to zero after the intervention (Response no. 9).

6.1.4 The moon

The second-last question (Question no. 11) involved the following 7 sub-questions to probe students’ observations about the moon:

i. Do we see the moon every night in the sky?

iia. Have you seen the moon in the daytime?

iib. If you have seen it, draw its picture.

(The drawing responses for the sub-question (iib) are summarized in separate Table 6.23)

iiia. Does the shape of moon change every night or it remain same?

iiib. If it changes, draw how it changes and name the shapes.

(The drawing responses for the sub-question (iiib) are summarized in separate Table 6.24)

iv. Name the direction in which the moon rises?

v. Does the moon rises at same time every day or the rising time changes?

vi. Name the direction in which the moon sets? —-

vii. Does the moon set at the same time every day or does the setting time change?

Table 6.21: Percentages of responses to 7 sub-questions on the moon (Question no. 11)

Question	No.	Response *N*	Gr4 *87*	Gr7 *62*	Gr8t *52*	Gr8c *72*
M every night	**1**	N	24*	42*	64	49
	2	Y	72*	55*	32	49
M in daytime	**3**	Y	13*	26	43	32
	4	N	48*	13	21	35
Shape of the M	**5**	Changes	75	77	72	85
	6	Remains same	8	3	4	1
Direction of rise	**7**	East	52	47*	79*	57
	8	West	20	23	11	19
	9	South	14*	2	2	1
	10	North	5*	15*	0	1
Time of rise	**11**	Changes	36*	66*	94	82
	12	Remains same	33*	15*	0	3
Direction of set	**13**	West	44	48*	79*	54
	14	East	24	18	11	10
	15	South	3	8	2	3
	16	North	17*	5	2	3
Time of set	**17**	Changes	37*	66*	92*	76
	18	Remains same	41*	15*	2	10

* Denotes significant difference at p<0.05 between that value and the one to its right in the same row.

From Table 6.21, most of the students (72% to 85%) knew that the shape of the moon changes every day (Response no. 5). The percentage of students who know that the moon is not seen every night and it is sometimes visible during daytime also is almost double in Grade 7 than that in Grade 4 (Response no. 1 & 3). Similarly, the percentage of Grade 7 students who know that the time of moon-rise and moon-set changes every day is more in Grade 7 than in Grade 4 (Response nos. 11 and 17). The percentages of correct responses for the direction of moon-rise were similar in Grade 4 (52%) and Grade 7. Note that one often observes the crescent moon on the Western horizon in the evening, when it is actually setting, but because it has become visible only after sunset, it may give an impression that the moon is rising in the West.

Table 6.22 compares the percentages of correct responses for changes in timings and direction of moonrise & sunrise and moonset & sunset. The percentages of correct responses for the direction of moonrise are significantly lower than those for sunrise, perhaps because sunrise and sunset are more prominent than moonrise and moonset. Besides, the textbooks for Grade 3 also mentions the former but not the latter.

Regarding changes in timing of sunrise and sunset, these are given in the geography textbook of Grades 6 & 7, but changes in timings of moon are not discussed in the textbook. Yet, the percentages of correct responses for the changes in timings of moonrise and moonset are almost same as the percentage of correct responses for changes in timings of sunrise and sunset (in 7 out of the 8 comparisons). The reason behind this can be either the drastic changes in timings of moon-rise and moon-set or, more probably the importance of timings of moon-rise in predictions of several religious fasts.

Table 6.21 shows that the percentages of correct responses for 5 out of the above 7 sub-questions increased after the intervention (Response nos. 1, 7, 11, 13, 17) and for 3 of these sub-questions, the percentages of correct responses were significantly higher in the treatment group than in the comparison group (Response nos. 7, 13, 17). Thus the intervention helped students to know that the time and direction of the moonrise and the moonset changes every day.

Gibbous is the most frequently seen shape of the moon during daytime, followed by half moon and thick crescent. A crescent is less frequently seen because

Table 6.22: Comparison of percentages of correct responses for similar questions on the moon and the sun (Question nos. 2 and 11)

No.	Question *N*	Gr4 *87*		Gr7 *62*		Gr8t *52*		Gr8c *72*	
	Moon/ Sun	Moon	Sun	Moon	Sun	Moon	Sun	Moon	Sun
1	Direction of rise (E)	52*	76	47*	89	79*	93	57*	94
2	Direction of set (W)	44*	76	48*	95	79*	94	54*	94
3	Changes in time of rise	36	25	66	65	94	93	82	72
4	Changes in time of set	37	31	66	66	92	91	76*	89

* Denotes significant difference at p<0.05 between that value and the one to its right in the same row.

it is at a smaller angle with the sun. A full moon is impossible to be seen in the daytime since it rises at sunset and sets at sunrise.

Table 6.23 summarizes the percentages of responses for the diagram of the shape of the moon seen during daytime.

Table 6.23: Responses for shape of the moon seen in day-time (Question no. 11 ii)

No.	Shape *N*	Gr4 *87*	Gr7 *62*	Gr8t *52*	Gr8c *72*
1	Gibbous	2	8	11	3
2	Incorrect gibbous	1*	8	6	1
3	Half	5	6	9	4
4	Thin Crescent	5	0	4	1
5	Thick Crescent	10*	31	21*	3
6	Full	7	21	32	19
7	No diagram	64	11	23	60
8	Wrong diagram	3	5	2	4

* Denotes significant difference at p<0.05 between that value and the one to its right in the same row.

Most of the students in Grade 4 and the comparison group did not draw any diagram (Response no. 7). The full moon, which is impossible to see in daytime, was a frequent response (except in Grade 4) (Response no. 6, Figure 6.4b). A frequent correct response, ‘Thick crescent’ (Response no 5; Figure 6.4a) is relatively less often seen during the day, but it also happens to be the prototypical shape that one draws for the moon. On the other hand the most plausible response (in terms of observational frequency) is that of a gibbous, and it is not very frequent in students (2 % to 11%) (Response no. 1). Unfortunately this trend, of drawing a thick crescent in preference to the gibbous, persisted in the treatment group after the intervention.

Incorrect gibbous (Response no. 2) is the shape seen during lunar eclipse or sometimes more than half a moon with a straight line boundary. Wrong diagrams are irregular shapes with no similarity to any of the phases of the moon (Response no. 8). No consistent trend across grades were seen in these responses.

Table 6.24 summarizes percentage of responses for different shapes of the phases of the moon and their names. The columns for incorrect gibbous shape (Response no. 5) gives two numbers: the first indicates the percentage of eclipse gibbous responses and the second indicates the percentage of other incorrect shapes for gibbous (such as one bounded by a straight line).

The percentage of students who drew the full moon is more in Grade 4 than in Grade 7 and that of students who drew the new moon is more in Grade 7 than in Grade 4 (Response nos. 1 & 2). The percentages for the new moon, half moon and gibbous significantly increased after the intervention (Response nos. 2, 3 & 5) and these percentages, along with that for the crescent are more in the treatment group than in the comparison group.

The percentages of correct names of the full moon, new moon and the crescent increased from Grade 4 to Grade 7. The percentages of names of all five shapes increased after the intervention and were greater in the treatment group than in the comparison group. Students' understanding of observable phases and their names thus showed an improvement after the intervention (Figure 6.5), though the connection of their knowledge with observations remained unclear.

6.1.5 Test 1: Comparison of total scores

Total scores for each grade were found by collapsing all three samples and tested for normality using the one sample Kolmogorov-Smirnov test. The scores of all the Grades were normally distributed for Test 1. The comparison between of mean scores gave the following results (see Appendix H):

Table 6.24: Percentage of correct and incorrect responses for shapes of phases of the moon and their names (Question no. 11 iv)

No.	Shape	Grade	*N*	Shape of the phase		Name of the phase	
				% Correct	% Incorrect	% Correct	% Incorrect
1	Full	Gr4	*87*	92*	2	1*	0
		Gr7	*62*	77	3	11*	0
		Gr8t	*52*	85	0	62*	0
		Gr8c	*72*	76	3	13	1
2	New	Gr4	*87*	1*	0	1*	0
		Gr7	62	10*	3	10*	0
		Gr8t	52	47*	2	43*	2
		Gr8c	72	6	0	7	1
3	Half	Gr4	87	44	8	0	0
		Gr7	62	39*	19	2*	3
		Gr8t	52	60*	6	23*	9
		Gr8c	72	24	1	1	0
4	Crescent	Gr4	87	59	13	0*	1
		Gr7	62	71	13	5*	3
		Gr8t	52	81*	8	38*	6
		Gr8c	72	61	11	3	0
5	Gibbous (eclipse + faulty)	Gr4	87	1	(29 + 7)*	0	0
		Gr7	62	2*	(42 + 15)*	2*	0
		Gr8t	52	36*	25 + 11	36*	4
		Gr8c	72	6	32 + 15	3	0

* Denotes significant difference at p<0.05 between that value and the one below it in the same column.

1. Observations of Grade 7 students were better than observations of Grade 4 students (Gr7 > Gr4).

2. Observations of Grade 8 students improved significantly after the intervention (Gr8t > Gr7).

3. Observations of Grade 8 students from the treatment group were significantly better than those of Grade 8 students in the comparison group (Gr8t > Gr8c).

4. However the treatment group was significantly better than the comparison group in terms of their observations even before the intervention (Gr7 > Gr8c).

6.2 Test 2: Textbook Facts

The basic facts about the sun-earth system were probed in Test 2. More conceptual questions based on the content in the textbook is dealt with in Test 4 (Section 7.1). The original test and its translation are given in Appendix A.2. A total of 277 students attempted this test from Grades 4, 7, 8- treatment group and 8-comparison group (Table 3.3). The analysis of questions on similar topics is grouped together and presented in the following Subsections: questions related to the earth (Subsection 6.2.1; Question nos. 1, 3 i, 4, 5, 6 & 8), the solar system (Subsection 6.2.2; Question nos. 2, 3 ii, iii & 7), terms related to astronomy (Subsection 6.2.3; Question no. 9), judgement of sizes and distances (Subsection 6.2.4; Question nos. 10, 11). Table A.3 shows the correspondence between the subsections below and the original question numbers.

6.2.1 The earth

First question called for free response on ‘What is Earth?’ followed by more close-ended questions about the earth (its shape, motion, time period, etc.). The responses are given in Table 6.25.

Seventeen kinds of correct responses were found as a description of the earth. The most common response, ‘where we live’, shows that students had identified the earth properly (Response no. 1). It also shows that the dual earth model (Vosniadou and Brewer, 1992) was practically absent in our sample. We did not find any evidence for dual earth model in any other question in the questionnaires as well as in the interview. The remaining responses (Response no. 2 onwards in Table 6.25) are not analyzed here since separate questions have probed these aspects.

The following descriptions were found in less than 1% students of the total students: ‘is a celestial sphere/ is in space’, ‘has water/ atmosphere around it’, ‘seven continents/ of countries/ districts’, ‘has 1/3 land/ two thirds water/ more water than the land’, ‘non-luminous’, ‘sun gives light/ has 1 sun/ near sun’, ‘the earth has poles’, ‘is smaller than the sun’, ‘day-night occur on it’.

Question no. 3 included 3 sub-questions. In the first sub-question students were

Table 6.25: Percentage of students' responses for the question 'What is the earth?' (Question no. 1)

No.	Response to 'What is Earth?'	Gr4	Gr7	Gr8t	Gr8c
	N	*88*	*58*	*54*	*77*
1	Where we (or living beings) live	32*	59	59*	33
2	Shape (round, circle, egg)	55*	17	26	39
3	Shape (sphere)	3	9*	24*	5
4	Size (big)	6	4	2	0
5	Planet	21	29	35*	18
6	Motion (rotation or revolution)	32*	7	13	14
7	Motion (rotation and revolution)	19*	5*	30	16
8	Information about origin (made up of stones, soil, lava gases..)	3*	14	20	9
9	Time periods (either one is correct)	18*	0*	11	4
10	Time period (both correct)	11*	2	9*	1
11	Land	2*	13	5	2
12	Colour (Blue)	6	5	4	4
13	Has satellite/ moon revolves around/ bigger than moon	5	0	6	4
14	Natural (*Nisarga-nirmit*) made up of sun	0	2	6	4
15	Third in solar system	2	4	0	1
16	World	1	2	4	1
17	Has gravitation/ Pulls objects	0	2	2	1
18	Wrong responses	1	4	2	1
19	No response	7	10	4*	30

* Denotes significant difference at $p<0.05$ between that value and the one to its right in the same row.

asked to choose one of 4 objects whose shape might resemble the shape of the earth. The percentages of each kind of response is given in Table 6.26. Sub-questions **ii** and **iii** were related to the solar system and their analysis is presented in Subsection 6.2.2.

Number of students who believed that the earth is round like a solid sphere was higher in the treatment group than in the comparison group (Response no. 1, Table 6.26). Maximum number of students in the comparison group believed that shape of the earth is like an egg (Response no. 4). The geography textbook of Grade 5 mentions that the earth is bulged near equator due to its rotation, however students often drew a vertical egg instead of flattened sphere mentioned in the textbook or

Table 6.26: Percentages of correct and incorrect responses for shape of the earth (Question no. 3 i)

No.	Response	Gr4	Gr7	Gr8t	Gr8c
	N	*88*	*58*	*54*	*77*
1	Ladu (solid sphere)	67	59	72*	25
2	Plate	7	12	17*	3
3	Bowl	5	2	6*	0
4	Egg	18	22*	2*	70
5	No response	7	5	0	1

* Denotes significant difference at p<0.05 between that value and the one to its right in the same row.

identified by Vosniadou and Brewer (1992). The percentage of students who believed that the shape of the earth is like an egg decreased after intervention and it is less than the comparison group.

Three questions (Question nos. 4, 6 and 8) were about motion of the earth. In Question no. 4, there were 2 sub-questions. In first sub-question, students were asked whether the earth moves and in the second sub-question students were asked to describe the motion of the earth if it does move. Time periods of rotation and revolution was asked in questions 6 and 8 respectively. These three questions were not given together: they were given in a distributed fashion so that an earlier question would not directly influence the response to a later question.

Most students from Grade 4 onwards knew that the earth moves (Response no. 1). Surprisingly, more number of Grade 4 students could answer that the earth rotates than could Grade 7 students (Response no. 3). Students had learned about rotation in Grade 4 while learning day-night and perhaps forgot it by the time they came to Grade 7. About 15% students specified the direction of motion as 'from West to East' after the intervention (Response no. 5). The number of students who could answer the question about revolution increased by Grade 7 (Response no. 4). More number of Grade 4 students knew about rotation than revolution (Response nos. 3 & 4). Responses to questions about time period also confirm this (Response nos. 6 & 10). This might be because Grade 4 students had freshly learnt about rotation and day night, while revolution was simply mentioned, and not connected with any phenomenon.

Table 6.27: The percentages of correct and incorrect responses for motion of the earth (Question nos. 4, 6 and 8)

No.	Response	Gr4	Gr7	Gr8t	Gr8c
	N	*88*	*58*	*54*	*77*
1	Earth Moves	71	83	89	84
2	Earth doesn't move	22	12	6	10
3	Rotation	89*	59	69	58
4	Revolution	34*	55	63	55
5	From East to West	1	5	15*	0
6	Rotation time = 24 hours / 1 day	67	62	70	69
7	Rotation time = 24	18	9	6	8
8	Rotation time = 365	6*	24*	9	5
9	Rotation time = other wrong	10	2*	7	0
10	Revolution time = 365 days / 1 year	40*	67	69	55
11	Revolution time = 365	17*	2	6*	0
12	Revolution time = 24	32	22	9	21
13	Revolution time = other wrong	6	2	9	9

* Denotes significant difference at $p<0.05$ between that value and the one to its right in the same row.

Interestingly the number of students who gave an answer citing a time period is greater than the number of students who said that the earth moves (Response nos. 1, 6-9 & 10-13). The respective numbers of students citing a period of rotation and revolution is also greater than the numbers of students who mentioned rotation and revolution respectively in their description of the earth's motion (Response nos. 3 & 4). Also many students did not write the units (hours/ days) (Response nos. 7 &11; which was considered partially correct) or interchanged the numbers for rotation and revolution (Response nos. 8 & 12). These observations suggest that students recalled a number but they could not retrieve the related motion from their mental model or from observations.

In Question no. 5, students were asked to draw a diagram of the earth and to draw and name its axis, poles and equator. They were also asked to show that the earth is rotating around itself. The percentages of correct responses are summarized in Table 6.28. Most of the students from all grades drew a circular earth (Response no. 1). The percentage of students who drew the poles was significantly higher in Grade 7 than in Grade 4 and it further increased in Grade 8 (both in the treatment and comparison groups) (Response nos. 2 & 3). The percentage of students who drew the axis and showed the rotation of the earth was similar in Grades 4, 7 & 8c (Response nos. 6 & 5). However, the intervention seems to have had a strong effect on representing motion since the percentage of students who drew the axis and showed the rotation of the earth is significantly higher in the treatment group after intervention than that in the pre-tests and in the comparison group (Figure 6.6). The analysis of students' representation of motion in Tests 4 & 5 is already given in Subsection 5.3.3.

Table 6.28: Percentage of students who correctly drew elements in the diagram in the earth (Question no. 5)

No.	Response *N*	Gr4 *88*	Gr7 *58*	Gr8t *54*	Gr8c *77*
1	Earth	91	97	98	95
2	North Pole	6*	52*	85	81
3	South Pole	3*	55*	85	81
4	Equator	2*	62*	87*	48
5	Rotation	3	4*	78*	7
6	Axis	0	2*	78*	7
7	No/ irrelevant Response	5	0	0	4

* Denotes significant difference at $p<0.05$ between that value and the one to its right in the same row.

6.2.2 The solar system

To find out whether students know the categories of the celestial objects, the second question asked students to match the pairs between specific instances ('the Earth', 'the Sun', 'Jupiter', 'Pole Star', 'the moon', 'Sirius') and categories ('planet', 'star', and 'satellite'). The percentages of correct responses are given in Table 6.29.

In 2 cases, the earth and the moon, there is definite increase in correct responses with age; but no further increase after the intervention (Response no. 1 & 3). In two cases the significant increase in correct responses is due to intervention since the percentage of correct responses in the comparison group has not increased much: Jupiter and Sirius (Response nos. 2 & 6). In case of the Pole Star the number of correct responses are strikingly constant, This may be because in Marathi the name

Table 6.29: Percentage of students' responses for matching the instances with their categories (Question no. 2)

No.	Response	Gr4	Gr7	Gr8t	Gr8c
	N	*88*	*58*	*54*	*77*
1	Earth	56*	74	70	69
2	Jupiter	59	62*	81*	60
3	Moon	42*	72	72	75
4	Pole Star	74	74	74	72
5	Sun	48	59	48	43
6	Sirius	32	40*	82*	36
7	No response	1	0	0	3

* Denotes significant difference at $p<0.05$ between that value and the one to its right in the same row.

of Pole Star is '*Druva*' which is usually followed by *tara* or 'star', and it is well known in mythology.

The second and third sub-questions of Question no. 3 asked for basic information about the solar system: Number of planets in the solar system and their names. The percentages of responses for these two sub-questions are given in Table 6.30. About 50% students could correctly answered that there are 9 planets in the solar system (Response no. 1). Although the textbooks recorded the number of planets to be 9, Pluto was declared a 'dwarf planet' ('not a planet') about a year before the intervention began. Therefore, Response no. 2 (No. of planets = 8) was considered correct. Students who gave wrong answers generally wrote the number of planets equal to the number of names they could recall (Response no. 3).

More than 90% students could name at least one planet. The percentage of students who could name all 9 planets was more in Grade 4 than in Grade 7, probably because students learnt the names of planets in Grade 4 and forgot some of them by Grade 7 (about three fourths of Grade 7 and 8c students could name more than 4 but less than 9 planets (Response no. 7)). The percentage of students who named all 9 planets increased after the intervention and was higher than comparison group (Response no. 5).

In Question no. 7 students were asked to draw the sun-earth-moon system (including the orbits of the earth and the moon). From Table 6.31, most of the

Table 6.30: Percentages of students' responses for number and names of planets in the solar system (Question nos. 3 ii, iii)

No.	Response	Gr4	Gr7	Gr8t	Gr8c
	N	*88*	*58*	*54*	*77*
1	No. of planets = 9	55	45	46	47
2	No. of planets = 8	13	21*	7	9
3	Incorrect responses	26	22	24	16
4	No response	5	7	19	29
	Number of planets students could name				
5	Students who could name all 9 planets	15*	3*	28*	12
6	Students who could name ≤ 4 planets	8	14	6	4
7	Students who could name > 4 planets	68	74*	54*	78
8	No response	8	9	9	7

* Denotes significant difference at p<0.05 between that value and the one to its right in the same row.

students drew the circular sun and the circular earth (Response nos. 1 & 2). The percentage of students who drew the moon and its orbit was more in Grade 7 than in Grade 4 and the intervention further helped students in placing the moon (along with its orbit) in the sun-earth system, since this percentage increased after intervention and was more in the treatment group than in the comparison group (Response nos. 3 & 5) (Figure 6.7). The percentage of students who drew the orbit of the earth was similar in the treatment group before and after the intervention, thought it is more than in the comparison group (Response no. 4). The analysis of students' representation of motion in Tests 4 & 5 is given in Subsection 5.3.3. All the students drew partially correct diagrams for both Question nos. 5 & 7 after the intervention.

To see whether students have a rough idea about sizes and distances, we checked the percentages of students who drew the sun bigger than the earth (Response no. 1), the earth bigger than the moon (Response no. 2) and the sun-earth distance greater than the earth-moon distance (Response no. 3). Table 6.32 shows no clear trend in students' understanding of sizes (Response nos. 1 & 2). However, the percentage of diagrams showing the sun-earth distance more than the earth-moon distance increased after intervention and was higher than the comparison group (Response no. 3).

Students made two kinds of mistakes while drawing these diagrams. Some-

Table 6.31: Percentage of students who correctly drew these objects or elements in their diagram of the sun-earth-moon system (Question no. 7)

No.	Response *N*	Gr4 *88*	Gr7 *58*	Gr8t *54*	Gr8c *77*
1	Sun	84	91	87	84
2	Earth	79	88	85	79
3	Moon	16*	45*	70*	51
4	Orbit of the Earth	9*	52	54*	34
5	Orbit of the moon	1*	9*	43*	10
6	No/ irrelevant Response	6	4	0*	9

* Denotes significant difference at p<0.05 between that value and the one to its right in the same row.

Table 6.32: Percentage of correct relative sizes and distances in the diagram of the sun-earth-system (Question no. 7)

No.	Response *N*	Gr4 *88*	Gr7 *58*	Gr8t *54*	Gr8c *77*
1	Size: sun > earth	40*	19*	41	31
2	Size: earth > moon	21*	40	48	50
3	Distance: sun-earth > earth-moon	6	9*	57*	20

* Denotes significant difference at p<0.05 between that value and the one to its right in the same row.

times the relations among different objects or elements were incorrect (incoherent diagrams) or the perspective from which different elements were drawn was not the same (inconsistent perspective) (see Section 5.3.3). The percentages of coherent diagrams and diagrams with inconsistent perspective for Question nos. 5 & 7 are given in Table 6.33.

The percentages of coherent diagrams in Grade 7 is higher than that in Grade 4 for both the diagrams. For the SEM system, the percentage of coherent diagrams in the treatment group is higher than that in the comparison group. The perspective consistency of Grade 7 students is higher than the Grade 4 students for the diagram of the earth (Response no. 3). The perspective consistency for SEM system improved in the post-test of the treatment group (Response no. 4) .

The percentages of coherent diagrams and diagrams with inconsistent perspective were higher for the diagram of the earth than the diagram of the SEM system.

Table 6.33: Percentages of coherent diagrams and diagrams with consistent perspective (Question nos. 5 (earth only) & 7(SEM system))

No.	Response	Gr4	Gr7	Gr8t	Gr8c
	N	*88*	*58*	*54*	*77*
1	Coherency (Question no. 5)	3*	47	56	47
2	Coherency (Question no. 7)	11*	29	44*	25
3	Perspective consistency (Question no. 5)	0*	62	65	73
4	Perspective consistency (Question no. 7)	1	5*	24	13

* Denotes significant difference at p<0.05 between that value and the one to its right in the same row.

This is understandable since the diagram of the earth included only only 3 elements (pole, equator and axis), but the diagram of the SEM system included 5 elements (orbit of the earth, orbit of the moon, axis/ axial motion of the earth, axis / axial motion of the moon and equator of the earth). In the intervention students were explicitly made aware that they have to keep the perspective consistent while they are drawing. The low percentages especially for perspective consistency of the SEM system show that there is a major difficulty in constructing a coherent mental model (Figure 6.8a) and more difficulty in keeping objects and their motions in consistent perspective (Figure 6.8b),

6.2.3 Terms related to astronomy

In Question no. 9 students were asked to classify the given objects into luminous and non-luminous. These objects included 5 celestial objects, 2 objects in the sky (cloud, firefly) and three objects on the earth. Table 6.34 gives the percentages of correct responses for each grade.

Most students answers are correct for the sun, which is but natural (Response no. 1). Mirror and earth were also easy for students (Response no. 2 & 3). Many Grade 4 students had problems about Clouds, Firefly and Planets (Response nos. 4, 5, & 6). More than 60% students from Grade 4 and more than 40% students from Grades 7 and 8 (comparison group) think that the moon emits its light, but the corresponding percentage in the treatment group is higher (82%) (Response no. 10).

Table 6.34: Percentage of correct responses for the classification of objects as self-luminous and non-luminous (Question no. 9)

No.	Response *N*	Gr4 *88*	Gr7 *58*	Gr8t *54*	Gr8c *77*
1	Sun	81*	93	96	90
2	Mirror	61	72*	88	83
3	Earth	61*	88	89*	71
4	Cloud	43*	81	83	70
5	Firefly	35*	83	85	83
6	Planet	46*	67	74	71
7	Stars	57*	81	65	51
8	Flame	52	64	61	66
9	Bulb	49	60	54	65
10	Moon	33*	50*	82*	57

* Denotes significant difference at $p<0.05$ between that value and the one to its right in the same row.

In general, Grade 7 students' understanding of terms luminous and non-luminous is better than that of Grade 4 students and there is progress in the post-test on 6 out of 10 items (Response nos. 1, 3, 4, 5, 6, 7, 10). The percentage of correct responses increased for only two cases after intervention (Mirror & Moon; Response nos. 2 & 10) and the treatment group has performed significantly better than the comparison group in two cases (Earth & Moon; Response nos. 3 & 10), though in the case of the earth there was no pre-post difference.

6.2.4 Sizes and distances

In two questions students were asked to arrange the objects according to distances from the sun (Question no. 10) and sizes (Question no. 11) from small to large. An object was judged to be in its correct position if either it was at its correct place in the sequence or if it was correctly placed with respect to its neighbours. The percentages of correct responses for distances and sizes are given in Tables 6.35 & 6.36 respectively.

Grade 7 students' judgement about relative distances appears better than that of Grade 4 students, except for judgment about distance of the Pole Star. How-

Table 6.35: Percentage of correct responses for the order the objects according to their distance from the earth (Question no. 10)

No.	Response	Gr4	Gr7	Gr8t	Gr8c
	N	*88*	*58*	*54*	*77*
1	Firing	11*	41	44	40
2	Moon	11*	29	33	29
3	Pole Star	19*	4*	32	21
4	Sun	10*	24	28*	14
5	No response	6	4	2*	12

* Denotes significant difference at p<0.05 between that value and the one to its right in the same row.

ever, the percentage of correct placing of the Pole Star increased significantly after instruction (Response no. 3). Students' judgment of distance of the sun was significantly better in the treatment group than in the comparison group (Response no. 4), although here again the pre-post difference was not significant.

Table 6.36: Order the objects according to their sizes (Question no. 11)

No.	Response	Gr4	Gr7	Gr8t	Gr8c
	N	*88*	*58*	*54*	*77*
1	Shooting star	49	54	67	66
2	Sun	30*	50	67*	36
3	Moon	32	41	57*	38
4	Earth	19*	35*	57*	17
5	Jupiter	16*	2*	48*	25
6	No response	6	5	2	3

* Denotes significant difference at p<0.05 between that value and the one to its right in the same row.

From Table 6.36 we can see that Grade 7 students' judgment about sizes is significantly better than that of Grade 4 students for the sun & earth (Response nos. 2 & 4). In two cases there is significant increase in the treatment group after the intervention (the earth, Jupiter; Response nos. 4 & 5). Students from the treatment group had better judgement about the sizes of 4 celestial bodies than the comparison group in four cases (the sun, moon, earth & Jupiter; Response nos. 2, 3, 4 & 5).

6.2.5 Test 2: Comparison of total scores

Total scores of all the Grades (after collapsing all three samples) were found to be normally distributed for Test 2. By the comparison of means (see Appendix H) we found that:
1. Grade 7 students knew more textbook facts than Grade 4 students (Gr7 > Gr4).
2. Grade 8 students' scores on the Textbook Facts improved after the intervention (Gr8t > Gr7).
3. Grade 8 students from treatment group knew the textbooks facts better than Grade 8 students in the comparison group (Gr8t > Gr8c).
4. The Grade 8 (comparison group) was similar to Grade 7 in terms of their understanding of textbook facts ($Gr7 \simeq Gr8c$).

6.3 Test 3: Indigenous Knowledge

Test 3 was designed to check whether students know any of the terms used in the indigenous knowledge system, whether they know examples, meaning and observational significance of these terms (see Appendix A.3). The test was attempted by 191 students from Grade 7, Grade 8 (treatment group) and Grade 8 (comparison group) students (Table 3.3). Test 3 was not administered to the Grade 4 students, but the question were asked orally to the entire class, for the reasons explained in Subsection 3.5.2.

Indigenous knowledge traditions in India are closely bound with religious practices. 80.5% of the Indian population belongs to the Hindu community, which is itself quite heterogeneous in composition. The students in our sample all are from the "Hindu" community in a broad sense. Although different versions of the Hindu calendar are in use, but the students in our sample, all from the State of Maharashtra, followed a single calendar system called '*Chaitri Panchang* (a calendar which starts with the month *Chaitra*)'. The various versions of the Hindu calendar are all lunisolar in nature. All the months starts on the first day after the new-moon and end on the next successive new-moon. A month is named after the *Nakshatra* in which the moon is visible on the Full-moon[4]. The days are counted from 1 to 14 ('*tithi*' in Marathi: *Amawasya, Partipada* (sometimes referred as *Prathama* in the intervention for the sake of simplicity), *Dwitiya (Beej), Tritiya (Teej), Chaturthi, Panchami, Shashti, Saptami, Ashtami, Navami, Dashami, Ekadashi, Dwadashi, Trayodashi, Chaturdashi, Pournima*) after the new-moon and again after the full-moon. The name of the phase of the moon and the name of the date is identical. The latter is usually accompanied by the word '*Shukla*' (or '*Shudhha*') or '*Vadya*' (or '*Krishna*') to indicate waxing and waning respectively. An extra month ('*Adhika Maasa*') is added once every two or three years to compensate for the approximately eleven fewer days per year in twelve lunar months in comparison to the solar calendar. The common terms in indigenous astronomy are explained in Appendix G.2.

Originally developed from an observational base, the indigenous calendars are now derived from tabulations and their format is integrated with the Gregorian calendar. A widely used printed calendar (found in literate households) marks the Gregorian months as also the weeks and the solar days, along with symbols and colour coding to show lunar months, days and special events, festivals and national holidays (both religious and secular). An image of this calendar and an elaboration of its cells is given in Appendix E. Traditional calendar is still used to organize agricultural activities through the year as also numerous festivals and fasts which are named after the phase of the moon. Women in the households tend to practice fasts and rituals more than men do. Schools too celebrate festivals and declare local holidays for the more prominent festivals. Most importantly these traditional calendars contain notings on numerous observational facts such as phase of the moon, in which division of the sky and zodiac sign the moon is seen, the daily times of sunrise and sunset, the times of moonrise and moonset on important days, and also the name of the month, which shows which star group or '*Nakshatra*' is visible on the sky through the night (see Appendix E).

The first question of the test on indigenous knowledge probed whether students know the relation between festivals and phases of the moon. The analysis of their responses is provided in Subsection 6.3.1. In Question nos. 2, 3 & 4 students were

[4]A '*Nakshatra*' or lunar mansion is one of the 27 or 28 divisions of the sky, identified by their prominent star(s), that the moon passes through during its monthly cycle, as used in Hindu astronomy and astrology.

asked to name the instances of terms used in indigenous astronomy (and astrology) such as names of the Marathi months,'*Nakshatra*' and '*Rashi*', and the analysis of these questions is given in Subsection 6.3.2. Question nos. 5, 6 & 7 dealt with the observational significance of terms and phrases used in indigenous astronomy, and their analysis is given in Subsection 6.3.3. The last question (Question no. 8) was related to students' attitudes towards astrological effects of stars, and its analysis is given in Subsection 6.3.4. For correspondence between the Subsections and the question numbers see Table A.4.

Some responses were close to the correct response but clearly showed that students did not know the exact name, or they might have overheard it somewhere. These are given a half mark in scoring but are counted as correct response in the qualitative analysis. For example, if students wrote a name which bore a resemblance to the name of a festival/ month/ *Nakshatra*/ *Rashi* they were given 0.5 marks, but while counting, this name was given full credit. In case of drawings of phases, approximately correct responses (such as a crescent with outer boundary less than a half circle) or correct responses which did not fit in the sequence (e.g. *Dwitiya*-crescent, *Chaturthi*-gibbous, *Panchami*-crescent or little difference between *Dwitiya*, *Chaturthi* and *Panchami*) were also given a half mark in scoring but are counted as correct response here.

6.3.1 Festivals and phases of the moon

The first question was asked to test whether students know the connection between the festivals (which follow the indigenous calendar) and phases of the moon (astronomy). The question asked students to name the festivals occurring on a Full moon, New moon, *Dwitiya* - Second day after full (or new) moon, *Chaturthi* - Fourth day after a full (or new) moon, *Panchami* - Fifth day after full (or new) moon, *Ashtami* - Eighth day after full (or new) moon (i.e. same as half moon) and *Dashami* - Tenth day after full (or new) moon). In the same question students were asked to draw the picture of the moon on each of above phases.

Knowledge about festivals

When students were asked to list the festivals occurring on different phases of the moon, initially they were puzzled. It had not occurred to them that the festival dates had any observational significance. After we hinted that the names of the festivals, in most cases, incorporated the term for phase of the moon on that day, students wrote some responses.

All students together gave total of 1492 responses. Table 6.37 summarizes students' responses to each phase. The order of phases is kept the same as that in the test. Some peculiar responses which are not mentioned here are: *LalitaPanchmi* (mentioned by 7 tribal students in pre-test; perhaps because it is an important festival for that community), and also responses which are neither as correct nor counted as wrong like '*Balu mamacha san/ puja*' (*san* = festival), 'breaking coconut', *Jatra (masoba, margubai, dhaloba, Jyotiba, adabal-sidhdhha)* for *Amawasya*. These responses are not more than 10 and mostly come from rural and tribal students.

Some students used different names of the festivals such as '*Nagarajachi Puja*' (worship of the Kobra-King) for *Nag-Panchami*, *Ganapaticha San* for *Ganesh-Chaturthi*, and *Krishnashtami*. These responses came mainly from rural students. The responses are recorded here to convey the sincerity of engagement of the students, who wrote whatever they knew, without bothering whether these are 'accepted responses' or not. This is unusual in the Indian context, since such questions are never asked in a formal place like examinations, so students are not accustomed to giving such informal responses.

Out of the total responses, maximum number of responses were given for Full moon 392 (26%), followed by 284 (19%) responses for *Panchami*. Fifteen percent responses were given for *Chaturthi*, 12% for *Dashami* and little less than 12% for *Ashtami* and *Amawasya*. Students could give the least number of responses for the *Dwitiya* (less than 5%).

Also from Table 6.38 the percentages of wrong responses for '*Chaturthi*' and '*Panchami*' (out of the total number of responses for that phase for each Grade) is much less than those for other phases (8%-22% and 7%-8% respectively), whereas the percentage of wrong responses is quite high for *Dwitiya* (68%). It so hap-

Table 6.37: Percentage of students who gave particular (correct) responses (Question no. 1)

No.	Response	Gr7	Gr8t	Gr8c
	N	*59*	*54*	*78*
	Pournima (Full mon)			
1	*Holi*	68	39	45
2	*Narali-Pournima*	25	52	19
3	*Vat-Pournima*	3	22	3
4	*Budhha-Pournima*	5	4	24
5	*Guru-Pournima/ Vyasa-Pournima*	0	13	0
6	*Kojagiri/ Ashwini-Pournima*	8	4	0
7	*Baindur*	20	7	12
8	*Hanuman-Jayanti*	0	2	0
9	*Rakhi-Pournima*	32	7	1
10	*Datta-Jayanti*	0	0	6
	Amawasya (New moon)			
11	*Diwali/ Laxmipujan*	51	33	35
12	*Mahashivratra*	0	28	1
	Dwitiya (2^{nd} day after new or full moon)			
13	*Bhaubij*	15	6	4
14	*Bakari Id*	3	0	1
	Chaturthi (4^{th} day after new or full moon)			
15	*Ganesh-Chaturthi*	80	78	94
16	*Sankashti*	5	31	13
	Panchami (5^{th} day after new or full moon)			
17	*Nag-Panchami*	63	69	83
18	*Rang-Panchami/ Pani-Panchami*	80	52	55
19	*Rishi-Panchami*	0	2	8
	Ashtami (8^{th} day after new or full moon)			
20	*Gokul-Ashtami*	51	48	82
21	*Durgashtami*	0	2	0
	Dashami (10th day after new or full moon)			
22	*Dasara/ Vijaya-Dashmi*	56	52	79

pens that the nomenclature of two of the *Chaturthi* and two of the *Panchami* festivals incorporates the names of the moon's phases (*Ganesh-Chaturthi, Sankashti-Chaturthi, Nag-Panchami and Rang-Panchami*). The festivals which lie of the day of *Dwitiya* do not include the word '*Dwitiya*' as part of their name (e.g. *Bhau-bij*, although '*Bij*' does mean '*Dwitiya*' in rural Marathi).

Thus it seems that the students could mostly named the festivals based on their moon-related nomenclature. They did not know what is the phase of the moon on that particular festival. They knew the names of the festivals (since they could produce a large number of responses) but the connection of festivals with astronomy was not known. In the pre-test, out of 528 such responses given by 59 students (8.95 responses per student), 65% correctly matched the festival with the phase of the moon. This percentage increased to 76% for the post-test, though the total number of responses was reduced to 397 (7.35 responses per student). Seventy eight students from the comparison group gave a total of 567 responses (7.26 responses per student which is less than per student responses for the treatment group for both pre-test and post-test) and with almost 80% correct responses.

Table 6.38: Percentage of wrong responses for the phase out of the total responses produced (Question no. 1)

Grade	No.	1	2	3	4	5	6	7
	N	Full moon	New moon	Dwitiya	*Chaturthi*	*Panchami*	*Ashtami*	*Dashami*
		% wrong	% wrong	% wrong	% wrong	% wrong	% wrong	% wrong
Gr7	*59*	37	43	56	22	8	52	43
Gr8t	*54*	31	20	86	13	7	23	18
Gr8c	*78*	30	31	69	8	7	15	29

Knowledge about shapes of phases of the moon

In the first question, students were also asked to draw picture of the moon on that phase. This was asked to check whether they had observed the moon on that phase. On some festivals it is an inbuilt custom to watch the moon while on others it is not specifically permitted to do so.

Table 6.39 summarizes the percentages of student who produced particular (right or wrong) kind of pictures for each phase. Most of the students drew a picture of the full moon. The percentage of the students who drew correct new moon (either a dark circle or wrote that 'moon cannot be seen in the sky'), half moon, crescent & gibbous (for *Chaturthi*) and the total percentage of the correct responses increased from pre to post-test and was higher than the comparison group (Response nos. 3, 5, 8, 16 & 27). The percentages of correct responses for crescent for *Dwitiya & Panchami* were higher in the treatment group than in the comparison group (Response nos. 7 & 9). The percentage of wrong responses for the new-moon and Crescent for *Dwitiya* decreased from pre-test to post-test. Remarkably in the tribal and urban post-tests, not a single student drew a wrong picture for the full and new moon.

6.3.2 Naming the examples (names) of terms

Marathi Months

In Question no. 2 students were asked to name the Marathi months. The Marathi names of months are taught in school, though without reference to their observational significance. The percentages of students who named at least 1 month, less than or equal to 6 months, more than 6 months and all 12 months are provided in Table 6.40. The percentage of students who could name all 12 months increased from pre to post test and is greater than that of comparison group, and the percentage of students who could not name any month dropped to zero after the intervention. The number of months per student for each Grade is given in Table 6.41.

Rashi

In Question no. 4 students were asked to list names of the *Rashis* they know. There are 12 *Rashis* so the maximum possible marks for this Question were 12. The percentages of students who named at least 1 *Rashi*, less than or equal to 6 *Rashis*, more than 6 *Rashis* and all 12 *Rashis* are provided in Table 6.40 and the number of *Rashis* per student for each Grade is given in Table 6.41.

The percentages of students who could name at least one *Rashi* were similar to the percentage of students who could name at least one month months in pre-test. But in case of Marathi months, the percentage increased to 100% in the post-test, whereas in case of *Rashi* it did not increase. *Rashis* do not have much observational or astronomical importance in Indian indigenous calendar and since they are mainly

Table 6.39: Percentage of student who produced particular kind of picture for the phase (Question no. 1)

No.	Festival for	Gr7	Gr8t	Gr8c
	N	*59*	*54*	*78*
1	Correct Full moon	78	74	67
2	Incorrect Full moon	10	4	4
3	Correct New moon	37*	67*	32
4	Incorrect New moon	27*	4	5
5	Correct Half moon *Ashtami*	10*	35*	4
6	Incorrect half moon	31	17	23
7	Correct Crescent (*Dwitiya*)	14	28*	5
8	Correct Crescent (*Chaturthi*)	22*	41*	12
9	Correct Crescent (*Panchami*)	17	22*	6
10	Correct Crescent (*Dashami*)	8	15	5
11	Incorrect Crescent (*Dwitiya*)	15*	4	10
12	Incorrect Crescent (*Chaturthi*)	7	6	12
13	Incorrect Crescent (*Panchami*)	14	6	12
14	Incorrect Crescent (*Dashami*)	10	11	4
15	Correct Gibbous (*Dwitiya*)	3	7	1
16	Correct Gibbous (*Chaturthi*)	0*	7*	0
17	Correct Gibbous (*Panchami*)	0	4	0
18	Correct Gibbous (*Dashami*)	3	11	3
19	Incorrect Gibbous (*Dwitiya*)	15	6	9
20	Incorrect Gibbous (*Chaturthi*)	22	9	6
21	Incorrect Gibbous (*Panchami*)	20	17	10
22	Incorrect Gibbous (*Dashami*)	7	6	6
23	Incorrect Eclipse-Gibbous (*Dwitiya*)	10	9	8
24	Incorrect Eclipse-Gibbous (*Chaturthi*)	8	2	5
25	Incorrect Eclipse-Gibbous (*Panchami*)	3	2	4
26	Incorrect Eclipse-Gibbous (*Dashami*)	5	0	4
27	Total correct % †	49*	76*	53
28	No. of pictures per student	4	4	3

†Total number of correct pictures for that class/ total number of pictures produced for that class.

* Denotes significant difference at $p<0.05$ between that value and the one to its right in the same row.

related to astrology, we gave less importance to them in pedagogy. In the observation session we showed only a couple of *Rashis* (which are quite striking, like Leo and Scorpio). This could explain the no increase in the percentage of students who

Table 6.40: Percentage of students who could name Marathi months and *Rashis* (Question nos. 2 & 3)

Grade	*N*	Months = 0	Months (≤ 6)	Months > 6	At least 1 month	*Rashi* = 0	*Rashi* (≤ 6)	*Rashi* (>6)	At least 1 *Rashi*
Gr7	*59*	12*	5	83	88*	7	58	36	93
Gr8t	*54*	0*	11	89	100*	7	43	50*	93
Gr8c	*78*	13	8	79	87	5	27	68	95

* Denotes significant difference at p<0.05 between that value and the one below it in the same column.

could name at least 1 *Rashi*, compared with the maximum possible increase in the percentage of the students who could name at least 1 Marathi month.

An interesting thing to note here is that the names of the zodiac signs come from Sanskrit and are different from the common words used for their signs. Students wrote the words in common use like '*taraju*' (Marathi word for '*Tula*' which means Balance), '*Dhanushya*' (for *Dhanu* = Bow), '*masa*' (for '*Meen*'=fish). This might be because they remembered pictures which are given by the side of the name of the sign in the alstrological columns of newspapers or calendars. This observation confirms the students' familiarity to the *Rashis* is from fortune telling. From the observation session however we know that they were not aware that *Rashis* are the observable entities in sky.

Nakshatras

In Question no. 3 students were asked to list the names of *Nakshatras* they know. There are 27 *Nakshatras*, so the maximum score for this question was 27. About 7 students mistakenly wrote the name of a constellation which is not *Nakshatra* (constellations such as Great Bear which are not on the moon's or the sun's path hence not considered for the purpose of time keeping). These students are given 0.5 marks while counting their scores since these constellations are also called *Nakshatra* in Mathathi, although they are not so in a strict astronomical sense. None of the students wrote the such constellations in addition to 27 *Nakshatras*. So the maximum score is kept as 27. For the qualitative analysis, the *Nakshatras* and constellations are counted separately. The number of *Nakshatras* per student for each Grade is given in Table 6.41.

Table 6.41: Average number of Marathi months, *Nakshatras* and *Rashis* prduced by each student (Question nos. 2, 3 & 4)

Grade	*N*	No. of Marathi months/ student	No. of *Rashi*/ student	No. of *Nakshatra*/ student
Gr7	*59*	9	6	1
Gr8t	*54*	10	6	5
Gr8c	*78*	9	8	1

None of the differences between that value and the one below it in the same column were significant at $p<0.05$.

Table 6.41 shows that students were more conversant with names of zodiac signs (6-8 names per students out of 12) which have astrological meaning than with names of *Nakshatras* (only 1 name per student out of 27 before intervention) which have a significant time keeping role in astronomy. These responses show that students were exposed to indigenous knowledge through out-of-school resources, but this knowledge, being bound with astrology, remained unintegrated with observation on the one hand and school learning on the other.

The names of *Nakshatras* were frequently used during the intervention and their relation to the months was also explained. The observations and repeated use of names of *Nakshatras* also might have probably reinforced the names of *Nakshatras* as well as of the months.

6.3.3 Familiarity with terms and their meaning

In Question nos. 5, 6 and 7, phrases related to *Rashis* and *Nakshatras* were given and students were asked whether they have heard this term and do they know the meaning of that phrase. The percentages of students who had heard a particular phrase, and knew its meaning, are given in Table 6.42.

Phrases related to *Nakshatras*: In Question no. 5 and 6 two phrases related to *Nakshatras* (beginning of the *Nakshatra* and 'the sun entering in a *Nakshatra*' respectively) were given, both of which mean that the *Nakshatra* is exactly behind the sun and hence it will not be seen from the earth. Students were asked whether they know these phrases and what are their meanings.

Phrase related to *Rashi*: In Question no. 7, students were asked whether they know the phrase 'somebody is born in certain zodiac sign' and what does it mean?

Table 6.42 summarizes the percentages of correct responses for these three questions (Question nos. 5, 6 & 7). Response no. 1 gives the percentages of students who had heard the phrases, Response no. 2 gives the percentage of students who could correctly write the meaning of these phrases (that the earth is at such a position that a certain *Nakshatra* or *Rashi* is exactly behind the sun) and Response no. 3 gives the percentage of students who could tell the observational significance of the phrase (that the *Nakshatra* or *Rashi* wouldn't be seen).

Table 6.42: Percentage of students who had heard the phrases related to indigenous astronomy and could correctly explain their meaning in terms of observational astronomy (Question nos. 5, 6 & 7)

No.	Response	Question no. 5			Question no. 6			Question no. 7		
		Starting of a *Nakshatra*			Sun in a *Nakshatra*			Birth in a *Rashi*		
		Gr7	Gr8t	Gr8c	Gr7	Gr8t	Gr8c	Gr7	Gr8t	Gr8c
	N	*59*	*54*	*78*	*59*	*54*	*78*	*59*	*54*	*78*
1	Heard	42*	63*	24	37	44*	17	37	48	35
2	Meaning	0*	22*	0	0*	15*	0	0	6*	0
3	Observation	0	6*	0	0*	7*	0	0	0	0

* Denotes significant difference at $p<0.05$ between that value and the one to its right in the same row.

Neither *Nakshatras* nor *Rashis* are referred to in textbooks. In pedagogy we tried to explain the role of *Rashis* and *Nakshatras* for time keeping and explained related terms. The percentage of students who had heard the phrase 'starting of a *Nakshatra*' increased from pre-test to post-tests.

None of the students in pre-test and from the comparison group know the meaning of these phrases. The percentage of students could correctly tell the meaning of 'starting of a *Nakshatra*' and 'sun in a *Naksatra*' increased significantly after intervention. The percentage of Grade 8 students from the treatment group who correctly responded about the observational significance (that the *Nakshatra* or *Rashi* are not seen after they are started, or the sun enters into them) increased for the phrase 'sun in a *Nakshatra*'. The percentages for both meaning and observational significance of both the *Nakshatra* related terms in the treatment group were higher than those in the comparison group. The improvement on the question on *Rashi* is the least, which might again be explained on the basis of less emphasis on *Rashis* in the pedagogy (although, we expect students should know the meaning of the terms they know or use).

During classroom interaction, while students were asked what they know about eclipses, a few responses related to superstitions came from students (particularly from rural students). Beliefs and rituals mentioned by students were similar to those mentioned by Mohapatra (1991) given in Section 1.1. It must be recalled here that students reported that parents (especially mothers) ask them to read the calendar (when is particular phase of moon/ *Nakshatra* is starting) since they are the only or one of the few family-members who are literate. This means students who stay at home take active part in comprehending a calendar, whereas students who do not stay at home do not get chance to do that.

6.3.4 Scientific attitude

The eighth question which was the last question of the test directly asked the students whether they believe in astrology. We are aware that a single direct question related to attitude is not a good indicator of students' attitudes. However, since students knew that their responses will not affect their school grades and they were free to express their opinion, we believe that even this single question may give some indication of their attitude. Table 6.43 summarizes the average normalized scores on this question. The increase in total scores may mean that exposing students to indigenous knowledge may lead to healthier attitude towards the irrationalities within it rather than developing a mysterious curiosity about it. The scores of the comparison group are higher than that of pre-test for rural and tribal group, but they are less than post-test scores for rural and urban group.

From the Table 6.43 we can see that, In the pre-test, about 45% of the total students explicitly answered that they believe in astrology, whereas only 17% answered that they do not believe in astrology. About 22% were not sure and the remaining students did not answer the question.

Table 6.43: Percentage of students who responses that they believe or do not believe in astrological effects of stars and no responses

No.	Response	Gr7	Gr8t	Gr8c
	N	*59*	*54*	*78*
1	Believe	45*	19	26
2	Do not believe	17*	48*	26
3	Not sure	22	11	15
3	No response	16	22	33

* Denotes significant difference at p<0.05 between that value and the one to its right in the same row.

The percentage of believers in astrology in Grade 7 dropped from 45% to 19%, whereas the percentage of non-believers increased from 17% to 48% in the post-test. The percentage of students who responded that they did not believe in astrology is higher in the treatment group than in the comparison group. Thus, although our pedagogy used indigenous knowledge which was available with students linked with astrology, our students probably did not become more superstitious at the end of intervention. On the contrary many students become non-believers, although explicit preaching about superstitions was avoided. Simply understanding the meaning of terms used in astrology and the explanation of many of the astronomical phenomena may have helped. We would like to conclude that instead of bypassing knowledge that is already available with students, it is better to address it which may reduce its potentially harmful effects.

6.3.5 Test 3: Comparison of total scores

The total scores for each Grade (after collapsing all three samples) were found to be normally distributed for Test 3 using the one sample Kolmogorov-Smirnov test. By the comparison of means we found that scores of the treatment group in the post-test were significantly higher than the pre-test (Gr8t > Gr7) and that of the comparison group (Gr8t > Gr8c). The difference between Grade 7 students and the grade 8 students in the comparison group was not significant ($Gr7 \simeq Gr8c$) (see Appendix H).

6.4 Summary

This Chapter presents findings on students' observations about astronomical objects and phenomena (Test 1, Section 6.1), textbook information acquired by students (Test 2, Section 6.2) and indigenous knowledge of students (Test 3. Section 6.3). Findings related to students' observations and indigenous knowledge (Tests 1 & 3) are summarized here. Findings related to textbook information (Test 2) are summarized along with students' mental models in Subsection 7.3.

6.4.1 Observations

Quantitative observations are important in explanations of phenomena (e.g. time and position of the rising and setting sun help explain occurrence of seasons). However students' observations of daily phenomena in the sky were qualitative in nature (colour, brightness), rather then quantitative (position/ time). Most of the students (76%-95%) had observed the rising and setting of the sun and could describe the rising and setting sun in terms of its its colour, shape, size brightness etc.. Similar percentages of students knew the (East/ West) direction of rising and setting of the sun. Before intervention (Grade 7), 44% & 50% students respectively knew that the direction of sunrise and sunset changes every day, and 65% & 66% students knew that the time of sunrise and sunset changes every day. The percentage of these correct responses increased in Grade 8 (74%, 70%, 93% & 91% respectively). A small percentage of students without intervention (Grade 7 - 3% and Grade 8c - 4%) knew that the sun does not come overhead every day and, even after intervention, although this percentage increased significantly, only 34% of the students knew it.

Before intervention, visual properties (as above) were readily given by the students in their descriptions (rising sun, stars, differences between the setting sun & the sun at noon, day & night), followed by spatial (sometimes combined with temporal) responses and responses based on other sensory properties depending upon the context. Heat, temperature related responses were common for difference between the setting sun & the sun at noon and day & night and spatial responses (size, shape, motion) were more common in description of stars, shooting stars and the rising sun. Human centric responses were common. Living world related responses were present, particularly for the difference between day & night.

Night sky observations are often lacking in students' normal experiences. Initially, in the star-gazing sessions, students named a few, but they could not identify any of the planets, stars, *Nakshatras* and *Rashis* in the sky. They could not name any stars though they could name (though not identify) the planets which are given in their textbook. Most of the students (77%) knew about the phases of the moon, but they had problems in drawing the gibbous and naming the phases. For example, only 2% could draw the correct gibbous shape and 10% could name the full moon correctly as '*Pournima*' in Marathi (the percentages were less for other phases) in Grade 7.

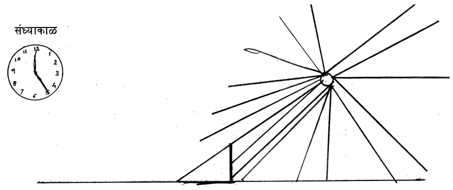
6.4.2 Indigenous knowledge

The results indicate that students' astronomical knowledge might have come from cultural practices rather than from observations or textbooks, and that this knowledge was associated with astrology. As an example, a large number (66%) of students knew before intervention that the time of moonrise and moonset changes every day, but fewer knew the directions of rising and setting of the moon before the intervention (47-48%). The percentage of students before intervention who knew that the time of sunrise and sunset changes every day was almost same as the percentage of students who knew that the time of moonrise and moonset changes every day (65%, 66%). The latter fact is not mentioned in textbooks, but it has religious significance. Another observation was that students knew the common terms in indigenous astronomy, and could name the Marathi months, *Rashis* and *Nakshatras*. Naming a *Rashi* (0.46 *Rashi*/ student) was somewhat more common than naming a *Nakshatra* (0.04 *Nakshatra*/ student). *Rashis* or 'star-signs' has significance in popular astrology (though *Nakshatras* are also used in more technical astrological predictions).

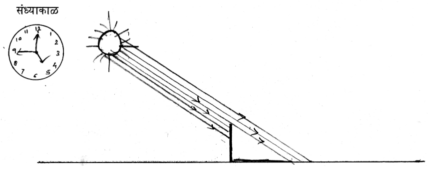
The connection between the indigenous calendar and observable astronomy was not known to students. They knew the names of the *tithis* (days of the fortnight), but did not know the equivalence between the phases of the moon and the *tithis*. Similarly they did not know about the observational context in which the terms *Rashi* and *Nakshatra* are used. The intervention helped them understand the meanings and context of the indigenous terms. For example, 22% students could explain the meaning of term 'starting of a *Nakshatra*' after intervention.

We conclude that it is possible to use indigenous knowledge in a positive way in teaching. Indigenous astronomical knowledge integrated with astrological beliefs is already prevalent widely (about half the students before the intervention stated that they believed in astrology). Therefore one needs to address the issue while teaching formal astronomy. Yet there is a danger of reinforcing superstitious beliefs while using indigenous knowledge. In the intervention we emphasized the scientific part of this knowledge and we connected cultural tools such as calendars to actual observations. Our study showed that the percentage of students who state that they believe in astrology (45%) sharply decreased (to 19%), and those who state that they do not believe in astrology (17%), sharply increased after the intervention (to 48%). Although the teacher's views relating to these beliefs were reflected in her teaching, any head-on criticism of astrology was avoided, which appears to have been a reasonably effective strategy.

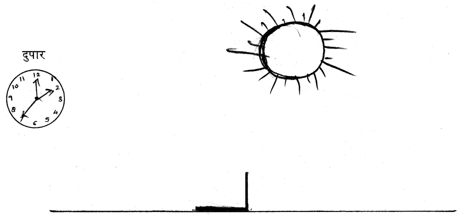
The grade-wise comparisons of all five tests are summarized in Section 7.4 and the comparison of rural, tribal and urban samples is presented in Section 7.5.



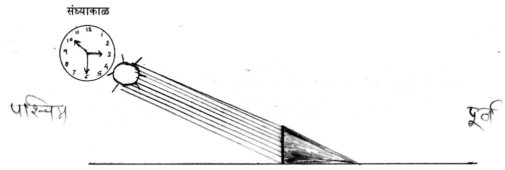
(a) A response by Grade 8 (treatment group) rural girl: Response no. 1



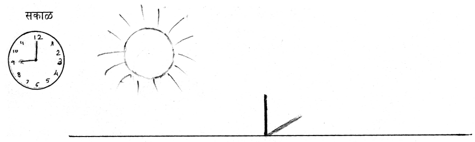
(b) A response by Grade 8 (treatment group) rural girl: Response no. 2



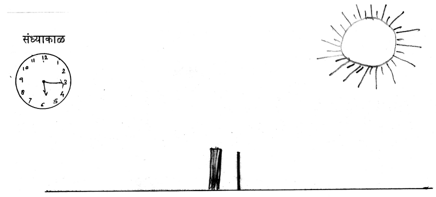
(c) A response by Grade 8 (comparison group) rural girl: Response nos. 4 & 7



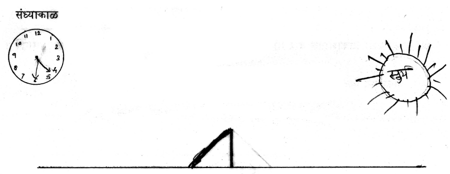
(d) A response by Grade 8 (treatment group) tribal boy: Response no. 8



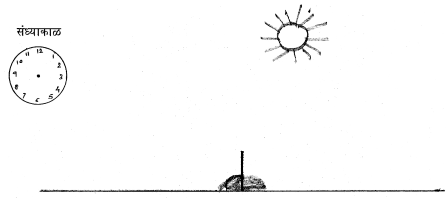
(e) A response by Grade 8 (comparison group) rural girl: Response nos. 4 & 10



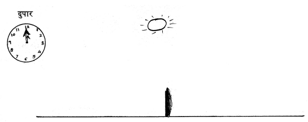
(f) A response by Grade 8 (comparison group) tribal girl: Response no. 11



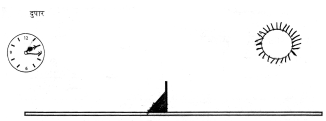
(g) A response by Grade 8 (comparison group) rural boy: Response no. 12



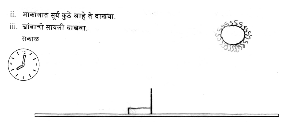
(h) A response by Grade 8 (comparison group) rural girl: Response no. 13



(i) A response by Grade 8 (comparison group) tribal boy: Response no. 14

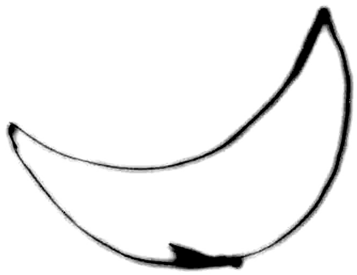


(j) A response by Grade 4 urban girl: Response no. 15

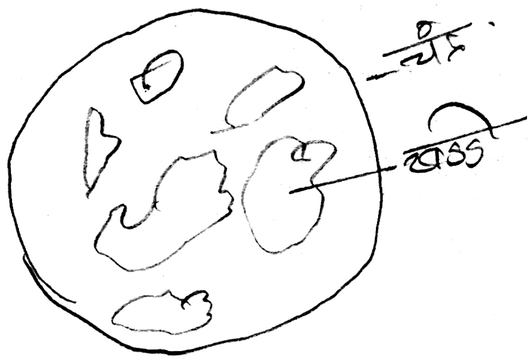


(k) A response by Grade 4 tribal girl: Response no. 16

Figure 6.3: Response to Question no. 3 in Test 1 (Table 6.12): Drawing shadow for different positions of the sun



(a) Thick crescent (Response no. 5): a correct shape of the moon seen in day-time by Grade 8 (comparison group) urban boy



(b) A full moon (Response no. 6) as a shape of the moon seen during day-time: An incorrect response by Grade 8 (treatment group) rural boy

Figure 6.4: Students' responses for shape of the moon seen in day-time (Question no. 11 ii)

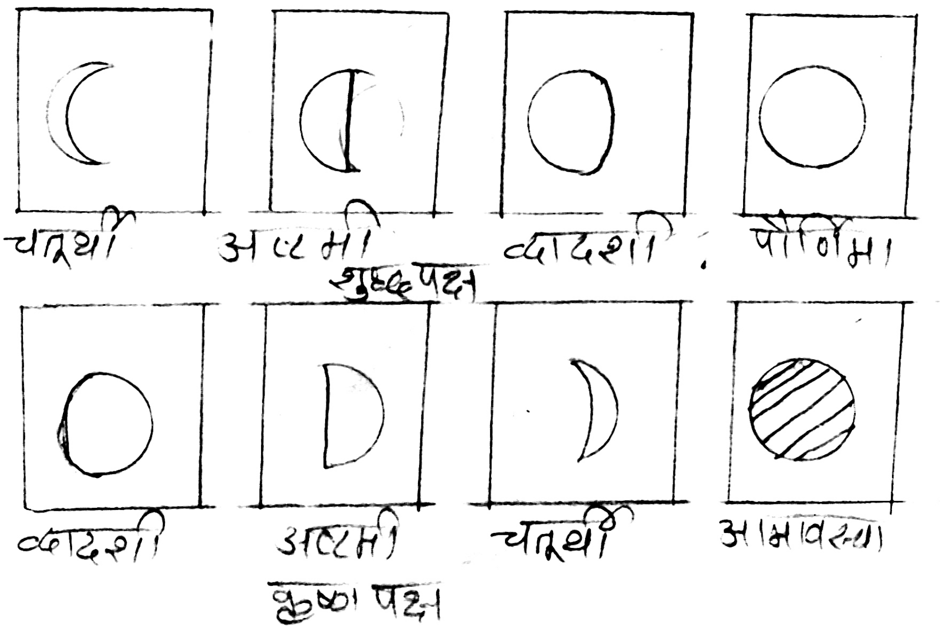


Figure 6.5: A correct diagram of the observable phases of the moon and their correct names (waxing/waning specified) by a Grade 8 (treatment group) rural boy (Question no. 5)

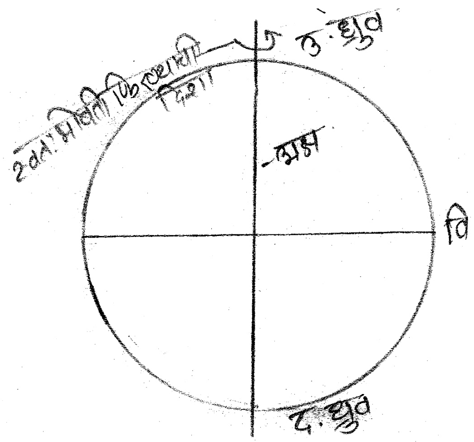


Figure 6.6: A correct diagram of the earth by a Grade 8 (treatment group) rural boy (Question no. 5)

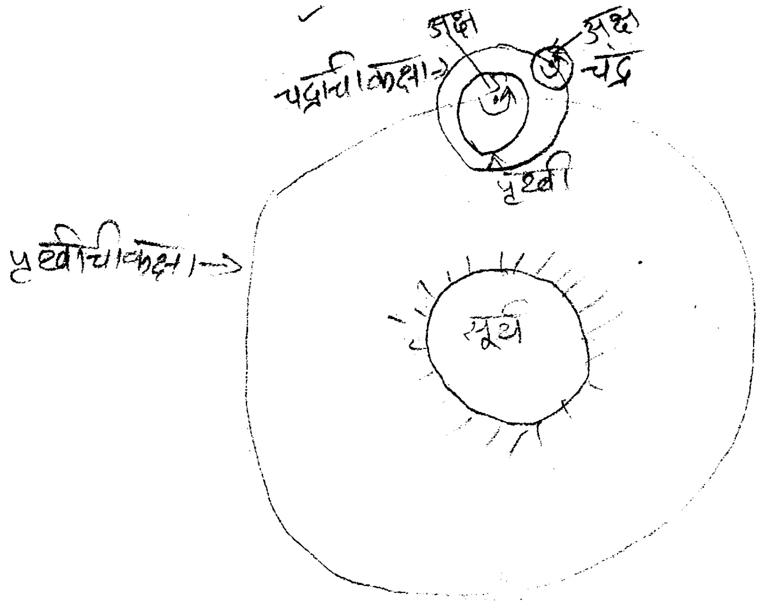
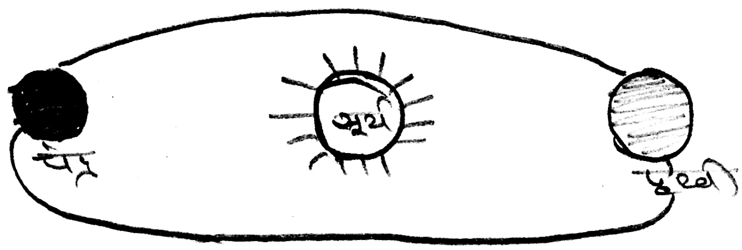
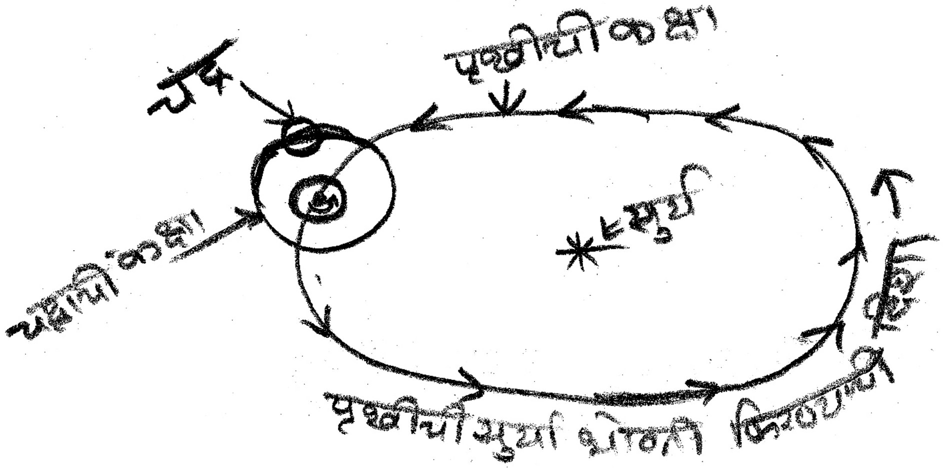


Figure 6.7: A correct diagram of the sun-earth-moon system by a Grade 8 (treatment group) rural boy (Question no. 7)



(a) The earth and the moon are in the same orbit: An example of incoherent diagram by Grade 8 (treatment group) urban boy



(b) The earth and the orbit of the moon are drawn as seen from above the North Pole, but the orbit of the earth is drawn from an oblique perspective: An example of perspective inconsistency by Grade 8 (treatment group) urban boy

Figure 6.8: Examples of incoherent diagrams and diagrams with inconsistent perspective

Chapter 7

Assessment of Astronomical Knowledge: Sun-earth-moon model

Out of five pre and post-tests, analysis of Tests 4 (the Sun-Earth Model) and 5 (the Moon) is presented in Sections 7.1 and 7.2 of this Chapter. The percentages of correct and incorrect responses in each grade were found for each question. Pairwise z tests between two successive columns (Grade 4 and Grade 7, Grade 7 and Grade 8 for the treatment group, and the Grade 8 treatment and comparison groups) were carried out for each category of response, as explained in Subsection 3.5.5. A * next to any value in the Tables indicate a significant difference between that value and the value in the cell to its right in the same row. Response numbers in bold denote the correct (or expected) responses or the objects/ aspects of the diagrams.

The summary of quantitative comparisons between Grades 4 & 7, pre & post-tests and treatment & comparison groups for all the tests is given in Section 7.4. Section 7.5 gives the quantitative comparisons between samples and possible reasons of differences. The chapter ends with method used for validation of coding of the data (Section 7.6).

7.1 Test 4: The Sun-Earth Model

Test 4 was designed to probe students' mental models of the round rotating earth. The original test and its English translation is given in Appendix A.4. Questions in it related to the spherical earth in motion and phenomena which can be explained using this model. This was the last test in the pre-intervention investigation and contained 7 questions based on the round rotating earth. The post-test contained 4 additional questions based on the model of the revolving earth, which students either did not learn according to the current Maharashtra Board curriculum or learnt in Grade 8. These questions were therefore only asked to the Grade 8 post-intervention and the comparison groups.

The analysis is presented in three Subsections. Subsection 7.1.1 deals with the mental model of the spherical earth combined with gravity (Question nos. 1, 2 & 3). Subsection 7.1.2 deals with the rotating earth and its consequences, namely, occurrence of day and night and apparent motion of the sun across the sky, which are the most common and predominant astronomical phenomena (Question nos. 4, 5, 6, 7, 9, 11a). Subsection 7.1.3 deals with the revolution of the earth and its consequences i.e., seasons and changes in night sky over the year (Question nos. 8, 10, 11b, & 11c). For correspondence between the Subsections and the Question numbers see Table A.5.

7.1.1 Spherical earth and gravity

Out of three questions related to the model of the earth in Test 4 (given in Appendix A.4), one (Question no. 1) related to its shape and two (Question nos. 2 & 3) related to the directions 'Up-Down' and hence consequently gravity. These questions probed whether students' mental models incorporated gravitation (a physical property) along with spatial information (i.e. shape of the earth).

Evidences of spherical shape of the earth

In the first question, students were asked, if they believed that the earth is spherical, to give three evidences to show that it is indeed spherical. The students had been exposed to at least three evidences in the Grade 5 (Maharashtra Board geography textbook).

Responses to this question are summarized in Table 7.1. A few students from all the grades responded that they were not convinced that the earth is spherical. Some of them stated that the earth is like an egg, others did not specify. The percentage of students who think that the earth is not spherical is the least in Grade 4 (1%), significantly less than the number of Grade 7 students (10%) who responded that the earth is not spherical in the pre-test. The latter percentage decreased to 4% in the post-test. Though this percentage is significantly less than the percentage of Grade 8 students from the comparison group (16%) who believed that the earth is not round, it is surprising that there were still few students in the post-intervention group with this misconception. The data shows that all the students who think that the earth is not spherical belong to the same class in each Grade (urban for Grade 4, 7, tribal in Grade 8 (treatment group) and rural in Grade 8 (comparison group). There is thus a possibility that this misconception came from single source (a student/ teacher/ book) in each class.

In Table 7.1, responses 2-7 are correct and responses 10-14 are incorrect evidences for the spherical shape of the earth. These are arranged according to their overall frequency.

Responses 8 and 9 denote partially correct evidences. Many students have responded that the evidence for the spherical shape is that half of the earth is lit and the other half is dark at any given time. Now, this response is not entirely correct since there could be other possible shapes, and choice of axis, for which half the earth would be lit and the other half dark. However since this response seems to have arisen from some spatial thinking, it is considered partially correct. Unexplained responses of the same kind (e.g. occurrence of day and night), which do not suggest any spatial argument, were counted in ‘Other incorrect responses’. Other partially correct responses included responses such as ‘because the sun (or other celestial bodies) are round’ and ‘The earth attracts towards itself’.

Correct responses: The most common response was ‘the earth (or its photograph) looks round from space’. Grade 4 students could produce this single correct evi-

Table 7.1: Percentage of students giving responses for evidence for the spherical shape of the earth (Question no. 1)

No.	Response	Gr4	Gr7	Gr8t	Gr8c
	N	*88*	*59*	*55*	*76*
1	I don't believe that E is round	1*	10	4*	16
2	Seen / photo from space	19*	3*	29*	0
3	Reach back to original position	0*	5*	29*	0
4	Ship in sea over horizon	0	0*	16	7
5	Horizon is round	0	3	7*	0
6	Shadow of the earth in the lunar eclipse	0	0*	7	1
7	Changes in positions of stars w.r.t. latitudes	0	0	4	0
8	Half day, Half night (partially correct)	2*	17	22*	0
9	Other partially correct	1	2	0	3
10	The earth rotates	16	29*	11*	25
11	The earth revolves in circular orbit	15	20	15	17
12	Life/ human beings/ animals/ trees/ we live on the earth	30*	15	5	12
13	Authoritative (scientist/ book/ diagram)	16	22*	2	8
14	Other incorrect	11*	24	25	24

* Denotes significant difference at $p<0.05$ between that value and the one to its right in the same row.

dence and it was provided by 19% of total Grade 4 students. Grade 7 students could provide the following 3 kinds of evidences in the pre-test:
Response no. 1: The earth as seen (its photograph) from space (12% of tribal students).
Response no. 2: We will reach back to the same position if we keep going in the same direction (8% rural and 8% urban students).
Response no. 3: The horizon looks round from everywhere (12% of tribal students).

The evidences were explicitly taught as part of the intervention through an interactive write-up based on the historical development of the model of round, rotating and revolving earth. Consequently, in the post-test, students gave 6 kinds of correct evidences, which included the above three (given by 29%, 29%, and 7% students respectively), and three further evidences, namely:
Response no. 4: When a ship approaches a shore (or goes away from a shore) we see the mast first and the hull at the end (or the hull vanishes first and the mast at

the end) because of the curvature of the earth (16%).
Response no. 5: The shadow of the earth during the lunar eclipse is always round (7%).
Response no. 6: The position of stars changes according to latitude (stars appear more and more towards South as we go towards North and vice versa) (4%).

Very few of the students from the comparison group gave a correct evidence and their responses were of two kinds: Ship in the sea (14% of the rural students) and shadow of the earth during lunar eclipse (3% of tribal students).

From Table 7.1 we can see that for 4 out of 6 correct responses, there is significant improvement from pre-test to post-test. For three out of the six correct responses the percentage of students in the treatment group is significantly higher than that in the comparison group. The direction of the difference in each case is in favor of the treatment group.

Incorrect responses: Of the 4 main kinds of incorrect responses in Table 7.1 the first two are superficially scientific, one category is of responses related to existence of human beings or artifacts on the earth (human beings or we live on the earth, there are various objects, houses, tress, animals etc. on the earth) and the last category is of authoritative responses such as, it is written in the book, or told by teachers or scientists.

The percentage of incorrect superficially scientific responses is maximum in Grade 7, followed by Grade 8-comparison group, followed by Grade 4 and least in Grade 8-treatment group. The percentage of the first incorrect superficially scientific response (the earth rotates) significantly decreased from pre-test to post-test and it is significantly less in the treatment group than in the comparison group. The differences in percentages for the other scientifically incorrect response is not significant.

The percentage of responses related to existence of human beings or artifacts on the earth is highest in Grade 4 and significantly more than in Grade 7 (and other grades). The authoritative category of responses are most common in Grade 7 (22%) but have significantly decreased to 2% after intervention.

Other incorrect responses include descriptive responses (‘the earth is blue’, ‘the earth is a planet', 'the earth is big', 'there is water (sea) all around the earth', 'the earth has layers around it', 'the earth is very far from the sun', 'there are many stones on the earth', 'there is atmosphere around earth'), responses related to origin of the earth ('the earth was a red hot sphere, which cooled down', 'the earth was part of the sun', 'the earth was created 8.5 billion years ago', 'carbon-di-oxide, oxygen, nitrogen, vapor formed a cloud') and other responses such as 'if the earth wasn't round, all the objects would have flown away, 'things fall down', 'ship floats on water', 'because of occurrence of seasons', 'sky looks round'. The percentage of 'Other incorrect' responses is significantly lower in Grade 4 students than in the higher Grades.

'Up' and 'Down'

Two questions were asked to probe whether students understand that the 'Up' and 'Down' directions are defined according to direction of the gravitational field (down is the direction of gravitational pull). 'Up-Down' directions are not absolute in space, but 'Down' is always towards the center of the earth and hence varies depending on ones position on the surface of the earth.

Positioning human beings on the earth: Students were asked to draw a picture of the earth and persons living on it. They were also asked to draw the line of horizon for two of these persons and show 'Up' and 'Down' directions for them. The percentage of students who drew the round earth and at least two persons (one in any orientation and another tilted or up-side down) correctly or incorrectly is given in the Table 7.2. Examples of correct and incorrect responses are shown in Figures 7.1 & 7.2

The earth: Most of the students drew a round earth (although some of them had stated in the previous question that they did not believe it to be spherical). In the comparison group 5% students drew a wrong shape for the earth (such as irregular or elliptical).

Drawing human beings: No matter how many human beings are drawn, only two human beings were chosen for evaluation. One which is drawn in any orientation

Table 7.2: Percentage of students who drew the elements of the diagrams correctly or incorrectly (Question no. 2)

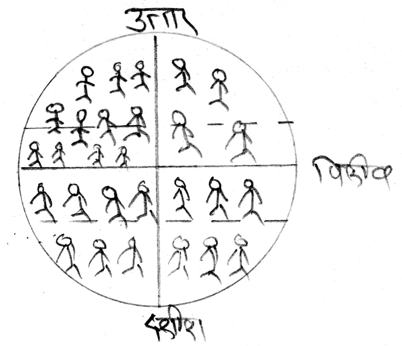
No.	Elements/ aspects of diagram *N*	Gr4 *88*	Gr7 *59*	Gr8t *55*	Gr8c *76*
1	Round earth (% incorrect responses in brackets)	100	92	98	92 (5%)
2	Human 1: Any orientation (% incorrect responses in brackets)	33*	8*	96*	17 (5%)
3	Human 2: Orientation other than vertical (head up) (% incorrect responses in brackets)	17* (5%)	0*	87* (7%)	3 (5%)

* Denotes significant difference at $p<0.05$ between that value and the one to its right in the same row.

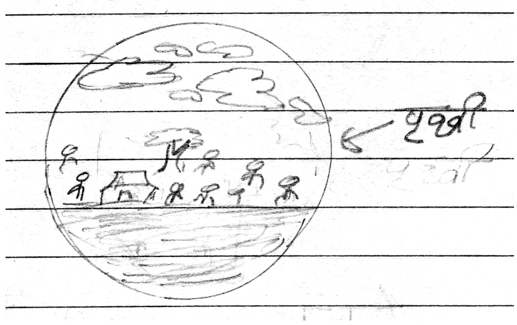
(usually vertical with his head up) is labeled Human 1 and another whose orientation is other than vertical (head up) is labeled Human 2. Five percent students in the comparison group drew wrong responses in the Human 1 and Human 2 categories (Figure 7.3).

Incorrect positioning: The percentage of drawings which contained incorrect placement of human beings are listed in Table 7.3. All these kinds of responses might have arisen from major alternative conception about the earth.

In Grades 4 and 7, 74% and 86% students respectively drew human beings inside the circumference of the earth. It is possible that students are not familiar with cross-sectional diagrams and hence tried to drew humans all over the surface of the earth (e.g. Figures 7.1a). However a few students may actually believe that the earth is hollow and human beings stay inside the earth (e.g. Figure 7.1b). In most of the cases it was hard to determine the exact reason behind such diagrams. The percentage of students who drew human beings inside the circumference of the earth (Response 1 in Table 7.3) may thus include both these kinds of students. The Table shows that the percentage of diagrams which contained human beings inside the earth is maximum in Grade 7 and has significantly decreased after instruction. However this percentage is also low in the comparison group, so the reasons for the decrease may lie elsewhere.



(a) A response by Grade 8 (comaprison group) rural boy: Response nos. 1 & 2 in Table 7.2 and Response nos. 1 & 2 in Table 7.3; Notice the absolute directions.



(b) A response by Grade 4 tribal girl: Response nos. 1 & 2 in Table 7.2 and Response nos. 1, 3 & 4 in Table 7.3

Figure 7.1: Responses for Question no. 2 in Test 4: Drawing human beings on the earth

Response 2 in Table 7.3 shows that in about 60% diagrams in Grade 4 and Grade 7 all humans were drawn vertically i.e. with their orientation matching the orientation of the paper. Out of the remaining 40% students, 23% Grade 4 and 31% Grade 7 students drew humans either vertically or slightly tilted (this includes human beings inside the circumference of the earth also). This response may arise from the alternative conception that the earth has absolute 'Up' and 'Down' directions. The direction of gravity does not seem to have been reconciled with the spherical shape of the earth. The percentage of students drawing all vertical (head up) or slightly tilted human beings decreased significantly after intervention (from 90% to 9%).

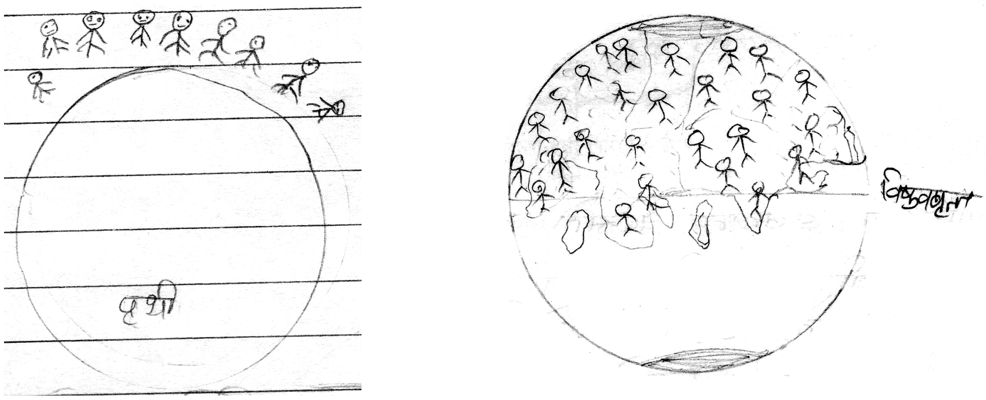
The same alternative model with gravity not reconciled with the spherical shape is more prominently evident when students do not draw human beings on the lower part (Response 4, Figure 7.2) or draw them only on the upper part (so that they have to draw only vertically standing human beings) on the sphere (Response 5). They may think that it is wrong to draw human beings on the lower part of the earth because those human beings will fall 'Down'. Even students who drew humans all over the earth rarely drew a human being close to the South Pole. The percentage of students who did not draw human beings on the lower part of the sphere (Re-

Table 7.3: Percentage of responses which indicate major misconceptions regarding positioning of human being on the earth (Question no. 2)

No.	Elements/ aspects of diagram *N*	Gr4 *88*	Gr7 *59*	Gr8t *55*	Gr8c *76*
1	Human beings inside circumference	74	86*	7	5
2	All humans beings vertical	58	59*	2	5
3	Humans beings vertical and/or tilted	23	31*	7	5
4	No human being close to South Pole	16*	34	20*	5
5	Human beings only in Northern hemisphere	8	14	4	5

* Denotes significant difference at $p<0.05$ between that value and the one to its right in the same row.

sponse 4) is highest in Grade 7 (significantly higher than Grade 4). Twenty percent Grade 8 students did not dare to draw human beings on the lower part even after the intervention. Although addressed in the intervention in various ways, this percentage did not significantly decrease after intervention, which shows the strength of this misconception. There are no significant differences between the Grades in the percentages of students who drew human beings only in the upper part of the earth (Response 5). Remarkably, percentages of these wrong responses in the Grade 8



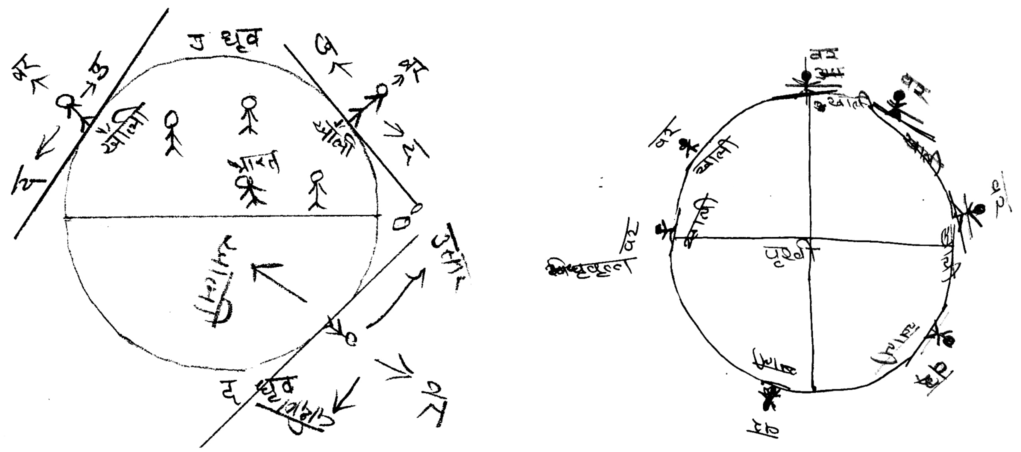
(a) A response by Grade 4 tribal girl: Response nos. 1 & 2 in Table 7.2 and Response nos. 3 & 5 in Table 7.3

(b) A response by Grade 8 (comparison group) rural girl: Response nos. 1 & 2 in Table 7.2 and Response nos. 1, 3 & 5 in Table 7.3; Notice the map.

Figure 7.2: Responses for Question no. 2 in Test 4: Drawing human beings on the earth

students in the comparison group is low (5%) without any extra instruction. They are comparable to percentages in the treatment group after instruction in all the cases except one. The percentage of students drawing no human being close to the South Pole is actually higher in the treatment group than in the comparison group.

Horizon and 'Up-Down' directions: None of the Grade 4 and Grade 7 students could draw the line of horizon or up-down directions for any of the persons. In the comparison group 5% students attempted to draw the line of horizon and Up-Down directions for both the persons, but all drew it wrongly. The percentage of Grade 8 students in the treatment group who could draw the line of horizon and show Up-Down directions (correctly or incorrectly) in the post-test is given in Table 7.4. A sample correct response from the treatment group is shown in Figure 7.3.



(a) Response by a Grade 8 (treatment group) tribal girl

(b) Response by a Grade 8 (treatment group) urban boy

Figure 7.3: Correct responses for Question no. 2 in Test 4: Placing human beings on the earth, determining their horizons and local directions

Most of the students (73% to 85%) in the treatment group could draw the lines of horizon and up and down directions. Comparing Response nos. 2, 4 & 6 with response nos. 1, 3 & 5, the percentages for the person whose orientation is not vertical (head up) are slightly less than the percentages for a vertical (head up) human beings in all three cases, which shows some difficulty of the task of placing the person on the surface of the earth. Although drawing a person whose orientation

Table 7.4: Percentages of correct and incorrect responses for the elements present in the diagram of the earth and local horizon and directions for a person standing on it in the treatment group (Question no. 2)

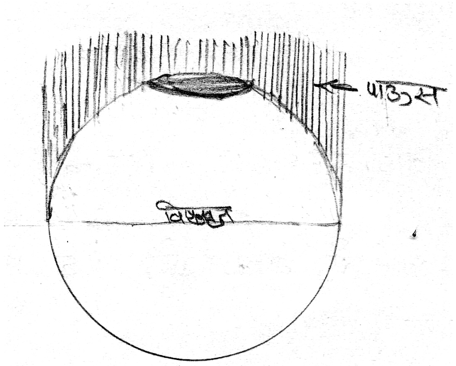
No.	Elements/ aspects of diagram: 1 = For human in any orientation; 2 = For person other than vertical (head up) orientation	Gr8t	
		N=55	
		% Correct	% Incorrect
1	Line of horizon1	85	4
2	Line of horizon2	80	2
3	Up1	78	2
4	Up2	75	2
5	Down1	80	2
6	Down2	73	2

None of the students from other groups drew these elements

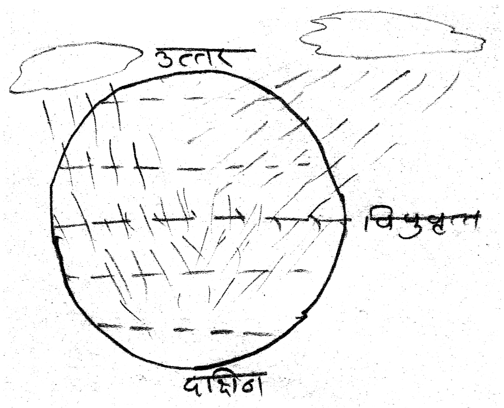
does not match with the paper, and drawing a line of horizon and directions for that person are slightly difficult tasks, most of the students in the treatment group could do them after instruction, but practically no student could do it without instruction. This is an important yet easily remedied part of conceptual understanding that is missing in current standard instruction.

Direction of Rainfall: In another question, students were asked to show the direction of the rainfall all over the circumference of the earth. The percentages of the different responses are given in Table 7.5.

There are two main categories of students' responses:
Responses 1 (which included combinations of responses 1a-1d) (Figure 7.4a): Rain is drawn from one or more of the 4 sides (from above, from left, from right and/or from below).
Responses 2 (which included combinations of responses 2a-2d) (Figure 7.4b): Rain is drawn diagonally from one of the 4 Cartesian quadrants. Table 7.5 shows that responses of the first kind were more common in Grade 4 and responses of the second kind were more common in Grade 7 and in the Grade 8-comparison group. The Grade 8- treatment group was the only one that did not show any preference



(a) A response by Grade 8 (comparison group) rural girl: Response nos. 1a, 4 & 5 in Table 7.5



(b) A response by Grade 8 (comparison group) rural boy: Response nos. 2a, 2b, 6 & 7 in Table 7.5

Figure 7.4: Responses for Question no. 3 in Test 4: Drawing rain on the earth

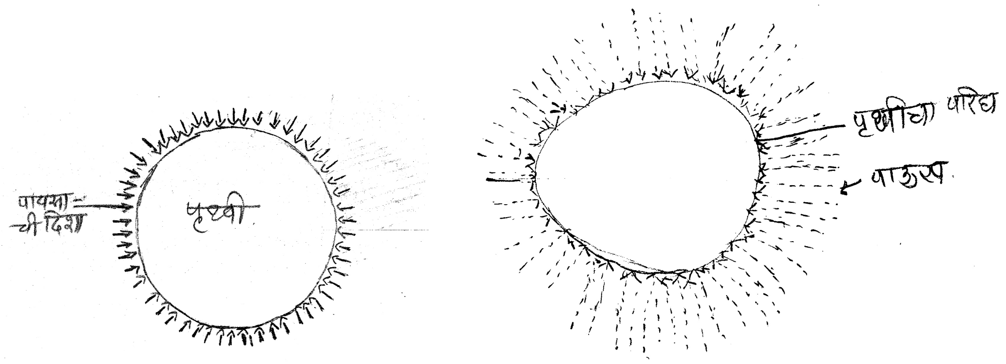
between Response 1 and Response 2 (44% each).

Grade 4 students were more likely to draw rain falling from above the circle depicting the earth (Response 1a) rather than from the other sides (Responses 1b-1d). Grades 7 and the 8- comparison group drew rain in other than the vertical 'downward' directions. They predominantly drew the rain falling from one or more of the diagonal corners (Response 2). Perhaps they selected the diagonal directions in order to avoid the rain falling vertically from below the circle depicting the earth (Response 1d). Response 1d was rare in all the groups except the Grade 8- treatment group, in which 25% students drew this response.

The percentage of rain from the horizontal (Responses 1b and 1c) and vertical (Responses 1a and 1d) sides increased significantly from Grade 7 to Grade 8 and it was significantly higher in the treatment group than in the comparison group.

A few students from all the grades drew rain from all around the earth (combination of Response 1 and 2). These are labeled as Response no. 3 (Figure 7.5). There are no significant differences in the percentages of Response no. 3 among the grades.

Students' responses representing particular misconceptions were counted separately and listed as Responses 4 to 7 in Table 7.5 (of these only responses 5 and 6



(a) Response by a Grade 8 (treatment group) rural girl

(b) Response by a Grade 8 (treatment group) tribal boy

Figure 7.5: Correct responses (Response no. 3) for Question no. 3 in Test 4: Showing direction of rain on the earth

are mutually exclusive).

Responses 4, 5 and 6 may have arisen from the notion of absolute ‘Up-Down directions’ on the earth. Drawing rain (either vertical or diagonal) in only the upper half parts was common among all grades. It was least in Grade 4 (31%) and significantly higher in Grade 7 (54%). Drawing only vertical rain (Response 5) was common in Grade 4 (68%) and significantly less frequent in the higher grades. Drawing vertical and/or tilted rain (Response 6) was common among Grade 4, Grade 7 and Grade 8 - comparison group, but was significantly less in Grade 8 after intervention. This shows that the intervention helped to break the notion of ‘absolute Up-Down direction’. Yet unfortunately 15% students in the treatment group did hold on to this notion (Response nos. 5 & 6).

Drawing rain inside the circle of the earth (Response 7) shows either a lack of familiarity with cross-sectional diagrams (Figure 7.6a) or a mental model of the hollow earth (figure 7.6b). Response 7 is most common in Grade 4. The percentage significantly decreased in Grade 7 and again significantly decreased in Grade 8 after intervention. There is a significant difference in the percentages of Response 7 in the treatment and the comparison groups.

Table 7.5: Percentage of students' responses depicting rain falling of the earth (Question no. 3)

No.	Elements/ aspects of diagram *N*	Gr4 *88*	Gr7 *59*	Gr8t *55*	Gr8c *76*
1	Rain from above, below and sides (one or more of these)	20	14*	44*	22
1a	From above	20	14*	40*	20
1b	From left	6	7*	27*	1
1c	From right	6	5*	24*	1
1d	From below	3	7*	25*	1
2	Rain from one or more of the diagonal corners	7*	46	44	39
2a	1^{st} quadrant	6*	41	42	33
2b	4^{th} quadrant	5*	19	18	32
2c	2^{nd} quadrant	2*	24	24*	1
2d	3^{rd} quadrant	1	5*	18*	0
3	From 8 sides/ all around (Figure 7.5)	11	8	2	3
4	Rain only in upper half part	31*	54	36	47
5	Vertical rain	24*	7	2	7
6	Vertical and/or tilted rain	44	54*	13*	71
7	Rain inside circumference	69*	31*	13*	55
8	No response / no rain	1	1	4	10

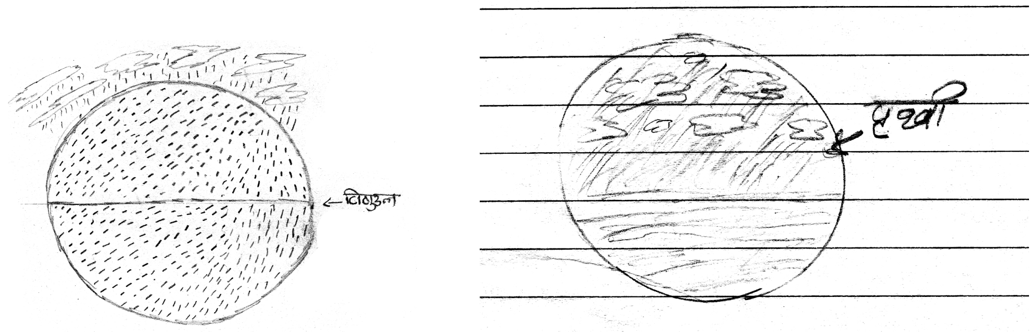
* Denotes significant difference at $p<0.05$ between that value and the one to its right in the same row.

7.1.2 The rotating earth

Four questions were asked which required understanding of the rotating earth (Appendix A.4). Two of these (Question nos. 4 & 5) were about the apparent motion of the sun and two (Question nos. 6 & 7) were hypothetical questions in which students were asked to predict what would happen if the earth stopped rotating.

Apparent motion of the sun

Students were asked to explain why the sun appears to move and where does it go at night. Students' responses to this question are listed in Table 7.6 along with the corresponding percentages for each Grade.



(a) A response by Grade 8 (comparison group) rural boy: Response nos. 1a, 4, 6 & 7 in Table 7.5

(b) A response by Grade 4 tribal girl: Response nos. 2a, 2b, 4, 6 & 7 in Table 7.5

Figure 7.6: Responses for Question no. 3 in Test 4: Drawing rain on the earth

Diagram: Most of the students in Grade 4 did not draw a diagram for this question. Significantly more number of students in Grade 7 attempted to draw, but the percentage of students was still only 15%. Though this percentage was significantly higher in Grade 8, there was no significant difference in percentages of students who drew a diagram (as a response to this question) in the treatment and the comparison groups.

Seven elements essential or important to explain the apparent motion of the sun through a diagram are listed as Response nos. 2 to 7 in Table 7.6. Very few students from Grade 4 and Grade 7 drew any of these elements. There are significant differences between percentages of students' in the pre-tests and post-tests for all the elements and aspects. The percentages of essential elements such as the sun (or sun-rays) (Response 2) and the round earth (Response 3) increased from 2% to 40% and 42% respectively. Yet the rotation of the earth (Response 4 and 5), which is the main component of the explanation, is shown by only 27% of students in the treatment group through diagrams. This percentage was nonetheless significantly higher than that in the comparison group. Moreover, only 11% students in the comparison group mentioned the rotation of the earth as cause of the apparent motion of the earth in their textual responses (Response no. 8). Thus the absence of a component of motion in the diagram may not be just due to unfamiliarity with the technique of showing motion in the diagram, but perhaps because most of the students in the comparison group were unable to locate the cause of apparent motion of the sun in the rotation of the earth.

Significantly more number of students from the comparison group as compared with the treatment group showed the day-night: half lit and half dark earth (Response 6) in their diagram. Thus they were able to draw a descriptive diagram, yet as seen in Response nos. 4 and 5, the explanatory components were missing in it. Moreover, only one student from the comparison group distinguished between the 'terminator' (sometimes referred to as 'twilight zone' or 'gray line') and line of axis of rotation (Response 7), whereas a significantly higher proportion of students from the treatment group showed the two distinctly. This distinction becomes important in the explanation of seasons, and the terminator circle projected as a line in two dimensions coincides with the axis of rotation on the two equinoxes as a special case.

Textual Explanation: Response 8 in Table 7.6 is the correct response and there are significant differences in percentages of response in the pre-test and post-tests, and in the treatment group and the comparison group. Thirteen percent students from the treatment group specified the direction of rotation (from West to East), which none of the other groups did. Many students from all the Grades gave ambiguous response about the motion (Response 9). This partially correct response is ambiguous as it may refer to rotation or revolution of the earth. The percentage of Response 9 too is significantly higher in the treatment group than in the comparison group.

Responses 11 and 12 are incorrect. The 'revolution' of the earth as a cause of apparent motion of the sun (Response 11) was the most frequent among all the textual responses (sadly, in 33% students in the treatment group). A few students from all the grades attributed the cause to both the rotation and the revolution of the earth. The percentages of both these incorrect textual responses were significantly less in Grade 4.

Table 7.6: Percentages of diagrammatic and textual responses for explanation of the apparent motion of the sun and the position of the sun at the night (Question no. 4)

No.	Response	Gr4	Gr7	Gr8t	Gr8c
	N	*88*	*59*	*55*	*76*
1	Percentage of students who drew diagram	5*	15*	60	57
	Elements present in the diagram				
2	Sun (Sun rays)	2	2*	40 (2)	36 (9)
3	Round Earth	1	2*	42	45
4	Axis of rotation	0	2*	27*	3
5	Direction of rotation	0	0*	27*	3
6	Day-night	0	2*	20*	41
7	Terminator does not coincide with the axis	0	2*	13*	1
	Textual responses				
8	Rotation of E (From West to East)	5	7*	29* (13)	11
9	Motion of the earth (ambiguous)	20	19	27*	13
10	Half part lit, half dark	0*	10	5	13
11	Revolution of the earth	7*	22	33	28
12	Both rotation and revolution	2*	10	7	13
	Position of the sun at night				
13	On the other (back) side of E	9	14	16*	5
14	Beneath the legs/ down	0	3	9*	0
15	Below horizon	0	3	2	0
16	Not seen because of rotation of the earth	0	3	9	4
17	S at night (/always) in the sky	19	12	13	8
18	The sun is static	13	17*	31*	12
19	The sun does not appear to move	0	3	0	0
20	The sun actually moves	7	5	5	3
21	Sets (at West/ night)	11	10	2	1

22	Goes behind cloud	1	2	2	3
23	Sets behind hill/ mountain	7	3	0	0
24	Goes to the god/ god's house/ lives below E	0	3	0	0
25	Other correct	2	2	4	1
26	Other incorrect	22	24	13	17

* Denotes significant difference at p<0.05 between that value and the one to its right in the same row.

Twelve kinds of responses (Responses 13 to 24 in Table 7.6) were produced by students in response to the question "where is the sun at the night?". Response nos. 13, 14, and 15 are absolutely correct, whereas Response nos. 16, 17, and 18 are correct but do not give a specific answer to the question. "The sun is static" (Response 18) was the most common and "The sun is always in the sky" (Response 17) was next most common. There was a significant difference between Grade 7 and Grade 8- treatment group, and in the treatment and the comparison group for Responses no. 18.

The percentages of two of the relevant and correct responses (Response nos. 13 and 14) were significantly higher in the treatment group than in the comparison group.

In terms of diagrams the main result here that Grade 8 students in both the treatment and comparison groups drew the highest number of diagrams for this question. The type of diagrams in the treatment group however were significantly more of the explanatory type. This qualitative improvement in diagrams may be attributed to the intervention.

Day and Night

Students were asked to explain the occurrence of day and night: a standard question in the textbook whose answer is accompanied by a diagram in the textbook. All the students responded to this question with the help of a diagram, which was very similar to the textbook diagram. A few of students produced a diagram in which the dark side of the earth, often labelled 'night' faced the sun (Figure 7.7). These students appear to recall the diagram in a rote but incorrect manner, not accompanied by reasoning. Students' responses are summarized in Table 7.7.

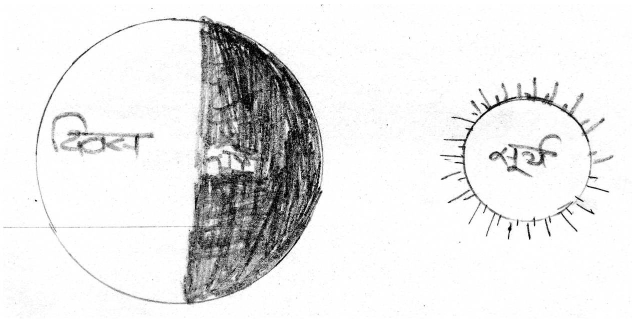


Figure 7.7: An example of rote learnt diagram by a Grade 8 (comparison group) rural boy: Dark side of the earth labelled 'night' faces the sun

Diagram: Most of the students drew the essential objects such as the earth and the sun in their diagram. There were no significant differences among the Grades in the percentage of students who drew the earth and the sun (Response nos. 1 & 2). None of the students from Grade 4, 7 and the comparison group drew parallel rays for the earlier question (Why does the sun appear to move?), but many drew parallel sun-rays (with or without the sun) (Response no. 3) for this question (Why does day and night occur?). Note that the textbook diagram to explain day-night contains parallel rays, whereas in the case of apparent motion of the sun there is no textbook diagram which could have helped the students. The percentage of grade 8 students who drew parallel rays for the later question was significantly higher in the treatment group than that in the comparison group (Figure 7.8). A few students in Grade 4 and Grade 8 drew divergent rays.

Most of the students from all grades drew day and night (Response 5) on the earth and there were no significant differences in the percentages among the Grades. Further, if both the sun and the earth are assumed to be in the plane of the paper, the circle depicting the earth should get equally divided into day and night (Response no. 6). However, significantly more number of Grade 4 students showed this cor-

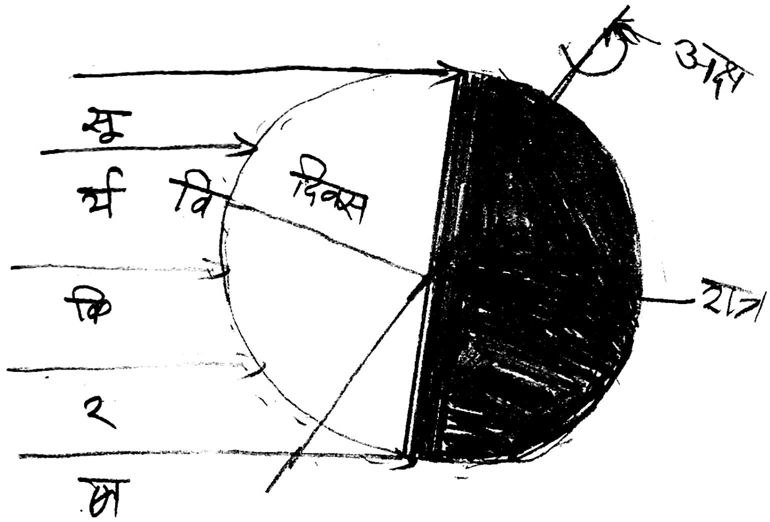
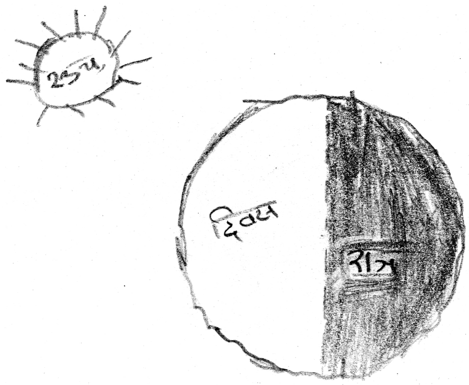


Figure 7.8: A correct response to explain occurrence of day-night by a Grade 8 (treatment group) rural girl

rectly than Grade 7 and Grade 8 from both the treatment and the comparison group. This may be due to the fact that the explanation for day and night along with the diagram occurs in the Grade 4 textbook. The relatively worse performance of the treatment group on this aspect could not be explained. The percentage of students

(a) A response by Grade 8 (comparison group) rural boy: A case of Response no. 7 in Table 7.7



(b) A response by Grade 8 (comparison group) rural boy: A case of Response no. 13 in Table 7.7

Figure 7.9: Responses for Question no. 5 in Test 4: Explanation of occurrence of day-night

who drew the axis of rotation (Response no. 8) was significantly higher in Grade 7 than in Grade 4. The percentage of students who drew both the axis of rotation (Response no. 8) and the direction of the rotation (Response no. 9) of the earth increased significantly from pre-test to post-test and was significantly higher in the treatment group than in the comparison group. Moreover, the percentage of diagrams in which the axis of the rotation does not coincide with the line of projection of circle of terminator (Response no. 10) was significantly higher in the treatment group than in the comparison group (Note that many of the students in other grades did not draw the axis (Response no. 8)). Because the terminator coincided with the axis or otherwise, sometimes the terminator was not perpendicular to the sun-earth line (Response no.13). There were no significant differences in the percentage of students who did not draw the terminator perpendicular to the sun-earth line among Grades. But maximum number of Grade 4 students drew the terminator perpendicular to the sun-earth line (Response no.12), followed by Grade 7 students. This response significantly decreased in the post-test, which was unexpected.

Textual responses: Response nos. 14-20 in Table 7.7 were produced as an explanation of the occurrence of day and night. Response no. 14 is the correct cause of day and night and Response nos. 15-18 are correct extensions of the cause. Response no. 19 is partially incorrect because, students responded that the day-night occur due to earth's motion but it was not clear whether they were referring to rotation or revolution. Response no. 20 (day-night occur due to revolution of the earth) was the incorrect response. (Many students drew the orbit of the earth in their diagram; Figure 7.10). Similar to the finding for earlier questions, the percentage of Grade 4 students who responded that 'the revolution of the earth' is the cause of day-night (Response no. 20) was significantly lower than in the higher Grades.

The percentage of Response nos. 15-18 was greater than that of the more precise cause of day and night (Response no. 14). Here the possibility of ambiguous conceptions like Response no. 20 & 19 cannot be ruled out.

There were significant increases in the percentages of correct responses (Response no. 14) and partly correct (Response nos. 15 & 16) responses between Grade 4 and Grade 7 and, in two of the cases, from pre-test to post-test. Moreover

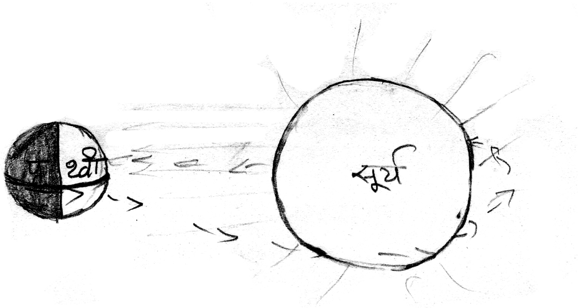


Figure 7.10: Many students drew the orbit of the earth in their diagram (Grade 8 (comparison group) rural girl)

significantly greater number of Grade 8 students in the treatment group gave Response nos. 15 & 16 than those in the comparison group.

Predictive Questions: In the next question (Question no. 6, Appendix A.4), students were asked to predict what will happen if the earth stops rotating around its axis and in the Question no. 7 (Appendix A.4), they were asked to predict the same specifically in relation to the (apparent) motion of the sun, stars and the moon. The responses for these two questions being similar, are listed in same Table 7.8 along with the percentages of each response for the respective Grades.

Responses about the sun and day & night: Response no. 1 (day-night will not occur) was the most common response for all the Grades, with no significant differences between Grades. In the earlier question, where students were asked to explain the cause of occurrence of day-night, the percentages of students who correctly stated the cause as rotation (Response no. 14 in Table 7.7) was low in all the Grades (3%, 15%, 35%, and 38%). Remarkably, in a predictive question the majority of students could relate day-night with the rotation of the earth. Seven percent students from the treatment group stated in the post-test that the there will be 1 day in one year (Response no. 2), which is the spatially or geometrically accurate answer of this question, and could be considered as an evidence of running a complex simulation on a spatial mental model.

A few students from Grade 4, 7 and the comparison group stated that it will be

Table 7.7: Percentage of students for diagrammatic and textual responses for explanation for occurrence of day and night (Question no. 5).

No.	response *N*	Gr4 *88*	Gr7 *59*	Gr8t *55*	Gr8c *76*
	Elements present in the diagram				
1	The round earth	95	86	89	76
2	The sun (without parallel rays)	55	51	49	59
3	Parallel sun-rays	24	20	36*	16
4	Divergent sun-rays	2	0	2	8
5	Day-night	91	90	84	75
6	Half day- half night	94*	83	78	71
7	Unequal division of lit and dark part	2	7	5	3
8	Axis of rotation	0*	8*	33*	9
9	Direction of rotation	2	2*	42*	3
10	Terminator differs from axis	0	2	9*	0
11	Terminator coincides with axis	0*	8	18	11
12	Terminator perpendicular to the sun-earth line	67	56*	36	43
13	Terminator was not perpendicular to the sun-earth line	10	20	11	12
	Responses in text				
14	Rotation of the earth	3*	15*	35	38
15	Part towards S/ lit part: day	10*	25*	51*	28
16	Part away from S/ dark part: night	10*	25*	44*	24
17	24 hours to complete 1 rotation	2	2	5	1
18	The sun is static	0	0	4	1
19	Ambiguous motion: moves round	5	10	16	11
20	Revolution of the earth	2*	10	22	36

* Denotes significant difference at p<0.05 between that value and the one to its right in the same row.

always dark (Response no. 3) or always lit (Response no. 4). This response might have come because students considered only one location on the earth, which was either in dark or in light when the earth stopped rotating. None of the students in the treatment group produced this partially correct response.

Other incorrect responses regarding the sun (Response no. 6) included 'the sun will rise from the West', 'the sun will go from South to North', the sun will not be seen/ come in the sky', 'there will be no/ less/ changes in sunlight', 'we wouldn't be able to see anything', 'there will be no '*Uttarayan-Dakshinayan* (apparent Northward and Southward motion of the sun)'.

None of the students mentioned the motion of the sun in response to Question no. 6, but when provided a hint about the apparent motion of the celestial bodies (Question no. 7), many students correctly responded that the sun (and other bodies) would be seen at the same place (Response no. 5, Table 7.8). Taking Question nos. 4-7 (Tables 7.6 - 7.8) together, there appears an interesting pattern. Question nos. 6 and 7 which had to do with a prediction, were easier than Question nos. 4 and 5 which had to do with an explanation. Within the 'explanation' questions, the direct question about Day-Night (Question no. 5) was easier than the question about the apparent motion of the sun (Question no. 4). The same pattern was seen in the 'prediction' questions, where the prediction of Day-Night (Question no. 6) came readily while that regarding to the motion of the sun came only after a specific hint (Question no. 7).

Responses about the stars: A few students in response to Question no. 6 and comparatively more in response to Question no. 7 said correctly that the stars will be seen at the same place (Response nos. 7 & 8 respectively). The accurate response would have been that a star (including the sun) would appear to move around the earth once in the year (since the revolution of the earth is not stopped), but none of the students could produce it before or after although the annual motion of the stars was addressed in the intervention.

The incorrect responses (Response nos. 9 & 10) were: 'stars will be seen to the South', 'stars will be seen in daytime', 'different stars will be seen at the place of earlier stars', 'stars will twinkle', 'stars will stop twinkling', 'stars will set together', and 'stars will not be seen'.

Responses about the moon: A few students in response to Question no. 6 and comparatively more in response to Question no. 7 responded that the moon also will appear to be at the same place (Response nos. 11 & 12 respectively) if the earth

Table 7.8: Percentage of students' responses for prediction of situation if the earth stops rotating (Question nos. 6 and 7)

No.	Response *N*	Gr4 *88*	Gr7 *59*	Gr8t *55*	Gr8c *76*
	The sun				
1	No day night (Q6)	59	63	73	71
2	1 Day-night = 1 year (Q6)	0	0	7	0
3	Dark everywhere/ no light (Q6)	3	3	0	8
4	Always lit (Q6)	1	3	0	0
5	The sun will remain at same place (Q7)	26	34	40	12
6	Sun: other incorrect responses (Q7)	4	4	7	8
	The stars				
7	Stars will be seen at same place (Q6)	6	7	9	0
8	Stars will be seen at same place (Q7)	25	27	36	9
9	Stars: incorrect responses (Q6)	1	0	0	0
10	Stars: incorrect responses (Q7)	0	7	9	3
	The moon				
11	Moon at same place (Q6)	3	7	5	1
12	Moon at same place (Q7)	26	25	22	7
13	Only Moon will move/ no difference in Moon's motion (Q7)	0	3*	15*	1
14	Moon wrong (Q6)	7	2	4	4
15	Moon wrong (Q7)	1	7	11	3
16	Moon: other incorrect (Q7)	8	7	0	8
17	Sun, stars are static (Q7)	0	2	4	1
18	There wouldn't be any difference (Q7)	15	8	15	8
19	Other partially correct (Q7)	3	0	2	0

* Denotes significant difference at $p<0.05$ between that value and the one to its right in the same row.

stopped rotating. The correct response however is that although its daily motion from East to West will not be seen, the moon will complete one revolution around the earth in roughly 30 days (Response no. 13), which is its actual motion, and it will appear to move slowly from West to East. Without specifying the direction, two Grade 7 students in the pre-test, one Grade 8 student from the comparison group and a significantly higher percentage from the treatment group (15%) in the post-test produced Response no. 13. This was a heartening evidence that some students were able to successfully run simulations over mental models.

Incorrect responses regarding the moon (Response nos. 14, 15) included ‘the moon will not be seen (or come in the sky)’, ‘the part where the moon is will be dark’, ‘direction of the moon will change’, ‘there will be no phases of the moon and/or eclipse’, ‘the sun, earth and the moon will not come in a straight line’, ‘both faces of the moon will be visible from the earth’, and ‘the moon will move from South to North’.

Responses such as ‘ the sun, stars are static’ and ‘there will not be any difference in motion of sun, stars and moon’ are partially correct because although they do not state anything about the apparent motion, they are not wrong about the actual motion. Their percentages together are given in Response no. 19.

Analysis of additional questions asked only in post-tests: Question nos. 8 to 11 of Test 4 were asked only in the post-tests and hence Tables 7.9 onwards contains only 2 columns: one for the treatment group and another for the comparison group.

Diagram representing model of the spherical earth from a specific perspective

In Question no. 9 students were asked to draw a diagram of the earth as seen from exactly in the plane of the equator, showing the axis of rotation, equator and a person on equator. They were further asked to draw the line of horizon for that person and show ‘Up’, ‘Down’, ‘North’ and ‘South’ directions for that person. Finally they were asked, at what angle would a person standing on the equator see the Pole Star?

This question is similar to Question no. 2 except that the students were asked to draw a diagram, to check whether they could (visualize and) draw the diagram from a specific point of view. The required point of view happened to be the same as that in the textbook diagram, thus the percentage of correct responses to Question no. 9 might have been the same as the percentage for Question no. 2, held the students been consciously aware that the frequent representation of the earth seen in the textbook is drawn from within the plane of equator. The point of view from above the North Pole was considered in Question no. 8 which is discussed in Section 7.1.3.

Elements in the diagram: The percentages of students from the treatment and the comparison group who drew the required elements in their diagram (correctly or incorrectly) as a response to this question are given in Table 7.9 (Response nos. 1-12). The percentage of students who drew a round earth for Question no. 2 was 98% and 92% (Response no. 1, Table 7.2) which decreased to 78% and 36% for Question no. 9 (Response no. 1 in Table 7.9) in the treatment and comparison group respectively. The specification of perspective confused students, especially from the comparison group, since the percentage of students who drew a round earth was significantly lower in the comparison group than in the treatment group. There were significant differences between the treatment and the comparison group in percentages for all the elements (Response nos. 4-12) present in the diagram except the percentages for the North and South Poles (Response nos. 2 & 3). The percentages of correct responses for the human being (Response no. 7), line of horizon (Response no. 8) and directions (Response nos. 9-12) for the comparison group range from 0% to 3%, whereas for the treatment group they ranged from 33% to 73%. The percentage of incorrect placement of the human being on the earth (Response no. 7) was significantly higher in the comparison group than in the treatment group. Thus a significant number of Grade 8 students after intervention learnt to place a human being on the earth, and to determine the local directions for this person. Only one student from the comparison group drew the line of horizon correctly. Considering the vital importance for visualization of concepts like positioning the human beings on the earth, local directions and horizon, explicit instructions about them are necessary to include the in pedagogy of astronomy.

Between two thirds and three fourths of the students in the treatment group could draw the round earth (Response no. 1), equator (Response no. 5), human being on equator (Response no. 7), and Up-Down directions (Response nos. 9 &10), and more than half of them could draw a line of horizon for the person (Response no. 8), axis (Response no. 4) and direction of rotation (Response no. 5) of the earth after the instruction (Figure 7.11). However, percentages for North and South Poles (Response nos. 2 & 3) and North-South directions (Response no. 11 & 12) were lower (from 24% to 35%) even after intervention.

Apparent position of the Pole Star: Students were asked to predict the apparent

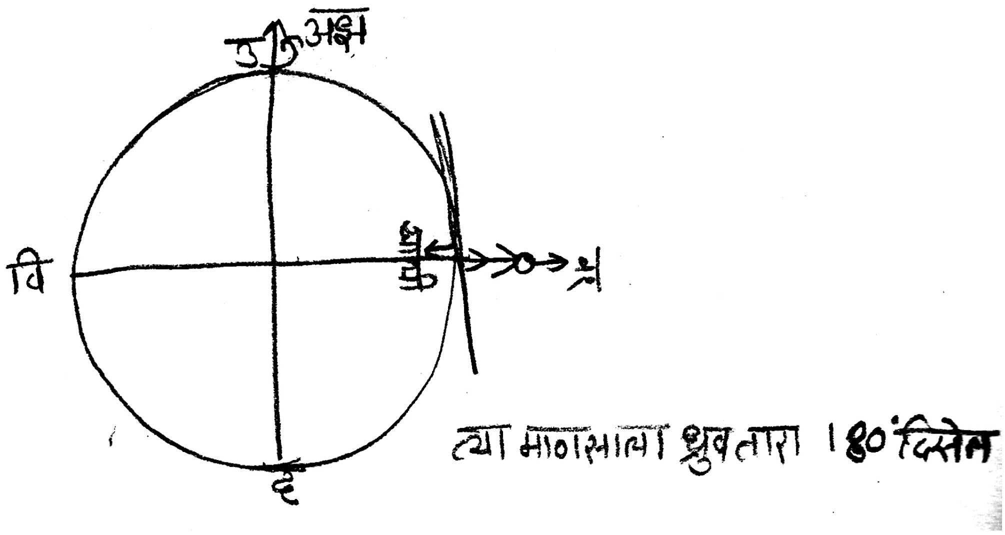


Figure 7.11: A correct response by Grade 8 (treatment group) rural girl to Question no. 9: The earth as seen from within the plane of equator

position of the Pole Star as seen from the equator. They were expected to draw parallel rays from the Pole Star (perpendicular to equator) and in that case, the angle of the Pole Star with the horizon for a person on equator would be zero (Response no. 13). Only 13% students from the treatment group and none from the comparison group could correctly answer this question. The significantly higher number of students from the treatment group (36%) who answered this question incorrectly (compared with the comparison group (7%), may be due to the fact that significantly more number of students from the treatment group attempted the question, as seen from no-response rate.

Comprehending diagrams to draw an inference

Question no. 11 consisted of 3 separate questions (11a, 11b and 11c), each accompanied by a skeletal diagram. Students had to answer the questions on the basis of these diagrams. Thus diagram-based reasoning was called for in these questions, as in the other questions in this test. However we assume that it is easier to infer from a given diagram than to draw a diagram to explain something. Therefore, although two of these questions (Question nos. 11a and 11c) were similar to the previous

Table 7.9: Percentages of elements present in the diagram of the earth as seen from within the plane equator and positioning human beings with her local horizon and directions (Question no. 9)

No.	Elements / aspects in diagram *N*	Gr8t *55*		Gr8c *76*	
		% correct	% wrong	**% correct**	% wrong
1	The round earth	78*	4	36	0
2	North Pole	25	2	16	0
3	South Pole	24	2	14	0
4	Axis of the earth's rotation	58*	4	13	3
5	Direction of rotation	53*	7	3	1
6	Equator	71*	0	32	3
7	Human being on equator	73*	5*	1	29
8	Line of horizon	55*	2	1	3
9	Direction- Up	67*	0	0	0
10	Direction- Down	69*	0	0	1
11	Direction- North	35*	7	3	0
12	Direction- South	33*	9	3	0
13	Location of the Pole Star (Correct: On horizon/ 0°/ 180°)	13*	36*	0	7

* Denotes significant difference at p<0.05 between that value and the corresponding value for the Grade level to its right in the same row.

questions (9 and 10), in which explanations were asked, we felt that these questions would help those students to respond who may not be able draw diagrams on their own, but might reason if a skeletal diagram was provided.

Question no. 11a was similar to Question no. 9 (Table 7.9) except that instead of asking students to draw the person (X) on the equator, they were given a diagram in which the person was shown at 20° (N) latitude, and stars A, B, C, D, E and the Pole Star were shown in the sky. Students were asked the following three sub-questions:

i. Name the stars which person X would be able to see.

ii. Where would person X see the Pole Star?

iii. Where would person X be after 12 hours as a result of rotation of the earth?

To respond to the first two of the above sub-questions (i & ii), students needed to draw the line of horizon (Response no. 1) for the person X. Only one student from the comparison group drew the line of horizon and significantly more number of students form the treatment group drew it (Figure 7.12b). The percentage of students from the treatment group who drew the horizon was 40%, not insignificant also considering the importance of this as a first step towards solving the problem in a conceptual and accurate way.

Students from the comparison group could guess which stars would be seen by person X. Significantly more number of students from the treatment group answered correctly for the star C (Response no. 5). However, only a small percentage of students from both the groups could answer that the Pole Star will also be seen (Response no. 2). From the given diagrams it is not apparent that person X will be able to see the Pole Star, but if parallel rays from the Pole Star are drawn, one can derive that the Pole Star will be seen at 20° above the horizon towards North. This problem had been solved during the intervention for the students' local position and confirmed by the observed position of the Pole Star. Yet only 2% students from the treatment group drew parallel rays from the Pole Star (figure 7.12a). The difficulty in learning to use parallel ray approximation in case of stars has been discussed on Subsections 4.2.7 & GCPS.

None of the students in the treatment group and only one student in the comparison group could state the position of the stars in terms of degrees above the horizon. About one third of the students responded that the Pole Star will be seen towards North (Response no. 9). It was difficult to tell whether this answer came through reasoning on the diagram or from their prior knowledge, but this percentage did happen to be the same as the percentage of students who could identify North and South directions for a person standing on the earth (Response nos. 11 & 12 in Table 7.9). Almost half the students from both the groups answered this question incorrectly (Response no. 13 in Table 7.10).

The third sub-question (iii of Question no. 11a) probed whether students could simulate the rotation of the earth for the axis in the given diagram and whether they knew that the earth completes half of its rotation in 12 hours. In the intervention we found that students had tendency to draw the position of the person after 12 hours at the diagonally opposite side of current position (as if the axis was perpendicular to

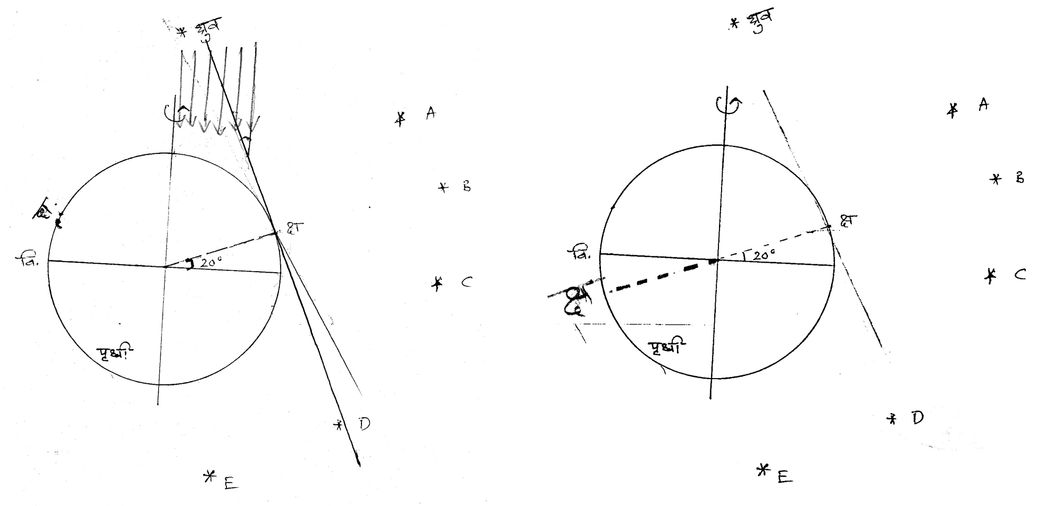
Table 7.10: Percentages of responses to the Question no. 11a

No.	Response *N*	Gr8t *55*	Gr8c *76*
	Which stars will be seen?		
1	Line of horizon	40*	1
2	Pole Star	7	8
3	Star A	85	75
4	Star B	87	76
5	Star C	75*	33
6	Other incorrect responses	0	1
7	No answer	2*	12
	Angle of Pole Star with horizon for a person on 20° latitude		
8	Parallel rays from Pole Star	2	0
9	North	35	32
10	At 20° (only in text)	0	1
11	Will not be seen	11*	0
12	Other correct	2	0
13	Other incorrect (angle/ direction)	56	47
14	No answer	4*	18
	Position of a person X at 20° latitude after 12 hours		
15	Correct position drawn	29*	3
16	Wrong position	13*	0
17	20° (only in text)	4	1
18	Other incorrect responses	56	55
19	No response	4*	28

* Denotes significant difference at $p<0.05$ between that value and the one to its right in the same row.

the plane of the paper) (Figure 7.12b). Correct simulation of the motion of the earth would lead to a different inference. The percentages of students who attempted this sub-question and answered correctly as well as incorrectly, were significantly higher in the treatment group than in the comparison group. Although 29% and 3% of students from the treatment and the comparison group respectively could draw the correct position, only 4% and 1% students from the respective groups could respond in text (but they did not draw a diagram) that the latitude will remain 20° after the 12 hour rotation.

The percentage of incorrect responses was as high as 55% for both the groups for this question. The percentage of students who did not respond was significantly



(a) Only 2% students from the treatment group drew parallel rays from the Pole Star (Response by a urban boy)

(b) A response by Grade 8 (treatment group) rural boy: Problem in simulating the motion of the earth from the given diagram

Figure 7.12: Responses to Question no. 11: Predicting observable position of the Pole Star and simulating motion of the earth

higher in the comparison group for all three sub-questions.

7.1.3 Revolution of the earth

Four questions were asked related to the sun-earth system, out of which one (Question no. 8) called for representing the model in the diagram, two (Question nos. 10 and 11c) called for the explanation of occurrence of seasons and one (Question no. 11b) had to do with changes in the night sky over the year and its relation to the Indian (indigenous) calendar.

Mental model of the sun-earth system

In Question no. 8 students were asked to draw a diagram of the sun-earth system as seen from above the North Pole and shade the dark (night) parts on the earth using hatched lines. The percentages of students who drew responses that contained the required elements are summarized in Table 7.11.

From Table 7.11, we see that percentages of correct responses were significantly higher in the treatment group than in the comparison group for all the elements which were required to be drawn except for the axis of the earth's rotation (Figure 7.13). The percentages of correct responses in the treatment group ranged from 25% to 53%, whereas these in the comparison group ranged from 0% to 20%. There were no significant differences in percentages of incorrect responses in two groups.

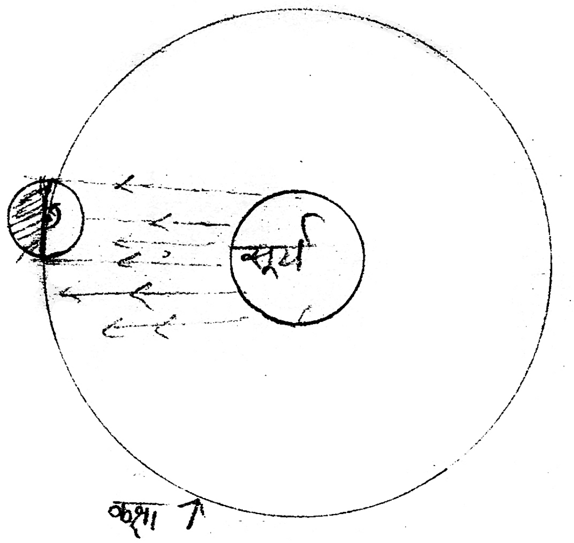


Figure 7.13: A correct response by Grade 8 (treatment group) rural boy to Question no. 8: The sun-earth system as seen from above the North Pole

Response no. 7 in Table 7.11 shows that percentage of students who depicted a consistent point of view from above the North Pole. Although textbooks do use different perspectives in diagrams, they do not explicitly not make students aware of choosing any particular perspective. Significantly more students from the treatment group could produce the diagram of the sun-earth system by imagining it from the given point of view.

Table 7.11: Percentages of the elements present in the diagram when students were asked to draw the sun-earth system as seen from above the North Pole (Question no. 8)

No.	Elements and aspects in diagram *N*	Gr8t *55*		Gr8c *76*	
		% correct	% wrong	**% correct**	% wrong
1	The round earth	53*	0	20	0
2	Round orbit of the earth	38*	5	0	1
3	The sun (Sun rays)	47*	2 (4)	16 (1)	0 (4)
4	Axis of the earth's rotation	25	11	13	3
5	Direction of rotation	31*	4	0	0
6	Day-Night	33*	7	16	4
7	Choice of view (from above North Pole)	35*	4	11	3

* Denotes significant difference at p<0.05 between that value and the corresponding value for the Grade level to its right in the same row.

Seasons

In Question no. 10, students were asked to explain (with the help of a diagram), 'why do we have summer and winter in India?' The percentages of students who drew relevant elements in the diagrams and wrote the correct explanation in the accompanying text is given in Table 7.12.

Out of 10 elements to be drawn in the explanatory diagram for occurrence of seasons, 7 elements were drawn by significantly more number of students in the treatment group then in the comparison group. These elements are (Response nos. 2-4, and 6-9): parallel sun-rays, round earth, choosing the correct point of view, axis with correct inclination to the ecliptic, day and night, terminator (not coinciding with axis), and indicated that summer was going on in the Northern hemisphere (Figure 7.14). There were no significant differences in percentages of students drawing the sun and the equator, and indicating that it was winter in the Southern hemisphere when it was Summer in India. Remarkably, all students drew the situation for the Summer solstice (in the Northern hemisphere), even though in the textbooks and in our pedagogy both the summer and winter solstice positions were drawn. Possibly there is a widespread bias towards showing a 'forward' tilt (not just in diagrams but perhaps in writing and gesturing too).

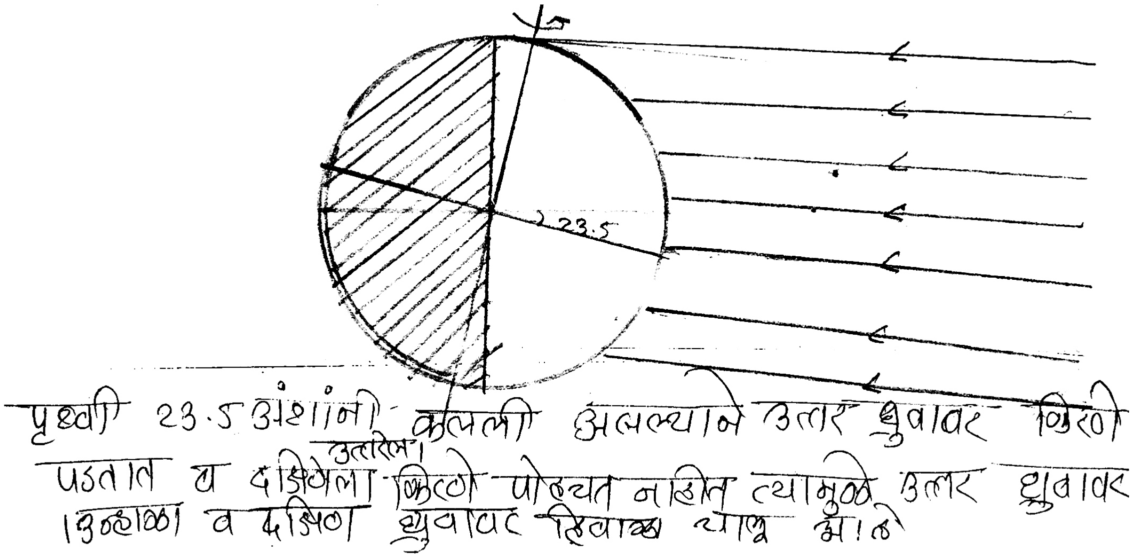


Figure 7.14: A correct response by Grade 8 (treatment group) rural boy for explanation of occurrence of seasons (Question no. 10)

Although approximately 20% students in the treatment group drew the correct diagram (Response no. 6), only 5% students wrote the correct explanation in their accompanying text (Response no. 11), and none of the students from the comparison group did it.

The difficulty level of explanation of seasons is seen by the fact that the percentages of correct responses in the comparison group were as low as 0% and 1% for all the factors, and those for the treatment group were around 20% to 30%.

In Question no. 11c a skeletal diagram was provided and students were asked to infer on its basis. The diagram represented the situation at the time of summer solstice in the Northern hemisphere (Appendix A.4) and students were asked the following sub-questions:

i. Is the sun exactly overhead for a person on the equator?

ii. If not, the sun is in which direction of zenith?

iii. A person in which hemisphere would have the sun overhead?

iv. Which season is going on in the Southern hemisphere?

Table 7.12: Percentages of students' responses for the occurrence of the seasons in which diagram was provided and students were asked the inferences (Question no. 10)

No.	Elements / aspects in diagram *N*	Gr8t *55*	Gr8c *76*
1	The sun	7	1
2	Parallel rays	24*	0
3	The round Earth	31*	1
4	Correct view (from within the plane of equator)	25*	1
5	Equator	7	1
6	Axis of earth's rotation (with correct inclination to ecliptic)	20*	1
7	Day-Night	25*	0
8	Terminator does not coincide with axis	20*	0
9	Summer in Northern hemisphere	15*	1
10	Winter in Southern hemisphere	7	1
11	Correct text	5	0

* Denotes significant difference at $p<0.05$ between that value and the one to its right in the same row.

The percentages of correct and incorrect responses for the four sub-questions of 11c are summarized in Table 7.13. An impressive percentage from the treatment group could answer the first sub-question. The percentage of correct responses was significantly higher and the percentage of incorrect responses was significantly lower in the treatment group than in the comparison group. In the second sub-question the percentage of correct responses was significantly higher in the treatment group but almost half of the students answered this sub-question incorrectly and the percentages of incorrect responses were similar in the treatment and the comparison groups.

For the second and third sub-questions, there were no significant differences in percentages of correct responses in the two groups. Moreover, the percentage of incorrect responses was quite high and in fact significantly higher in the treatment group than in the comparison group for the last sub-question.

Comparing Table 7.12 and Table 7.13, more students from the comparison group attempted the question when the diagram was provided and they were asked

Table 7.13: Percentage of responses for occurrence os seasons when the skeletal diagram was provided (Question no. 11c)

No.	Response *N*	Gr8c *55*	Gr8c *76*
	Is the sun overhead for a person on the equator?		
1	No	85*	49
2	Yes	9*	36
	If not, in which direction to the head is the sun?		
3	North	44*	8
4	Incorrect response	44	43
	The sun will be overhead for a person in which hemisphere?		
5	Northern hemisphere	38	29
6	Southern hemisphere (or other wrong)	44	42
	Which season is going on in Southern hemisphere?		
7	Winter	47	39
8	Incorrect response	33*	24

* Denotes significant difference at $p<0.05$ between that value and the one to its right in the same row.

to infer (Question no. 11). Moreover, some of the students in the comparison group could also answer the questions correctly when a diagram was provided (but not when a diagram needed to be drawn for the sake of explanation). However, the percentage of students who answered incorrectly was also high and was similar in both the groups (with the exception of the 1^{st} sub-question).

Changes in the night sky over the year

Question no. 11b had to do with the changes in the night sky as an effect of the revolution of the earth. The sun, earth and orbit of the earth were drawn as seen from above the North Pole, with a background of stars all around with the Marathi names of those stars. Students were asked:

i. Which Marathi month is going on on the earth?

ii. Which *Nakshatra* would people on the earth see (overhead) at the midnight?

iii. In which *Nakshatra* is the sun located?

The percentages of correct and incorrect responses are given in Table 7.14. The percentage of students who responded correctly was significantly higher in the treatment group than in the comparison group for all three sub-questions, but the percentages of incorrect responses were significantly lower in the treatment group, only for the first sub-question.

Table 7.14: The percentages of correct and incorrect responses for the changes in the night sky as an effect of revolution of the earth when the diagram for the sun-earth system with background stars was provided (Question no. 11b)

No.	Response *N*	Gr8t *55*	Gr8c *76*
	Which Marathi month is going on on the earth?		
1	*Falgun* (correct response)	93*	58
2	Incorrect response	4*	29
	Which *Nakshatra* is seen at midnight from the earth?		
3	*Falguni*	38*	0
4	Other	53	43
	The sun is in which *Nakshatra*?		
5	*Bhadrapada*	45*	9
6	Incorrect response	36	32

* Denotes significant difference at p<0.05 between that value and the one to its right in the same row.

We know from results of the test on the indigenous knowledge (Section 6.3) that students were familiar with the terms for the Marathi months and hence the corresponding and similarly named *Nakshatras*. From Table 7.14 we can see that almost all students in the treatment group and almost 60% students in the comparison group were able to connect the months with the name of the *Nakshatra* (Response 1). Almost half of students in the treatment group and about 10% students in the comparison group know the meaning of the term ‘sun in a particular *Nakshatra*’ (Response no. 5). Comparatively fewer students (less than 40%) in the treatment group and none in the comparison group could however relate it with the observational prediction (Response no. 3). Usually the terms in the indigenous calendar are connected with astrology. The percentage of correct responses to Question no. 11b indicates that our attempt to explain the terms in the indigenous calendar in terms of observational astronomy was moderately successful.

7.1.4 Test 4: Comparison of total scores

Total scores for each Grade (after collapsing all three samples) were found to be normally distributed for Test 4 using the one sample Kolmogorov-Smirnov test. The comparison of means gave the following results (details Appendix H):

1. Grade 7 students' understanding of the sun-earth model was not significantly different from that of Grade 4 students ($Gr4 \simeq Gr7$).

2. Grade 7 students' understanding of the sun-earth model improved in Grade 8 after the intervention (Gr8t > Gr7).

3. For Grade 8, understanding of the sun-earth-moon model was better in the treatment group than in the comparison group (Gr8t > Gr8c).

4. The comparison group was not significantly different than the Grade 7 students in terms of their understanding about the sun-earth model. ($Gr7 \simeq Gr8c$).

7.2 Test 5: The Moon

The Maharashtra State curriculum up to Grade 7 includes explanatory models related to the sun-earth system only. In Grade 8 students learn explanations of the phenomena related to the moon. Hence a test to probe students' understanding about the SEM system and the phenomena related to the moon was administered close to the end of Grade 8, which coincided with the beginning of the third part of the intervention. At this point students had learnt the SEM system as a part of their regular school curriculum but not as a part of the intervention. The treatment group at this point is called Gr8t-pre. After intervention this group is called Gr8t-post. Gr8c is the comparison group, same as in the previous sections. The duration between the pre and post administration of Test 5 was of about 10 days whereas it was a little more than one year for Tests 1-4. The pre and the post versions of Test 5 were identical except that an extra question about the evidences for spherical shape of the earth was included in the test for Gr8t-post and Gr8c. The complete test can be found in Appendix A.5.

The analysis is presented in three Subsection. Subsection 7.2.1 describes evidences for the spherical shape of the earth (Question no. 1). Subsection 7.2.2

presents analysis of responses to questions on facts and observations regarding the moon (Question nos. 2, 3 & 4 in Appendix A.5). Subsection 7.2.3 describes the explanations of five phenomena related to the moon (occurrence of the phases, lunar eclipse, solar eclipse, observability of the same face of the moon, and inconsistency between duration of the synodic month and the sidereal month; Question nos. 5-9). For correspondence between the Subsections and the question numbers see Table A.6.

7.2.1 The spherical earth

This question was given only in the post-test to the treatment and the comparison group. It was similar to the first question in the test on the sun-earth model (see Subsection 7.1.1 and Appendix A.5), where students were asked to provide evidences of the spherical shape of the earth. In this question, the following four observations were provided as hints to help students give the evidences:
I. A photograph of the earth taken from a space-ship.
II. Lunar eclipse
III. The difference in positions of the stars if one goes a considerable distance towards North or South
IV. A ship in the sea approaching the coast
An extra space with the label 'Other' was provided for students to think of any other evidence.

The percentages of students who produced different evidences on the basis of the given observations for the spherical shape of the earth are given in Table 7.15. Response nos. 1-9 are the correct evidences for the spherical shape of the earth and the percentages of five of these responses (Response nos. 2, 3, 5, 6 and 8) are significantly higher in the treatment group than in the comparison group. Response nos. 1 and 2 are the correct evidences related to the photograph of the earth from space (Hint-I) of which Response no. 1 was the most common among both the groups. Forty six percent students from the comparison group and 51% students from the treatment group responded that the earth looks round or its photographs taken from the spaceship are round. In addition to these 51%, six percent students in the treatment group gave the more precise response that the photographs of the earth taken from the spaceship are always round (Response no.2). This response excluded the possibility of a disk-shape, cylindrical or spheroidal shape of the earth, which would look round only if seen from certain angles.

Response nos. 3 and 4 are correct evidences related to the shadow of the earth during a lunar eclipse (Hint-II). A significantly higher proportion of students from the treatment group (28%) responded that the shadow of the earth during the lunar eclipse being round is an evidence for the spherical shape of the earth. In addition to these 28% who could expand on Hint-II, 4% students from the treatment group specified that the shadow is always round, which is important for excluding shapes other than spherical but which project a circular shadow in special cases. None of the students from the comparison group felt it necessary to specify the consistency of this observation.

Response nos. 5 and 6 are correct evidences related to the positions of the stars at different locations on the earth (Hint-III). Both these response are equally correct but, it is remarkable that the 'view ahead' has been mentioned by more students than the 'view behind', perhaps a consequence of visualizing the situation and mentally simulating it.

Response nos. 7 is the expected correct response related to the observation of the ship approaching the coast (Hint-IV). However, 15% students from the treatment group responded that the ship would come back to the same position if it travels in a straight line (Response no. 8) i.e. one could use a ship to circumnavigate the earth. This too was naturally considered a correct response.

Other correct or almost correct responses (Response no. 9) include 'line of horizon changes', 'while going through sea, we do not see parts (of the earth) behind us, and see new parts', 'we cannot see too far', 'Vasco da Gama came to India by going all around the earth'.

The percentage of incorrect responses for each of the hints (Response nos. 10-13) and independent incorrect responses (Response no. 14) ranged from 9% to 55% in the treatment group and from 4% to 70% in the comparison group. Incorrect responses included correct and incorrect mechanisms of the lunar eclipse and responses such as, 'shape of the moon changes every day, that is called a lunar eclipse'

Table 7.15: Percentage of response as evidences for spherical shape of the earth (Question no. 1)

No.	Response	Gr8t	Gr8c
	N	*53*	*80*
1	Photo of the earth from space is round	51	46
2	Photo taken from any side is round	6*	0
3	Shadow of the earth during the lunar eclipse is round	28*	5
4	Shadow of the earth during the lunar eclipse is always round	4	0
5	Different stars are seen in the direction of walking	47*	8
6	Stars from the back will not be seen	19*	0
7	Upper part of the ship is seen first and then the lower part	23	14
8	Ship (or we) comes back to same position if keeps going in a straight line	15*	1
9	Other correct	4	1
10	Incorrect responses related to the photograph	42	38
11	Incorrect response related to shadow of the earth	55	70
12	Incorrect response related to stars	38	49
13	Incorrect responses related to the ship	34	33
14	Other incorrect	9	4

* Denotes significant difference at $p<0.05$ between that value and the one to its right in the same row.

(for Response no. 11), ‘only one side of the moon will be seen from the earth at the time of lunar eclipse’, ‘stars will appear smaller and smaller’, ‘we feel that stars are coming with us, but they are at same place’, ‘stars will appear the same’, ‘stars appear closer’, ‘we cannot recognize the directions’, ‘stars wouldn’t be seen’, ‘stars appear lower in circular direction’, ‘some stars will look brighter and some will be the same’ (for Response no. 12), ‘the ship comes in horizontal line’, ‘magnetic needle: because the earth is round, directions do not change’ (for Response no.13), ‘rotation of the earth’, ‘semicircular motion of the sun’, ‘occurrence of the seasons’ (for Response no.14), etc..

In Test 4 (the sun-earth model), students were asked to produce evidences for the spherical shape of the earth without hints (Subsection 7.1.1). Comparing Tables 7.1 and 7.15, we find that percentages of both correct and incorrect responses increased when the hints were provided.

7.2.2 Factual information and observations about the moon

The questions discussed here onwards were asked to all the three groups (Gr8t-pre, Gr8t-post, and Gr8c). One question related to factual information about the shape of the moon (Question no. 2) and two questions (Question nos. 3 & 4) probed students' observations of phases of the moon (Appendix A.5).

Actual shape of the moon

Table 7.16 shows students' responses to the open-ended question, 'what is the shape of the moon?' (Question no. 2, Appendix A.5). Response no. 1 is the unambiguously correct response (*ladu* is solid spherical-shaped Indian sweet), which was significantly more common on the post-test of the treatment group than in the comparison group. Response no. 2, 'like a ball', is also correct, though in the Indian context, balls that children play with are usually hollow, so this response perhaps leaves open the possibility of hollow moon. Significantly higher proportion of the comparison group gave this response.

Table 7.16: Percentage of responses for shape of the moon (Question no. 2)

No.	Response *N*	Gr8t-pre *43*	Gr8t-post *53*	Gr8c *80*
1	Spherical/ Like a *ladu*	30	45*	3
2	Like a ball	23	15*	38
3	Round (*gol*)	26	21	31
4	Changes every day	0	6	9

* Denotes significant difference at $p<0.05$ between that value and the one to its right in the same row.

About 21% to 31% students from all three groups stated that the shape of the moon is round (Response no. 3: *gol* in Marathi), which is ambiguous because it may refer to either a spherical or disk-shape. Six percent students from the treatment group and 9% in the comparison group stated that the shape of the moon changes every day (Response no. 4).

Observable shapes of the moon

In Question no. 3, students were provided eight empty squares and asked to draw shapes of the phases. They were expected to draw a sequence, for example from waxing crescent to new-moon (waxing crescent - waxing half-moon - waxing gibbous - full-moon - waning gibbous - waning half-moon - waning crescent - new-moon). Students were also asked to name the phases (all the phases have distinct names in Marathi as explained in Appendix G.2). Responses 1-16 in Table 7.17 have to do with the shapes of the phases and their corresponding Marathi name.

If a certain shape of a phase was drawn correctly irrespective of its order in the overall sequence, then it was counted as 'correct'. The waxing and waning status of the shape was determined from its local ordering with respect to the shape before and after it. If a name of a phase was matched correctly with its picture (irrespective of its waxing or waning specification), then the name was considered 'correct'. A name that was wrongly matched with the drawing was considered 'incorrect'. Response no. 1-16 therefore have to do with the drawings of the individual phases and their matching with the names, considering local ordering only.

From Table 7.17 we see that percentage of correct responses for pictures of the waning gibbous and new-moon (Response nos. 9 & 15) significantly increased from pre-test to post-test. Percentages for pictures of two phases (waxing crescent and waning gibbous: Response nos. 1 and 9) were significantly higher in the treatment group than in the comparison group. Percentage of students who drew the full-moon was significantly higher in the comparison group than in the treatment group. The low percentages of correct responses for the gibbous phase (Response nos. 5 and 9) in groups which did not undergo the intervention show that the gibbous shape presents particular difficulty. Students from the treatment group did better than the other two groups in case of the waning gibbous (Response no. 9).

The percentage of students who named the phases correctly increased from pre-test to post-test in case of 6 out of 8 phases (Response nos. 2, 8, 10, 12, 14, and

16). The difference between the treatment group and the comparison group was significant for names of 6 phases out of 8 (Response no. 2, 6, 8, 10, 14, 16) i.e. with the waxing and waning half-moon. Percentages of students who named the phases correctly were generally low (1% for both the crescents and gibbous moons, 4% and 6% for the two half moons) in the comparison group, except for the names of the full and the new moon.

Table 7.17: Percentage of responses for correct and incorrect drawings of observable phases and their names in Marathi (Question no. 3)

No.	Response *N*	Gr8t-pre *43*		Gr8t-post *53*		Gr8c *80*	
		% **C.**	% W.	% **C.**	% W.	% **C.**	% W.
1	Waxing crescent	46	11	55*	2	35	11
2	Marathi name: *Prathama-Saptami* (or *kor*)	7*	0	19* (+4)	0	1	0
3	Waxing half-moon	32	4	45	0	33	1
4	Marathi name: *Ashtami*	3	0	11	0	4	0
5	Waxing gibbous	10	31	19	23	11	21
6	Marathi name: *Navami-Chaturdashi*	3	3	13*	0	1	0
7	Full moon	87	3	81*	0	96	0
8	Marathi name: *Pournima*	17*	4	51*	0	26	3
9	Waning gibbous	4*	35	23*	25	8	29
10	Marathi name: *Prathama-Saptami*	0*	0	19*	2	1	0
11	Waning half-moon	21	0	34	4	33	3
12	Marathi name: *Ashtami*	0*	0	13	2	6	0
13	Waning crescent	42	0	42	8	38	8
14	Marathi name: *Navami-Chaturdashi*	0*	0	9*	8	1	0
15	New-moon	35*	0	62	0	51	1
16	Marathi name: *Amawasya*	7*	0	40*	0	24	0

* Denotes significant difference at $p<0.05$ between that value and the corresponding value for the Grade level to its right in the same row.

Period of phase cycle

Question no. 4 was asked to probe whether students know the time period of the phase cycle and whether they know (or can calculate) the time between two phases. The following three sub-questions were asked:
i. Duration between two successive full-moons.
ii. Duration between two successive Chaturthis (4^{th} day after new or full moon).
iii. Duration between two successive Ashtamis (half moons).

Table 7.18 summarizes the percentages of correct and frequent incorrect responses. Response nos. 1, 3 and 5 are the correct responses for above three sub-questions respectively. The accurate answer for the duration between two successive full moons is 29.5 days, but responses such as 30 days or 1 month are considered correct (Response no. 1). The sub-question on the full moon was correctly answered by the maximum number of students (more than 70% students in the pre-test and the post-test). The percentage of correct responses for the duration between two successive half moons is significantly higher in the treatment group than in the comparison group (Response no. 6).

Table 7.18: Percentage of responses for duration between two successive Full-moons, Quater moons (*Chaturthi*) and Half moons (*Ashtami*) (Question no. 4)

No.	Response *N*	Gr8t-pre *43*	Gr8t-post *53*	Gr8c *80*
1	Full-moon to full-moon: 30 days/ 1 month	72	70	54
2	Full-moon to full-moon: 14 / 15 days	21	9	18
3	*Chaturthi* to *Chaturthi*: 14 / 15 days	23	32	18
4	*Chaturthi* to *Chaturthi*: 30 days	16	19	15
5	*Chaturthi* to *Chaturthi*: 8 days	0	8	4
6	*Ashtami* to *Ashtami*: 14 / 15 days	28	38*	8

* Denotes significant difference at $p<0.05$ between that value and the one to its right in the same row.

7.2.3 Explanation of phenomena related to the moon

Explanations of five phenomena related to the moon (occurrence of the phases, lunar eclipse, solar eclipse, observability of the same face of the moon, and inconsistency between duration of the synodic month and the sidereal month) were asked in Question nos. 5 to 9 (Appendix A.5). Sufficient space was provided for diagrams and text.

Phases of the moon

In response to the question on why we see phases of the moon, students responded both in text (Response nos. 1-3) and through diagrams (Response nos. 4-22) in Table 7.19. The numbers in the brackets in Response nos. 13-15 &17 (Table 7.19) indicate percentage of incorrect responses. None of the students in any of the groups were able to fully explain the mechanism of the moon's phases in words. In the treatment group however 28% students could state a component of the correct explanation, namely, that phases were caused by the revolution of the moon around the earth (Response no. 1). About 15% to 24% students from all three groups stated that the shadow of the earth falling on the moon causes the phases (Response no. 2, Figure 7.17a). This alternative (wrong) explanation is widely documented (Subsection 2.1.2) and consequently the difference between lunar eclipse and phases was explicitly clarified and emphasized in the intervention. Yet, one fifth of students after the intervention continued to hold this common alternative conception.

Other incorrect responses (Response no. 3) included incorrect descriptions of motions of the earth and/or the moon, 'period of rotation and revolution are same for moon, so we see phases', 'because of the moon's rotation and revolution', 'because the moon is sometimes in apogee and perigee' (terms that are introduced in the textbook with no particular intent), 'while the moon revolves around the earth, it goes 15 days in light and 15 days in darkness', 'the sun, moon and the earth are in a straight line' and, 'the moon gets smaller due to stars and eclipses and is not seen on the new-moon night'.

Many students also provided irrelevant information which was correct, such as the meaning of the term 'phases', 'the earth-moon distance is 3 lakh 84 thousand km', 'the moon revolves around the earth', 'the rotation and revolution time of the moon are the same so we always see the same face of the moon', 'the moon is a satellite of the earth', 'tides depend on phases', etc.. These responses were not counted as incorrect responses and are omitted from Table 7.19.

Table 7.19: Percentages of students' correct and incorrect responses for the explanation of phases of the moon (Question no. 5)

No.	Response *N*	Gr8t-pre *43*	Gr8t-post *53*	Gr8c *80*
	Textual explanation			
1	Revolution of the moon	4*	28*	3
2	Explanation of the eclipse	24	19	15
3	Other incorrect responses	10	17	28
	Elements in the diagrams			
4	The sun	3	2	5
5	Parallel sun-rays	3*	34*	8
6	The earth	28	38	24
7	Day-night on the earth	3	9	20
8	Orbit of the moon from correct perspective	11*	42*	20
9	Half of the moon is always lit	3*	30*	8
10	Unequal dark and lit moon	3	8	10
11	Terminator is always perpendicular to rays	0*	23*	5
12	Terminator not perpendicular to rays	4	8	13
	Diagrams of phases			
13	Full-moon: correct (incorrect shape)	3*	32* (2)	14 (3)
14	New-moon: correct (incorrect shape)	3*	30* (2)	11 (6)
15	Half-moon, either waxing or waning: correct (incorrect shape)	0	4 (2)	1 (1)
16	Half-moon, both waxing and waning	3*	25	13
17	Crescent, either waxing or waning: correct (incorrect shape)	0*	9 (2)	4 (5)
18	Crescent (both waxing and waning)	3*	21*	6
19	Correct gibbous, either waxing or waning	3	4	5
20	Correct gibbous, both waxing and waning	0*	13*	3
21	Incorrect gibbous	6	8	6
22	Waxing-waning specified	0*	11	8
23	Ambiguous/ wrong diagram	63	53	62
24	No Response	7*	0*	8

* Denotes significant difference at p<0.05 between that value and the one to its right in the same row.

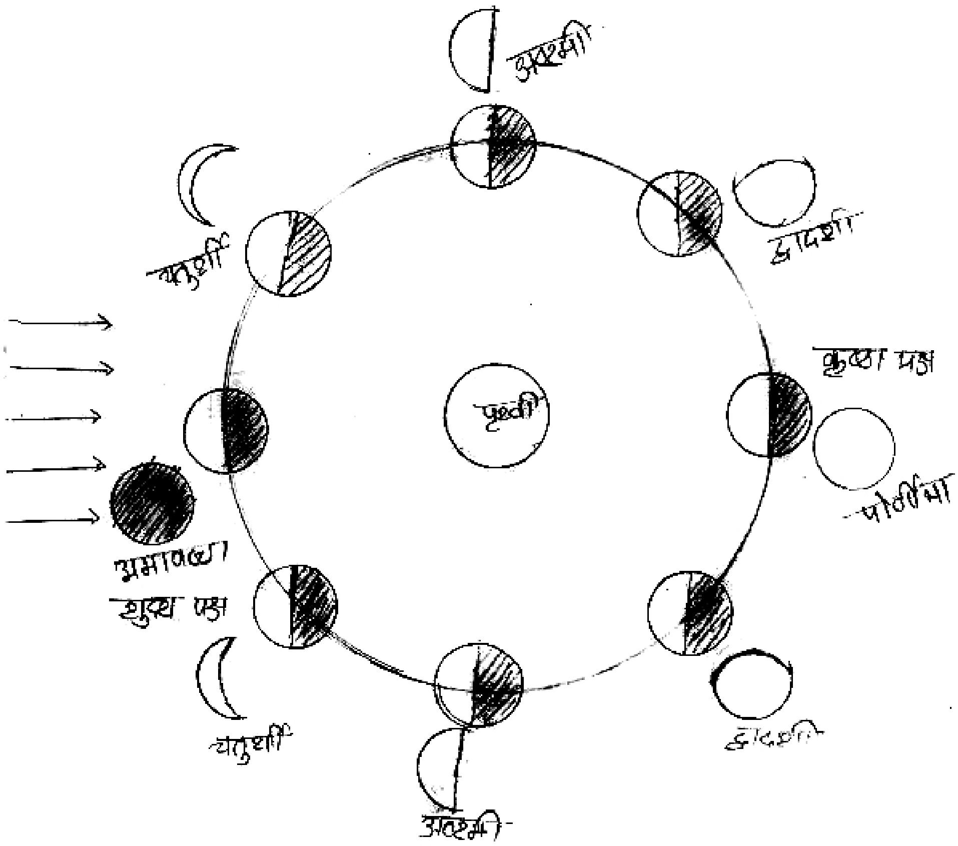


Figure 7.15: An example of correct response by a Grade 8 (treatment group) rural boy: correct names of phases, waxing and waning are specified (Response nos. 5, 6, 8, 9 & 11)

Response nos. 4 to 12 in Table 7.19 are the elements or aspects of the diagram drawn to explain the phases. Response no. 5 shows that a significantly high percentage of students from the treatment group preferred to draw parallel rays from the sun after the intervention. Other three factors in which students showed significant improvement after the intervention are, choosing the correct perspective, dividing the moon into equal half lit half dark parts and showing the terminator always perpendicular to the sun-rays (Response nos. 8, 9, and 11) (Figure 7.15). Of these factors the last one, Response 11 (Terminator always perpendicular to the rays) was the most difficult part for students, as they were often tempted to show the terminator line along the line of the orbit that was drawn already (Figure 7.16a).

A correct Response no. 11 implied that students had drawn parallel rays and it was almost always accomplished by the correct responses for the perspective of orbit and a half-lit moon (Response nos. 8 and 9). The presence of all of these elements (in 23% students in the treatment group) do appear to show an improvement in conceptual understanding and also better co-ordination of the thinking and drawing process in contrast to producing a rote learned diagram.

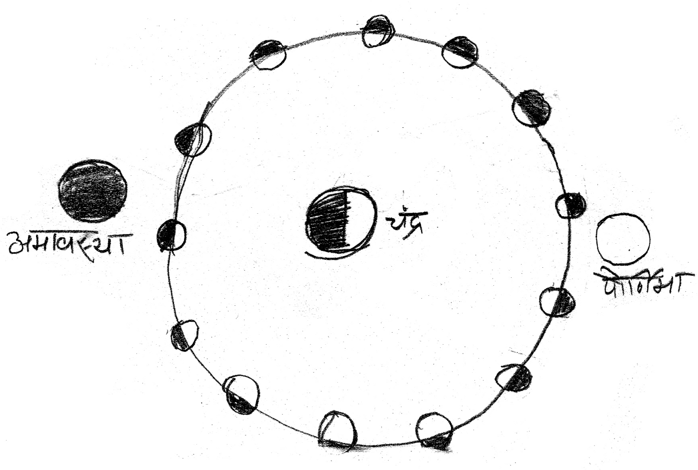
Students were expected to draw the observable phase near each position of the moon in its orbit. The correct and incorrect percentages of shapes are given in Response no. 13-21. The percentage of students who correctly drew a full-moon , new moon, half-moon, waxing and waning crescents and waxing and waning gibbous moons (Response nos. 13, 14, 16, 18, and 20) significantly improved after the intervention. The percentages of students in the treatment group who drew full-moon, new-moon, waxing and waning crescent (Response nos. 13, 14, and 18) are significantly higher than those in the comparison group. A few students drew either only the waning or only waxing phase of the half-moon, crescent or gibbous (Response nos. 15, 17, and 19), of which the difference between the percentages in the pre-test–post-tests was significant only for the crescent (Response no. 17). A few students from all the groups drew incorrect (mostly eclipse-like) shapes of the gibbous moon (Response no. 21). More students gave this explanation in their text response as noted earlier (Response no. 2).

None of the students specified the waxing and waning before the intervention, but significantly higher proportion of students did so after the intervention. However eight percent students from the comparison group specified the waxing and waning too (Response no. 22).

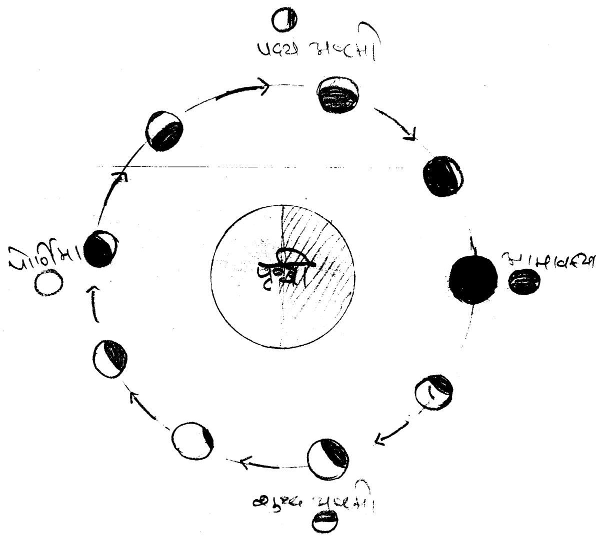
The no response rate (Response no. 24) was small (0% for the treatment group) but the percentage of ambiguous or irrelevant diagrams (Response no. 23) was high in all three groups (from 53% to 63%).

Lunar eclipse

Responses for the explanation of occurrence of the lunar eclipse (Question no. 6) are summarized in Table 7.20. Students gave both textual (Response nos. 1-6) and



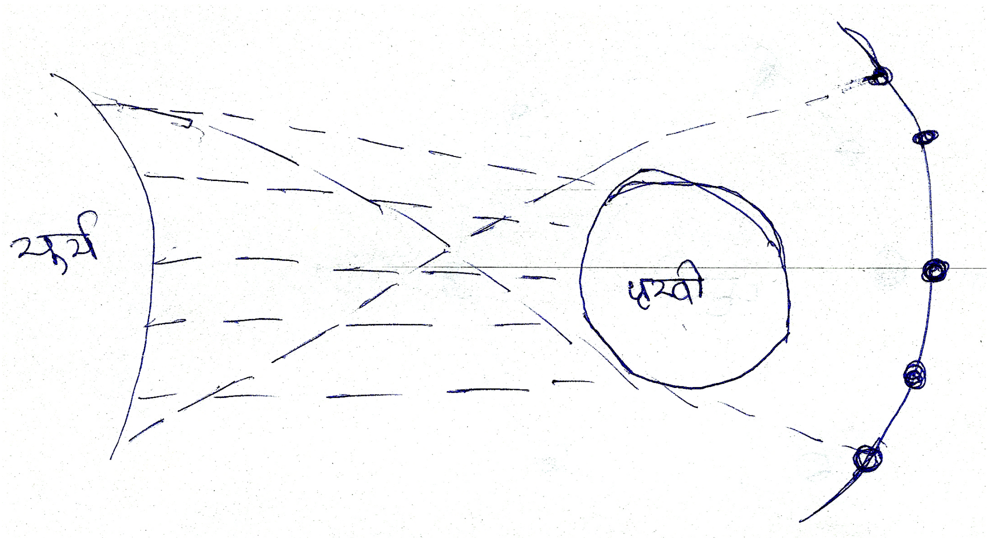
(a) Response by a Grade 8 (comparison group) rural boy: Direction of sunlight was not specified, the central body is labeled as 'moon' (Response nos. 7, 8, 9 &12 in Table 7.19)



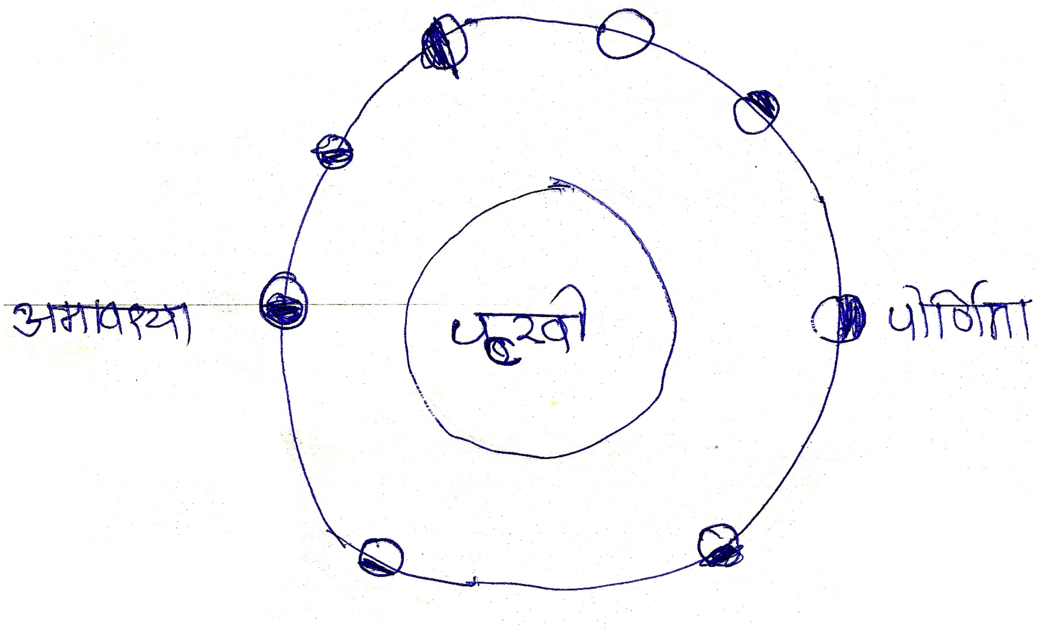
(b) Response by a Grade 8 (comparison group) rural girl: irregular shading on the moon (Response nos. 6, 7, 8, 10 &12 in Table 7.19)

Figure 7.16: Responses for explanation of phases of the moon (Question 5, Test 5)

diagrammatic responses (Response nos. 7-17). The correct arrangement (Response no. 1: the sun, earth and moon in a straight line) and the shadow of the earth falling on the moon (Response no. 2) are two components of the correct explanation. The



(a) Incorrect explanation for phases of the moon: Response no. 2 in Table 7.19



(b) 'Explanation' for lunar eclipse by the same student: Response no. 6 in Table 7.20

Figure 7.17: Responses by a Grade 8 (comparison group) rural boy: Students often confuse between explanation of phases and lunar eclipse

percentage of students in the treatment group is significantly higher for Response nos. 1 and 2 than in the comparison group. Response nos. 3-5 are not components of the explanation but they provide relevant information. Other such extra information (found in the Geography textbook of Grade 8) (‘reduced light when it goes in penumbra, when it comes our, light increases’, ‘maximum duration of a lunar eclipse is 1 hour, 45 minutes.’, ‘minimum 2 and maximum 3 lunar eclipses are seen per annum’) was given by many students. Incorrect responses (Response no. 6) included mechanism of solar (instead of lunar) eclipse, incorrect duration, or number of eclipses per year, ‘the moon is between the sun and the earth’, ‘when the moon, earth and stars come in a line.’, ‘the moon covers due to the earth’, ‘shadow of the sun and the moon falls on the earth’, ‘the moon gets smaller due to movement of planets’, and astrology related responses (‘lunar eclipse should not be watched’).

Among diagrammatic responses (Response nos. 7-17), 70% students drew the correct arrangement of the sun, moon and the earth after the intervention, a percentage that was significantly higher than in the comparison group.

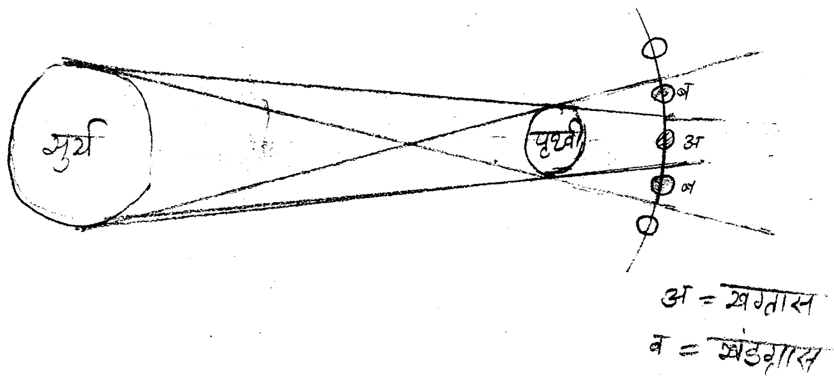
Eclipses have a place in the indigenous calendar and the terminology (as well as superstitions) associated with eclipses, their types and their stages, are part of local knowledge. The textbook for Grade 8 describes the lunar and solar eclipses, both total and lunar ones. Diagrams of these different types of eclipses, including details such as umbra, penumbra and the location of sighting of the eclipses, are given in the textbook. In order to draw these detailed ray diagrams the sun needs to be treated as an extended source at a finite distance, not an ideal distant source of parallel rays as drawn for explanation of other phenomena such as day-night, seasons and phases of the moon. In the intervention session we found that students had difficulty in drawing and understanding ray diagrams for extended sources (Figure 7.18c). Since this was not the main focus of our teaching we continued to use the parallel ray approximation in explaining the eclipses too. Details like the umbra and penumbra were not dealt with in the intervention. Despite this the percentage of students who drew the correct penumbra (Response no. 14) increased significantly after the intervention, and the percentages of correct umbra and penumbra (Response nos. 14, 15) were significantly higher in the treatment group than in the comparison group (Figure 7.18a). This shows that some students in the treatment group were perhaps able to use the technique of ray diagrams to understand and reproduce accurately the diagrams in their textbooks. A few students in the treatment group did also draw

Table 7.20: Percentage of students' responses for explanation of the lunar eclipse (Question no. 6)

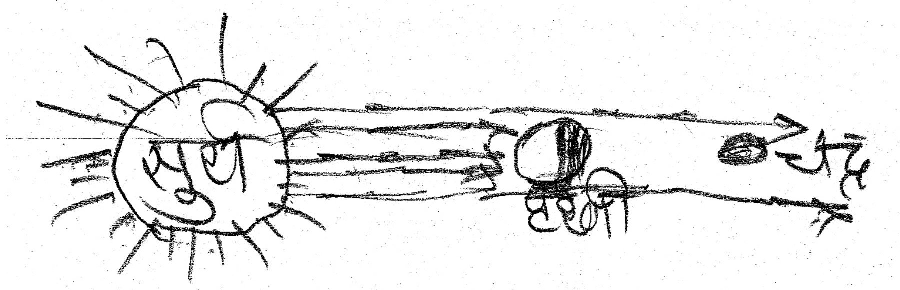
No.	Response *N*	Gr8t-pre *43*		Gr8t-post *53*		Gr8c *80*	
	Textual Response						
1	Correct arrangement: S-E-M	56		43*		20	
2	Shadow of the earth on the moon	39		34*		11	
3	Occurs on the full-moon	11		17		13	
4	Can be seen from entire dark (night) parts of the earth	0		4		0	
5	Types: total and partial	1		2		1	
6	Incorrect responses	28		25		39	
	Elements / aspects of the Diagram	% **C.**	% W.	% **C.**	% W.	% **C.**	% W.
7	Arrangement: SEM	74		70*		31	
8	Sizes- S > E	56	17	43*	19*	24	5
9	Sizes- E > M	59	14	51*	11	19	10
10	Distances- SE > EM	24	49	25	36*	16	13
11	Day-Night on the earth	11	0	11	2	10	0
12	Shadow due to parallel rays	3	0	9	0	3	0
13	Umbra	11	4	21*	15*	9	0
14	Penumbra	4*	7	26*	11*	9	0
15	Ray diagram	4	32	13	17	8	11
16	Orbit of the moon	32	0	36*	0	10	3
17	Ambiguous/ wrong diagram	24	0	23*	0	53	0
18	No response	0	0	0*	0	13	0

* Denotes significant difference at $p<0.05$ between that value and the corresponding value for the Grade level to its right in the same row.

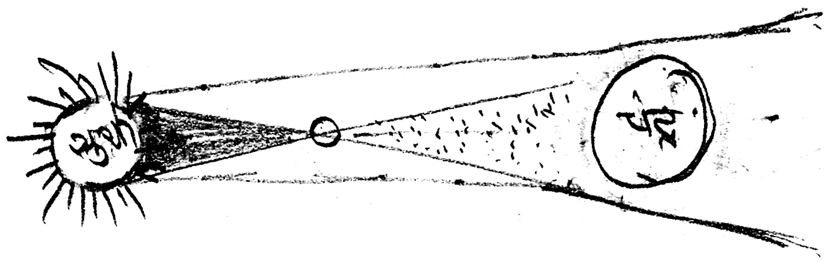
an incorrect umbra or penumbra, showing a trend observed in Subsection 5.3.3, of increase in correct as well as incorrect diagrams in the treatment group. The number of students who drew the shadow using parallel rays was small, and it included 3% students in the comparison group (Response no. 12, Figure 7.18b). The complete ray diagram was correct only in a few students whereas the percentage of incorrect ray diagrams ranged from 11% to 32%. The percentage of correct ray diagrams increased increased only to 13% after intervention(Response no. 15). This shows the difficulty level of drawing correct ray diagrams even in simple cases such as shadows.



(a) An example of correct explanation of the lunar eclipse by a Grade 8 (treatment group) rural boy



(b) An example of explanation by parallel rays by a Grade 8 (treatment group) tribal boy



(c) An example of incorrect ray diagram by Grade 8 (comparison group) rural girl: Response nos. 7, 8; Incorrect: 9, 10, 13, 14 ,15 & 16

Figure 7.18: Students responses to explain the lunar eclipse

After the intervention the percentages of irrelevant and ambiguous diagrams and responses without diagrams was significantly lower in the treatment group than in the comparison group. The percentage of irrelevant or ambiguous diagrams was more than 50% in the comparison group (Response no. 17).

Solar eclipse

The textual (Response nos. 1-6) and diagrammatic responses (Response nos. 7-18) for the explanation of the solar eclipse are summarized in Table 7.21. Response no. 1 is the correct explanation of the solar eclipse and Response no. 2 is a step towards explaining the egocentric observation. About 50% students from the treatment group produced Response no. 1 before and after the intervention. A few students produced Response no. 2 before the intervention, none in the comparison group and significantly higher percentage (yet only 8%) produced Response no. 2 after the intervention.

Response nos. 3 and 4 are factual information about the solar eclipse, but without any component of explanation. Other correct responses included types of solar eclipse, its description etc. (Response no. 5). Incorrect responses include explanation of the lunar eclipse, 'because the moon rotates around the sun', 'rays fall perpendicular during solar eclipse', 'the moon's shadow falls on the sun', 'shadow of the sun falls on the earth', 'shadow of the sun falls on the moon', 'any planet between the sun and the earth, its shadow in the earth' and superstitious responses such as 'solar eclipse causes big losses', 'it is said that solar eclipse should not be seen', etc. (Response no. 6).

The percentages of incorrect diagrammatic responses were in general higher for the solar eclipse than the earlier question on the lunar eclipse, so these are listed in Table 7.21 in separate columns for the percentages of incorrect responses (Figure 7.20a). The percentage of correct arrangement at the time of solar eclipse was highest in the treatment group before intervention (77%) followed by that in the treatment group after the intervention (57%) and was significantly lower in the comparison group (35%) (Response no. 7; Figure 7.19c).

The percentage for the correct penumbra (Response no. 14) was higher in the treatment group than that in the comparison group, a result similar to that for the earlier question on lunar eclipse (Response no. 14 in Table 7.20). A few students in the treatment group and the comparison group drew the shadow due to parallel rays

Table 7.21: Percentage of students' responses for explanation of the solar eclipse (Question no. 7)

No.	Response *N*	Gr8t-pre *43*		Gr8t-post *53*		Gr8c *80*	
	Textual Response						
1	The moon comes between the sun and the earth	56		43		29	
2	Total solar eclipse is seen from the parts which are in the shadow of the moon	3		8*		0	
3	Occur only on new-moon	17		15		8	
4	Types: total, partial, annular	3		6		1	
5	Other correct responses	0		6		4	
6	Incorrect responses	24		19		23	
	Elements / aspects of the diagram	% C.	% W.	% C.	% W.	% C.	% W.
7	Correct arrangement (S-M-E)	77*		57*		35	
8	Sizes- S > E or $S \leq E$	46	28	36	17	26	11
9	Sizes- E > M or $E \leq M$	35	39*	36	15	25	11
10	Distances- SE > EM or $SE \leq EM$	10	66*	15	34*	21	15
11	Day-Night on the earth	4	0	11	2	15	1
12	Shadow due to parallel rays	0	0	6	2	4	0
13	Umbra	21	3	8	11	10	3
14	Penumbra	11	10	15*	9	5	4
15	Ray diagram	7	28	9	15	4	20
16	Orbit of the moon	17	7	21	4	13	4
17	Orbit of the earth	3	0	0	0	0	0
18	Ambiguous/ wrong diagram	0	21	0	28	0	44
19	No response	0	0	0	2*	0	14

* Denotes significant difference at $p<0.05$ between that value and the corresponding value for the Grade level to its right in the same row.

(Response no. 12, Figure 7.19b). The percentage of students who drew completely correct diagrams (Figure 7.19a) was less than 10% in all the groups, comparable to the percentage of correct ray diagrams for the lunar eclipse (Response no. 15 in Table 7.20).

The percentage of irrelevant, ambiguous and descriptive diagrams as well as the no-response rate was highest among the comparison group (Figure 7.20b). All the students in the treatment group attempted the question in the pre-test and 98% attempted it in the post-test.

Explaining why we see only one face of the moon

The intervention dealt with the question of why we see only one face of the moon. Gesture 33 and Diagram 32b (Figure 4.31) were used. In Question no. 8 (Appendix A.5) students were asked to explain the same. Their responses are given in Table 7.22. Response no. 1 is the correct textual response and its percentage was higher in the treatment group (in post-test) than in the comparison group. 14% students in the treatment group stated the reason as 'the moon does not rotate' before the intervention (Response no. 2). Note that these students had gone through two parts of the intervention by this time, but the sun-earth-moon system was not yet dealt with in detail. These students tried to explain the phenomenon but came up with the common incorrect mechanism. None of the students gave Response 2 in the post-test but also not in the comparison group.

The percentage of incorrect textual and sometime creative responses (Response no. 3) included 'the moon must be at the centre of the earth and revolve around the earth and rotate', 'Northern hemisphere of the moon is seen from the earth', 'the rotation period of the moon is 24 hours and the revolution period of the moon is 27 hours', 'the moon doesn't change its place', 'rotation and revolution time of the moon should be the same as that of the earth', etc..

The expected diagram to explain that we see only one face of the moon consisted of 5 elements (Response nos. 4-8). Thirty five percent students from the treatment group drew the earth-moon system (Response nos. 4-6), but only 14% chose the correct perspective in the pre-test (Response no. 7) whereas 36% drew the earth-moon system and 23% chose the correct perspective in the post-test. These percentages were very low (3% and 1%) in the comparison group (Response no. 7). A flag or a mark to indicate that the same part of the moon is towards the earth (included in the intervention) was drawn by none of the students in the pre-test and significantly higher number of students in the post-test (Response no. 8; Figure 7.21). The percentages of all the elements except for the flag (Response no. 4-7)

Table 7.22: Percentage of students' responses to explain why we see only one face of the moon (Question no. 8)

No.	Response *N*	Gr8t-pre *43*	Gr8t-post *53*	Gr8c *80*
	Textual response			
1	Time for rotation and revolution is same	17	34*	9
2	The moon does not rotate	14*	0	0
3	Incorrect responses	18	15	19
	Elements / aspects of the diagram			
4	The earth	35	36*	3
5	The moon	35	38*	3
6	Motion: orbit + multiple moons	35	38*	3
7	Orbit of the moon (top view)	14	23*	1
8	Flag/mark	0*	9	3
9	Ambiguous/ wrong diagram	32	45	51
10	No response	25*	6*	34

* Denotes significant difference at $p<0.05$ between that value and the one to its right in the same row.

were significantly higher in the treatment group than in the comparison group.

The percentage of incorrect or ambiguous diagrams ranged from 32% to 51%. The percentage of students who did not respond was significantly less in the post-test-treatment group than in the pre-test-treatment group and in the comparison group.

Explaining inconsistency between the synodic month (phase cycle) and the sidereal month

Question no. 9 (Appendix A.5) read 'The time period of revolution of the moon is of 27 days. But to see the moon at the same place at the same time again from the earth, it takes 29 days. Why does this happen?' This phenomenon is not explained in the text book but was explained during the intervention using Gesture 39 (Section 4.4) (no diagram was drawn). It is difficult to show the explanation using a diagram, since two simultaneous interrelated motions need to be shown. Nonetheless space was provided in case students wished to represent through diagrams, which would enable us to study their spontaneous diagrams. The percentages of responses to

Question no. 9 are provided in Table 7.23.

The correct explanation has two components, first, that the earth is revolving around the sun (Response no. 1) and second, by the time the moon completes one revolution around the earth with respect to the celestial background, the earth has moved further in its orbit. So the moon needs some extra time (two days) to catch up (Response no. 2) (the precise calculation of two days was not expected from students). None of the students in the pre-test and in the comparison group produced either of Response nos. 1 and 2, but a significantly higher percentage of students in the treatment group produced these responses in the post-test. A few students in all three groups guessed the correct explanation, but could not express it explicitly. These intuitively correct responses were of the kind, 'the earth moves along too'.

Incorrect responses (Response no. 4) included 'the moon does not rotate, takes a long time to come back' 'rotation and revolution periods are the same', 'the moon is slower than the earth', 'the moon takes 364 days to complete one revolution', 'while rotating, the moon has to revolve around the earth, so it takes time', 'the moon revolves around the earth in elliptical orbit', 'the earth rotates and revolves around the sun, stars, planets','because the moon enters in a *Nakshatra* while revolving'.

In the post-test, about 17% students from the treatment group drew three elements of the sun-earth-moon system (Response nos. 5-7) and 9% students drew the orbit of the moon (Response no. 8). Drawing the orbit of the moon for the dynamic earth is difficult and students' diagrams (Figure 7.22) show some ways in which they handled this difficulty. None of the students in the treatment group before the intervention and in the comparison group drew any of these elements in their diagrams. The percentage of irrelevant diagrams also was significantly higher in the treatment group after the intervention than before the intervention and than in the comparison group (Response no. 9). A high percentage of students from the comparison group (86%) and of the treatment group before the intervention (52%) did not draw any diagram (Response no. 10). Thus although no related diagram was drawn during the intervention, 83% students tried to draw a diagram (not necessarily a correct diagram) after the intervention.

Table 7.23: Percentage of students' responses to explain the difference in time period for phase cycle of the moon and its revolution with respect to background stars (Question no. 9)

No.	Response *N*	Gr8t-pre *43*	Gr8t-post *53*	Gr8c *80*
	Textual Response			
1	Revolution of the earth	0*	34*	0
2	The moon requires two extra days to catch-up	0*	19*	0
3	Intuitively correct	7	2	1
4	Incorrect	25	26*	8
	Elements / aspects present in the diagram			
5	The earth	0*	17*	0
6	Orbit of the earth	0*	17*	0
7	The moon	0*	17*	0
8	Orbit of the moon	0*	9*	0
9	Ambiguous/ irrelevant diagram	21	34*	6
10	No response	52*	17*	86

* Denotes significant difference at p<0.05 between that value and the one to its right in the same row.

7.2.4 Test 5: Comparison of total scores

Normality of scores was checked for Test 5 (after collapsing all three samples) using the one sample Kolmogorov-Smirnov test. Total scores for Grades 4, 7 & 8t were normally distributed, but for Gr8t (both including and excluding Question no. 1) they were not distributed normally. The comparison of means gave the following results (see Appendix H):

1. Grade 7 students' understanding of the sun-earth model improved in Grade 8 after the intervention (Gr8t > Gr7).

2. For Grade 8, students understanding of the sun-earth-moon model was better in the treatment group than in the comparison group (Gr8t > Gr8c).

3. The treatment group in the pre-test was significantly better than the comparison group in terms of their understanding about the sun-earth-moon model (Gr7 > Gr8c). Note that students in the treatment group had already gone through two parts of the intervention when they appeared for the pre-test.

7.3 Summary: Mental models, explanations, and predictions

Before intervention many Grade 7 students knew the basic facts about celestial objects in the solar system, such as the number of planets (66%) and their names, but their understanding about sizes of the celestial bodies and their distances from the earth was poor (percentage of correct responses ranged from 4% - 41% for distances and from 2% - 54% for sizes). Rote learning was evident in the pre-intervention responses. Most students remembered the numbers related to the time periods of rotation and revolution (the percentage of correct responses was 62% & 67% respectively), but sometimes interchanged them (22% - 24%), or some forgot to mention the units (9% & 2% respectively).

Students from all three Grades suggested alternative shapes for the earth (such as egg - 22%, bowl - 2%, and plate - 9% in Grade 7). Pre-intervention, very few could produce evidences for the spherical shape of the earth (11% or less). They were unfamiliar with the concept of horizon and local directions for a person on the globe.

Students knew that the earth exerts gravitational force on the objects on it, but they could not reconcile this fact with the spherical shape of the earth. Pre-intervention they did not know that all the celestial bodies exert a mutual gravitational force on each other. We found that students had problems in placing model human beings on the globe (none of the students drew a human being in orientation other than vertical (head up) in the pre-test), hence we carried out an activity of pasting toy human figures on the globe in Part I of the intervention. Yet, when in the last part of the intervention students mimicked the gesture of rotating an apple (representing the earth) around a horizontal axis, so that the human figure appeared to be up-side-down, they became very uncertain about their gesture, and tended to stop the rotation before the person became up-side-down, as if they were taking a risk of falling. However, 87% students drew a human being in an orientation other than vertical (head-up) in the post-test. We conclude that the direction of gravitational force of the earth and its relation with the notion of ‘Up’ and ‘Down’ need to be addressed explicitly right from the beginning.

In the context of the coherent verses fragmented knowledge debate (Section 2.4) we found that students' mental models were fragmented. The relationships between different entities were unclear and were not always constant (5% diagrams were coherent and 1% were incoherent in the pre-test and, rest of the diagrams could not be judged for coherency because of absence of sufficient number of elements).

Before instruction students had not understood the causal relation between rotation of the earth and the apparent motion of the stars. The pattern of motion was also not clear to them, although many students (60%-66% in two questions) knew that the stars change their place overnight, and also through the year (68%). We were surprised to find that many (68%) students did not know that stars are present in the sky during daytime but are not seen because of sunlight (75%).

We found in the pre-tests, common alternative explanations consistent with those identified in the earlier literature (Section 2.1) such as, apparent motion of the sun in the sky (or occurrence of day-night) is due to revolution of the earth around the sun (22% &10% respectively for the two questions); and shadow of the earth fallen on the moon causes the phases of the moon (24%). These are robust alternative conceptions that remained persistent even after intervention.

Some advanced explanations such as appearance of the same face of the moon from the earth, and inconsistency between time periods of synodic and sidereal month, were absent before intervention, but about one third of the students could satisfactorily produce them after the intervention.

Many students could partially or correctly predict the observational consequences in hypothetical situations. In Test 4 when students were asked to predict what will happen if the earth stopped rotating, many (about two thirds) of the students from all three grades responded that day-night will not occur (more correctly, day-night will occur once in a year). However, only one fourth of the students gave partially correct responses related to the effect on apparent motion of the stars and the moon (stars and the moon will be seen at the same place). About 15% students after intervention gave a fully correct response (only the moon will appear to move).

Generally while explaining, and more often while predicting, students tended to guess the answers rather than approaching the problem through geometrical construction. For example, when students were asked to predict which stars a person in the given diagram would be able to see, before intervention they did not draw line of horizon and parallel rays from a star. During the intervention however there was a shift in the tendency to use diagrams for prediction.

In the post-intervention interviews, those students who could answer all of the questions satisfactorily (a rural girl, 2 rural boys and a tribal boy), were asked to predict some consequences in a hypothetical situation. These students could predict the seasons on a planet whose axis is in the plane of ecliptic, phases of the earth as seen from the moon, and how the earth and the sun will appear at the time of the solar and lunar eclipses.

7.4 Grade-wise comparisons

Grade 7 students' observations, knowledge of textbook facts and the sun-earth model (Tests 1, 2, and 4) was significantly better than that of the Grade 4 students (Test 3 on indigenous knowledge was not conducted on Grade 4). This indicates that students' observations improve and become more precise as they grow up. They accumulate information from textbooks and their conceptual understanding about the sun-earth system also improves. However, there is further scope for improvement. With respect to a few textbook facts, Grade 7 students performed worse than the grade 4 students. The total scores of Grade 7 students in all the tests improved after intervention (Gr8t > Gr7). The total scores of the treatment group in all the tests were significantly higher than the comparison group after intervention (Gr8t > Gr8c).

The scores of Grade 8 students in the comparison group were similar to the scores of Grade 7 students for the tests on textbook facts, indigenous knowledge and sun-earth model, which indicates that students' understanding of the sun-earth system does not improve much after Grade 7 (note that the Grade 8 textbook contains mostly explanation of phenomena related to the moon, the sun-earth system is dealt with up to Grade 7, but not in Grade 8). However, Grade 7 students from the treatment group turn to be better than Grade 8 students in the comparison group in terms of observations of daily phenomena (as seen from total scores on Test 1). One must admit the possibility that the observation skills of our treatment sample (though not obviously good) may have given them an advantage during the intervention, which the comparison group did not have.

Grade 8 students in the treatment group (Gr8-pre) performed better than the Grade 8 students in comparison group (Gr8c) on Test 5 on the moon, even before the instructions on moon were given. Recall that this test was conducted during the third part of intervention. This shows that students in the treatment group might have got advantage of the intervention while learning about the moon through their regular school curriculum, or were ready to try new problems and could answer some of them successfully.

7.5 Comparison between rural, tribal and urban samples

Scores of all four Grades (Gr4, Gr7, Gr8t and Gr8c) were collapsed to find mean scores of rural (R), tribal (T) and urban (U) samples for each test. Using the One Sample Kolmogorov-Smirnov test we found that (Appendix H):

1. For the rural sample the distributions of scores of Test 1, Test 4 (Q1-7) and Test 5 were not normal.

2. For the tribal sample distributions of scores on Test 4, Test 5 (Q2-9) and Test 5 were not normal.

3. For the urban sample distributions of scores for all the tests were normal.

The overall results from the pairwise comparison of means using the independent sample t-tests or Mann-Whitney tests as appropriate (Appendix H) are summarized in Table 7.24. The significant differences with the possible reasons are given here:

1. The tribal sample was better in terms of observations of daily astronomical phenomena than their rural and urban counterparts. The tribal schools were residential, with no nearby village for the treatment group (the comparison group did have a nearby village). Tribal students were mostly free in the evenings as opposed to rural and urban students which either had to work or had access to entertainment such as television. This might have resulted in tribal students observing the night sky together.

2. In overall comparison, we found that students from rural, tribal and urban samples knew textbook facts equally well. However, in Grade 4, urban students performed better than their rural and tribal counterpart and in Grade 8 (treatment group), urban students performed better than tribal students (in the test of textbook facts). Note that urban students have more access to communication media and are more exposed to modern science.

3. In general the rural students were more familiar with indigenous knowledge than were the urban and tribal students. In an informal discussion with rural students it came up that students' illiterate family members rely on students help to read and interpret the calendar to decide the timings of cultural practices.

On the other hand, during the course of the intervention we noted that these tribal students were living in a residential school and thus they probably had less contact with local cultural practices. Also their school functioned within a progressive framework which may have de-emphasized local practices in favor of modern ideas. Further these tribes originate from different parts of India, and it is possible that the astronomical knowledge of their various communities was slightly different from mainstream Maharashtrian indigenous astronomy. A separate study would be required to understand these influences. In the case of the urban students the explanation was more straightforward, as urbanization is known to reduce indigenous influences.

4. The differences between samples were not significant for the first seven questions of the Sun-Earth Model test (Test 4 as given to Grade 4 and Grade 7 before intervention). However, if we considered the complete test (given to Grade 8 treatment and comparison groups), the rural and urban samples performed better than their tribal counterparts. Similarly, Test 5 (The moon), which was completely based on advanced content, rural and urban samples performed better than their tribal counterparts (Table 7.24). Thus students from all three samples were equally competent with the basic knowledge, but the tribal students were less competent for the advance content. The social disadvantages suffered by tribal sample perhaps have a negative cumulative effect in the higher grades.

Table 7.24: Comparison between samples by collapsing Grades 4, 7, 8t & 8c (R: rural, T: tribal, U: urban)

Test	Statistics	Comparison
Test 1		T > (R, U)
	Means	(45.34) > (41.7, 38.35)
	N	87, 119, 72
Test 2		No difference (R, T, U)
	Means	(35.99, 37.02, 36.83)
	N	123, 85, 71
Test 3		R > (T, U)
	Means	(29.21) > (25.7, 22.52)
	N	92, 74, 26
Test 4		(R, U) > T
	Means	(41, 52.83) > (30.51)
	N	64, 9, 57
Test 5		(R, U) > T
	Means	(19.72, 24.56) > (13.09)
	N	59, 9, 65

7.6 Internal consistency

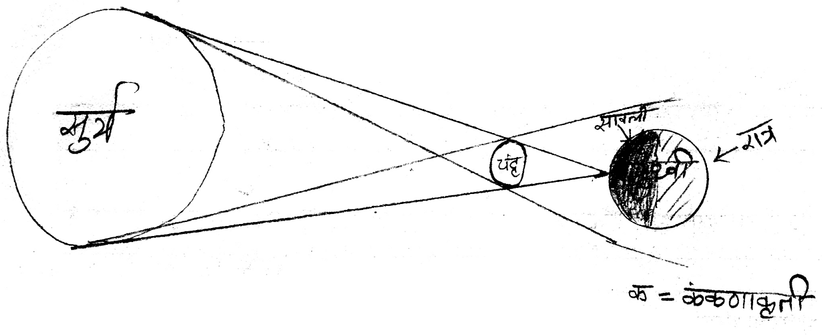
Since the coding of the questionnaire data was quite detailed and complex, inter-observer reliability was not feasible. We did check for consistency among students' responses. This consistency was seen more qualitatively than in terms of exact percentages.

For example, in Table 6.18 (Subsection 6.1.3): Two successive questions were asked to probe whether students know that the position of the stars changes overnight. The differences in the percentages for correct and incorrect responses ranged from 2% to 10% (except for Grade 8t).

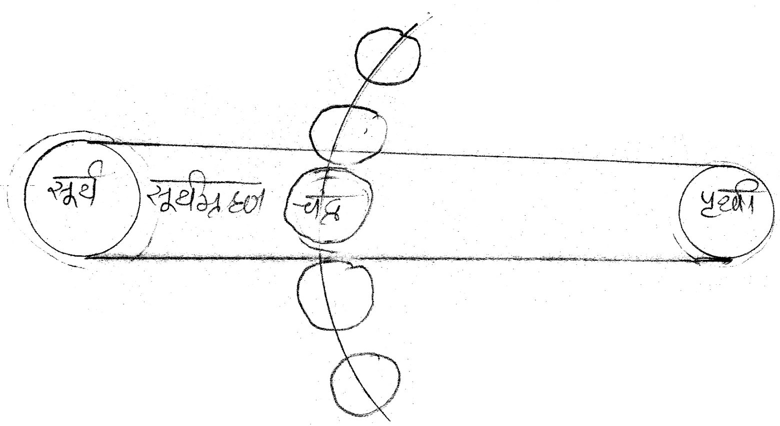
In Table 6.24 (Test 1: Subsection 6.1.4) & Table 7.17 (Test 5: Subsection 7.2.2): Students were asked to draw and name the observable phases of the moon. The pattern of most frequently drawn to least frequently drawn phases was similar.

Table 7.3 & Table 7.5 (both in Subsection 7.1.1): In two questions, students were asked to draw human beings and direction of rain in the diagram of the earth. Responses nos. 1, 2, 3 & 5 for placing human beings in Table 7.3 correspond to Response nos. 7, 5, 6, & 4 for drawing direction of rain in Table 7.5 which shows that students face similar difficulties in placing human beings and their environment on the earth and deciding 'Up-Down' directions on the earth.

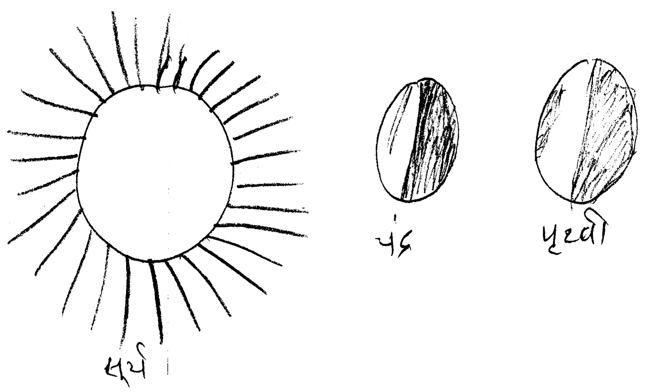
In future assessments we might more systematically build in questions for testing reliability and internal consistency of the tests.



(a) An example of a correct explanation of the solar eclipse by a Grade 8 (treatment group) rural boy

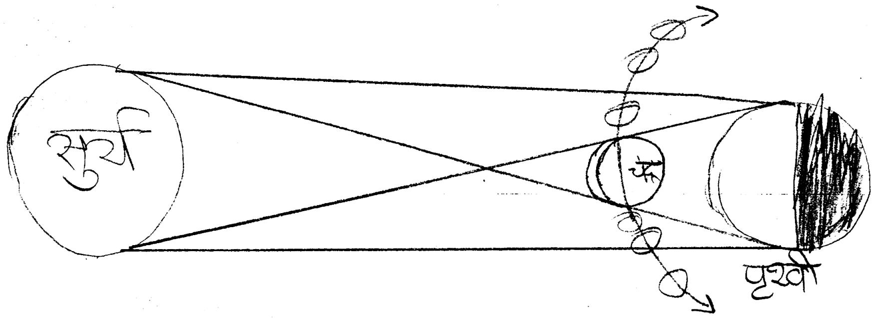


(b) The moon occulting the sun (parallel rays from the sun): Diagram by a Grade 8 (treatment group) rural boy



(c) Correct arrangement of the sun, moon and the earth, but no ray diagram: notice the shadow of the moon fallen on the earth: Grade 8 (treatment group) rural boy

Figure 7.19: Correct or partially correct responses for the explanation of the solar eclipse



(a) Incorrect ray diagrams: Grade 8 (comparison group) rural boy

(b) Partial, total and annular solar eclipse: A descriptive diagram by a Grade 8 (comparison group) rural girl

Figure 7.20: Incorrect responses for explanation of the solar eclipse (Figure b is a correct descriptive diagram; it is not explanatory.)

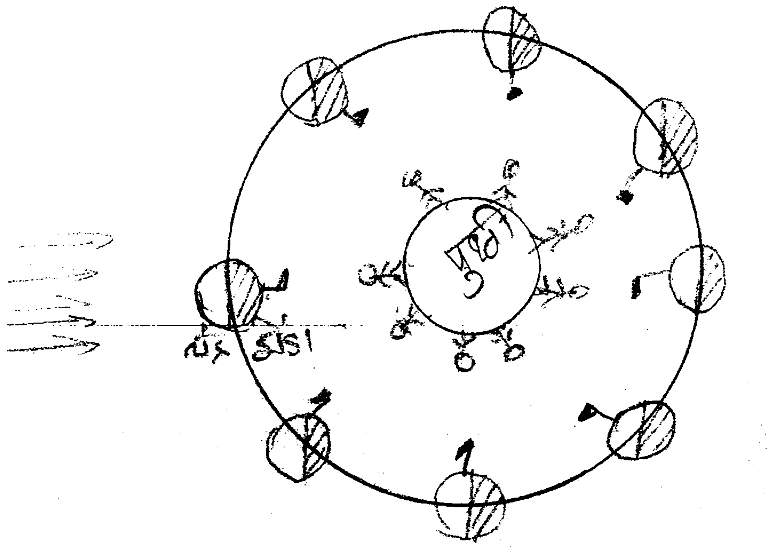
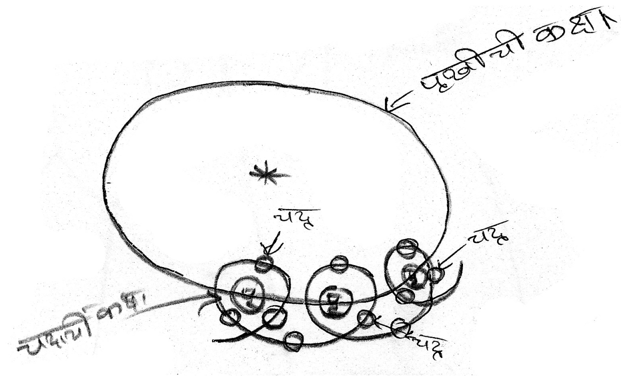
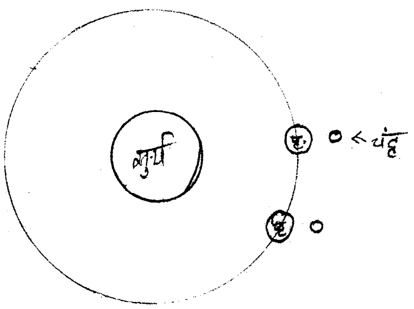


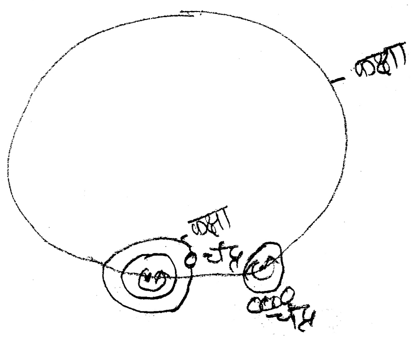
Figure 7.21: An example of a correct diagram to explain that the same face of the moon remains towards the earth: Grade 8 (treatment group) rural boy



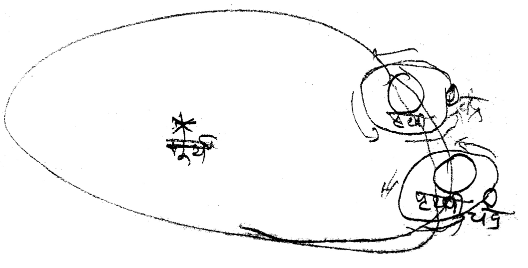
(a) Urban boy



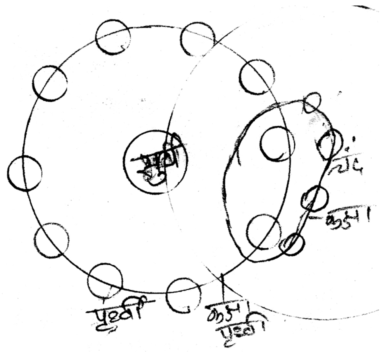
(b) Rural boy



(c) Tribal boy



(d) Tribal boy



(e) Rural boy

Figure 7.22: Students from the treatment group tried to explain the inconsistency between the synodic month (phase cycle) and the sidereal month with the help of a diagram, even though a diagram was not drawn during the intervention

Chapter 8

Conclusions

The thesis presents a study of spatial cognition and visualization in the context of elementary astronomy education. Its contribution lies at the interface between cognitive science and science education. The study developed through an intricate interplay between theoretical insights related to visualization and spatial cognition, data on students' understanding of astronomy, and a practitioner's reflections on her classroom practice.

In the first six sections of this Chapter we bring out the contributions of this thesis to science education research, development and practice. Then follow the limitations of the study (Section 8.7) and an outline of possible future directions (Section 8.8).

8.1 Bridging the gap between science education and visuospatial thinking

Science education research in the last 40 years has drawn insights and inspiration from several disciplines, including cognitive science and history of science. The conceptual change framework, discussed in Section 2.3, and the mental model framework, discussed in Section 2.4 are both examples of a cross-over from cognitive science and history of science into science education. Although such borrowing of ideas has often proven to be fruitful for science education, it has its limitations, as the priorities and methodological approaches of the various disciplines are fundamentally different. Cognitive psychologists in particular, might be inspired by basic philosophical questions about the nature and acquisition of knowledge, which they investigate by taking a bottom-up approach, to how knowledge is constructed in the laboratory. In contrast science education researchers examine students' ideas in their raw complexity, trying to disentangle their thinking processes on the one hand and their contexts of learning on the other.

The goal of science education is to enable students to learn a socially accepted body of scientific knowledge. We (science educationists) therefore begin from accepted knowledge and compare students' ideas with it. When this knowledge content becomes more involved and advanced, then borrowing insights from cognitive science to science education becomes more difficult. Learning and thinking about some specific visuospatial content in science for example, brings into play a whole range of complex cognitive considerations, from individual spatial abilities to sociocultural tools of learning. Given these challenges, this thesis has attempted, in a small way, to bridge the gap between research in visuospatial thinking and science education essentially through reflective classroom practice.

Visuospatial thinking is a comparatively less explored area in science education. Astronomical models incorporate significant spatial information and hence both visualization and spatial cognition play a role in learning astronomy. This thesis begins by juxtaposing the challenge of understanding astronomical space with known ideas from research in visuo-spatial thinking (Sections 1.2 & 1.3). It goes on to synthesise and extend research in astronomy education and visuospatial thinking in two ways:

1. By analysing difficulties in elementary astronomy related to visuospatial content.

2. By analysing spatial tools of general applicability in the context of elementary astronomy.

Results from both of these approaches are summarized in the next two sections.

8.2 Visuospatial content in elementary astronomy

Most of the research in astronomy education till date has been carried out within the conceptual change framework (Lelliott and Rollnick, 2009), (Chapter 2). Vosniadou and her colleagues incorporated into this research tradition another powerful framework from cognitive science, that of mental models (Vosniadou and Brewer, 1992, 1994; Samarapungavan et al., 1996). They studied young students' mental models about the earth and day-night, leading to a long debate among researchers on whether students' frameworks could be called 'mental models' or not (Section 2.4.1). In our research we did find (in support of the mental model skeptics) that relations among different entities were incorrect and sometimes absent among students (Section 5.3.3). However, if we grant, like Norman (1983) that mental models can often be incomplete and unscientific, then it is still appropriate to consider students' frameworks as mental models. Our task was then to help students transform their existing models to come close to the socially accepted model (consensus model, as termed by Gilbert and Boulter (1998)).

The research of Vosniadou and her colleagues on mental models in astronomy has an inherent limitation, in that the content of astronomy addressed is fairly basic. If you consider just day and night, its corresponding mental model (for example, the correct one, "the earth rotates around its axis") is quite close to the explanation. Only if you bring into consideration more specific events, like sunrise and sunset, and night time observations like visibility of stars, does the distinction between 'model' and 'explanation' become more apparent. Taking up slightly more advanced content such as phases of the moon and seasons, or an indigenous concept like 'starting of a *Nakshatra*', requires that the model under consideration be subjected to even more complex reasoning processes, before one can arrive at an explanation. Analysis of students' understanding in these contexts can fully employ the power of the mental model framework. Our results on students' learning and problem solving showed that simulating motion, and changing perspectives and frame of reference to draw inferences, were key difficulties in the area of visuospatial thinking (Subsections 4.3.3, 5.3.3). Lack of mastery over spatial tools was one identifiable barrier (Subsection 5.3.3, Chapters 6 & 7) which we tried to overcome. Some difficulties were more generic, such as, making fruitful assumptions (parallel ray approximation), and quantitative thinking (using diagrammatic-geometric reasoning) (Subsections 4.3.3). However these difficulties too in the case of astronomy relate to visuospatial abilities and skills.

8.3 Analysis of spatial tools

Models and diagrams are well known as educational tools and as tools for spatial cognition. Gestures are informally and sometimes inadvertently used by many good teachers, but their role in visualization and spatial cognition is only recently being realized.

We began this thesis with an evaluation of the literature on difficulties in understanding diagrams and analysis of diagrams used in the State textbooks (Section 1.4). Diagrams are commonly used in textbooks, but they are often descriptive rather than explanatory, are unconnected with text, sometimes confusingly use elements from multiple perspectives and do not incorporate information about dimensions (Section 1.4). Being static and two dimensional are inherent limitations of diagrams (Section 2.8). With these problems in mind, we designed a pedagogy which relied on spatial tools (Chapter 4). A rationale and specific suggestions for how to use these spatial tools are given in Chapter 5, which follow from the analysis of spatial tools used in our pedagogy. Some key points are revisited here.

8.3.1 Concrete models

Concrete models along with photographs present realistic details of a system, and hence form a good starting point to introduce any system. An important pedagogic exercise to be carried out at the outset is to have students list the differences between the concrete model and the real system which is being represented through that model.

8.3.2 Gestures

First we see how gestures and actions can be used in a systematic manner in combination with concrete models and diagrams. Then we recall some key results on spontaneous gestures produced by students during collaborative problem solving. Finally we compare the students' spontaneous gestures with the pre-designed gestures used in our intervention.

Designed pedagogical gestures

We have proposed that, just as we design models and diagrams for pedagogy, gestures too can be designed to convey and internalize concepts in science. The following two conjectures provided the rationale for design of gestures in our pedagogy for astronomy:

1. The 'phenomenon - gesture - mental model' link: Distance and time scales in astronomy being beyond direct perception, actions may provide the most accessible bridge from the phenomenon to the mental model. Both spatial as well as dynamic properties of a phenomenon or a scientific model can often be readily conveyed through gestures.

2. The 'concrete model - gesture - diagram' link: Gestures can be used along with concrete models to make these fluid, and with diagrams to add a third dimension. Both concrete models and diagrams can be made dynamic with the use of appropriate gestures. Out of the 40 gestures designed for instruction, 38 either followed concrete models, or were followed by diagrams, or both. Video clips showing all the designed pedagogic gestures are at http://web.gnowledge.org/pedagogic-gestures/

Although a good teacher may intuitively use some hand gestures or actions, like getting students to enact the solar system, such activities need to be designed and performed with specific motivation. We have shown that gestures can be used to achieve ownership of, and internalize patterns in, astronomical phenomena; to enact spatial properties of astronomical models or part of them; and to internalize space in general. In internalization of astronomical models, gestures give kinesthetic feedback to facilitate change of orientation and enable the visualization required in the process of change of reference frame from egocentric to allocentric. These are critical functions in the context of elementary astronomy education. Gestures are flexible and they do not make any permanent mark on space. Their role in the construction of a diagram may be akin to the role of speech in loud thinking before arriving at a well structured, written argument.

Students' spontaneous gestures

Students in our sample spontaneously used six main types of content-related gestures at an overall rate of about one gesture per minute. Along with the known categories of 'Deictic', 'Metaphoric' and 'Iconic' gestures, we found the need to construct a new category of 'Orientation change' gestures as part of instruction, and found that students too adopted this kind of gestures during collaborative problem solving, apparently as a tool for thought (rather than for communication). In the predominant category of deictic gestures, we found several that carried spatial content. These 'Deictic spatial' gestures communicate spatial properties such as length, orientation, direction, shape, etc.. The pointing in these gestures, when showing a proposed shape on the diagrams, appeared to support the hypothesis of gestures facilitating the 'mental model-diagram-phenomenon' link. In most cases, however, such linkages were difficult to detect.

The frequency of different kinds of students' spontaneous gestures varied across the sessions in accordance with the content of the problems which were to be solved in that session. These results, in conjunction with the literature cited in Chapter 2, underscore the role of gestures in communication and thought.

Students used a few gestures which they learnt during instruction, but their gestures were not an exact copy of the teacher's gestures. They also used many new gestures, especially metaphorical ones. A correspondence between the designed pedagogical gestures and students' spontaneous gestures was seen in the categories of 'Deictic spatial', 'Iconic' and 'Orientation change' gestures. Gestures that occurred spontaneously in the 'Metaphoric' category were simpler and less elaborate than the pedagogical gestures in the same category.

The discrete or "elementary" nature of students' gestures, as compared to the deliberately designed pedagogic gestures, may perhaps have been adequate to support their thinking in some of the problem-solving situations. In the pedagogic situation, in contrast, we do need to use fully elaborated gestures. We have also observed fairly elaborate spontaneous gestures in students of architecture during problem solving related to phases of the moon (Subramaniam and Padalkar, 2009). We feel that it would be good to develop this capability in school students too. On the other hand the students' elementary gestures may also suggest similar gestures for pedagogic use.

8.3.3 Pedagogic diagrams

Gestures played a pivotal role in our pedagogy and one of the main motivations to use them was to develop better understanding of diagrams among students. The pedagogy in that sense was essentially diagram centric and diagrams played a central role in assessing students' understanding. Diagrams in elementary astronomy represent either models, or phenomena, or explanations which relate models and phenomena, and each of these kinds of diagrams has certain distinct properties, as described in Subsection 5.3.2. We suggested four criteria for a diagram being pedagogically effective, and the last two of these were used to evaluate students' diagrams (Subsection 5.3.3).

Criteria for using diagrams effectively

Diagrams used in our pedagogy satisfied the following four criteria:

1. Integration with other spatial tools: Diagrams should be used in combination with other spatial tools such as concrete models and gestures, so as to overcome their limitations such as their two-dimensional, static and abstract nature.

2. Interactivity: Providing a skeletal diagram and eliciting individual and collaborative additions to it proved to be useful in learning and problem solving.

3. Transformability: Representing motion using conventions and using multiple perspectives makes diagrams more amenable to mental simulations and transformations. It again helps in overcoming the two-dimensional and static nature of diagrams.

4. Inclusion of explanatory elements: The reasoning process of a teacher becomes accessible to students through drawing of explanatory elements, perhaps similar to the process of writing intermediate steps in solving an equation. Such practices develop in students the habit of approaching a problem by reasoning rather than by guesswork. Also, since students' thinking gets reflected via explanatory elements, these elements can be used to assess students' diagrams and their reasoning. Elements which help define the local environment of an observer, and ray-diagrams, were found to be particularly useful in constructing explanations.

Students' diagrams

A general observation related to students' diagrams was that (like their textbook diagrams) they were descriptive rather than predictive or explanatory. Within such descriptive diagrams, many students could draw the required elements on the earth (equator, poles) and in the sun-earth-moon system (the sun, earth and the moon), but few could correctly show the axial and orbital motion. The number of diagrams which included motion increased after intervention, and students started to use more scientific conventions.

Students' diagrams were corrupt copies of textbook diagrams. Very few students before intervention (less than 5%) drew diagrams with coherent relationships between elements and maintaining a single perspective. Though this percentage increased significantly after the intervention, this still remained a major difficulty for students. Before intervention, students' diagrams lacked explanatory type of elements and elements representing motions. Their ray diagrams were drawn by guesswork. After intervention students started to draw more schematized diagrams in place of realistic picture-like representations and included more specific explanatory elements such as local directions and horizon in their diagrams.

8.4 Building a wholesome pedagogy

Although the focus of this study was on visuospatial thinking in astronomy, we found it natural to incorporate in our pedagogy other suggestions from astronomy education research.

Actual observations are pointed out as an essential component of astronomy (Section 2.1) and they were found to be equally important in the context of visuospatial thinking. Most of the astronomical observations in themselves have visual and spatial components and representing them using spatial tools and finding patterns in the relevant phenomena is further a spatially challenging task. In our pedagogy we developed ways to make such observations and analysis within the reach of students.

Several educationists have opined that collaboration should be part of any learning activity. For us, and our particular student samples, it was not only a component of learning, but was both a principle and practice of life. One of the strengths of our pedagogy was that collaborative ways of learning were inbuilt into it. Collaboration at three levels: teacher-students (in the classroom situation), among students (guided collaborative problem solving), and addressing shared understanding of the community to which students belong (use of sociocultural tools) helped to make students more active, and engaged (Chapter 4). Studies on collaborative learning usually focus on verbal discourse. However the tools that we describe, namely, concrete models, gesture and actions, and diagrams, can be used to first create collaborative situations, and then to study the process of collaboration. We encouraged use of these spatial tools in classroom activities and in collaborative problem solving, and also studied how students use these tools to collaborate.

Historically, astronomy was tied with astrology. In earlier studies, indigenous knowledge present among students was considered as a negative influence because of its association with superstitions. However, we used indigenous terms and phrases while teaching, incorporated their explanations into our pedagogy and used indigenous tools such as calendars for observations. This effort helped to bridge the gap between formal knowledge and out-of-school experiences. We hoped and expected that students would overcome their blind acceptance of astrology and associate its astronomical implications with reasoning and curiosity.

Our aim was to shift the focus of students' learning from acquisition of facts to constructing dynamic, coherent mental models and reasoning on the basis of these models. Our designed pedagogy appears to have been successful since scores on all five tests significantly improved after the intervention (Gr8t > Gr7) and the Grade 8 students from the treatment group performed significantly better than the Grade 8 students in the comparison group (Gr8t > Gr8c). Thus in all aspects, namely, observations, indigenous knowledge and understanding of the sun-earth-moon model the students improved after intervention. Intervention helped them towards constructing the accepted mental model of the sun-earth-moon system, as seen from improvements in their understanding of shapes, patterns of motions and quality of explanations, both verbal and diagrammatic. We believe that our pedagogy successfully addressed some of the important of these difficulties. The merits of the pedagogy are: it is multimodal, low-cost, culturally appropriate, flexible, and yet powerful in teaching some non-trivial content.

8.5 Significance of an under-represented student group

The study was carried out on an educationally disadvantaged sample. The three samples are different from each other but together they can be considered fairly representative of a large majority of students in India (Chapter 3). To conduct a study with such a sample the researcher has to contend with problems of transport, electrical shut-downs and other unforseeable obstacles. Therefore, not many researchers choose such a sample and hence such students are underrepresented in science education research. We believe that the data and experiences gained from these students will enrich our research base and will be particularly meaningful for curriculum designers and textbook writers. The sample-wise differences summarized in (Section 7.5) are interesting from this point of view. They bring out the particular strengths of tribal students (sky observations), rural students (indigenous knowledge) and urban students (textbook facts), and suggest that the social disadvantages suffered by the tribal students may have a cumulative effect in the higher grades. The overall results on these students' understanding in Chapters 6, 7 can be summarized as follows.

Students do observe several astronomical objects and events. However their observations are qualitative and relate to visual properties rather than spatial. The practice of systematic observations and their representation in different forms, such as tables, graphs and diagrams, needs to be cultivated among students. In school, although students learn many facts about astronomy, they fail to build consistent mental models. Sensitivity towards consistency for example, in depicting all the bodies in a diagram from the same perspective and in showing the correct spatial relationship between them, needs to be developed. Students' explanations of astronomical phenomena based on their models were erroneous and superficial. Understanding of dimensions (distances and sizes) and motions were areas of key difficulty. Careful efforts need to be taken to connect the formal and indigenous astronomy, while de-emphasizing and challenging the latter's related belief system and superstitions.

8.6 Contributions to methodology

Conjecture driven research design is as yet not among the common methodologies followed in science education research. Conjecture based design is situated in a classroom rather than a laboratory setting, and it aims at coming up with new widely applicable instructional strategies, while bridging the gap between research and practice of science education. We hope that the theoretical framework and the conjecture in this thesis will be useful for broad community of science education researchers and, at the same time, the pedagogy and material developed during the intervention will be directly useful for astronomy teachers. Often it is difficult for teachers and practitioners to translate research into practice. At times, findings from research are too abstract and hence vulnerable to misinterpretations. The thesis demonstrates in a modest way how results from research in visuospatial thinking and science education can be actualized in the classroom.

Adoption of a conjecture driven research design for science education turned out to be fruitful in providing important insights into the dynamics of teaching and learning. The content dealt with in this study, though routinely taught as a part of the school curriculum, was advanced in the sense of the cognitive capabilities required of students. Students needed a longer time and continuous scaffolding to assimilate the content and use it for reasoning. An intervention based on informed conjectures and continuous assessment was therefore necessary. Developing the conjecture with inputs from both data and theory was demanding but it has its rewards. We feel that conjecture driven research design needs to become more widely used in science education.

Scheme of analyzing gestures and diagrams

Since this study explored some unconventional ways of reasoning, the tools which were used for reasoning were also unconventional. Although gestures and diagrams are recognized to be important in science, research on their role in science reasoning and learning is currently almost non-existent. Available research on students diagrams and gestures is mostly domain general (Sections 2.7 & 2.8), i.e. not specific to any particular content area. Using some insights from earlier analyses we developed schemes for analyzing gestures and diagrams, which may serve also other content areas in science.

Specific gestures and diagrams vary according to the content being conveyed; they also vary from person to person and from time to time. Gestures and diagrams are flexible and have several qualitative aspects which makes it difficult to analyze them. Therefore, developing a useful scheme of analyzing content specific diagrams and gestures was a novel and challenging task. Here we found that the gesture-related research in cognitive psychology, which has considered spontaneous gestures, was inadequate for our purpose. In education, pedagogic and students' diagrams or gestures influence each other; therefore any scheme of analysis needs to address both of these and also their mutual influence. Our scheme of analysis has been useful in giving some insights into both pedagogic and students' gestures.

Our analysis of gestures was based on the purpose and cognitive functions that gestures play in a pedagogic context (Section 5.2). In the case of students' spontaneous gestures, measuring the frequencies of students gestures and relating them with the content is a new approach towards analyzing the gestures. Analysis of content-related diagrams, is also not common in science education. The specific criteria developed to describe and evaluate diagrams provided new and fairly generalizable parameters to analyze and score a diagram (Section 5.3).

8.7 Limitations of this study

The main limitation of the study is that verbal aspects of the pedagogy remained unexamined. We deliberately created situations in which the content was translated between different spatial tools (models, gestures and diagrams). In the classroom, since the diagrams were constructed in collaboration with students, 'diagram to verbal' and 'verbal to diagram' translations took place as a natural part of the intervention. These, however, were not the focus of our study. It might be interesting to study in detail these translations and also students' responses on text-diagram exercises such as describing a given diagram and drawing according to a given verbal description. For the analysis of the gestures too, verbal discourse would have been helpful to understand the exact meaning of the gestures and to gain access to students' arguments. The gesture-speech mismatch (discussed in Section 2.7) could also have been studied in that case. For reasons described in Section 5.2.2, this was not possible to do.

Another limitation is that we were not able to test inter-observer reliability in the case of assessment of astronomical knowledge and also in the coding of diagrams. This coding was very detailed (each kind and aspect of response was marked in a separate column), and another observer would have been needed to be involved in the entire process of teaching and developing the coding scheme. Because of the unavailability of such a person and limitation of time, the inter-observer reliability of scoring was not tested. However, we did find some evidence of internal consistency, by which we mean that, qualitatively the responses for similar questions in two different tests were comparable (Section 7.6).

In inquiry based learning the sequence 'Situation (or Observation) - Prediction - (Activity) - Description - Explanation' is recommended. Traditional textbooks usually do not take this interactive approach, but proceed with direct transmission of knowledge. Thus they typically assume that students have already made the observations and they begin with 'Description (of a model)' leading to 'Explanation of a phenomenon'. The important step of prediction, which helps students engage with the implications of their own intuitive ideas before being presented with the textbook model, is often missing. Predictions also enable students to play around with the model and its variants and to explore different aspects of these. A shortcoming that we noticed too late in the study was that questions which involved predictions in hypothetical situations were asked by us after explanations. We realized that students found these predictions easier than explanations even in hypothetical situations (e.g. what would happen if the earth stopped rotating). The reason might be that, in the simple cases of prediction that we are looking at, the relevant aspect of the model, based on which a prediction is to be made, is implicit in the question itself (in this case, it is the rotation of the earth), and one has to derive its consequences. Explanation on the other hand is a multi-step process. The phenomenon which is to be explained (for example, day-night) is known to some extent (though patterns in the phenomenon may not be fully known to begin with). Now one has to identify the correct aspect of the sun-earth model (i.e. rotation of the earth) and then build a (more or less elaborated) argument to explain the occurrence of the given phenomenon (in this case, day and night). Post-facto therefore we felt that predictions could have formed a stronger component of the intervention.

Most of the other limitations were related to lack of time. We attempted to teach almost the entire syllabus related to astronomy from Grade 3 to 8, in addition to some prerequisite content from mathematics and geography, in about 40 days spread across one year. Thus there were limitations to the content we could cover and the mastery we could expect from students. If the students had been competent with the earlier content, we could even perhaps have addressed advanced topics such as analemma, apparent motion of the planets and measuring distances of the stars by parallax method. All of these demand spatial thinking, and could be approached using our method of gestures and diagrams.

Often it was difficult for a single teacher to handle the whole class. This was particularly felt during guided collaborative problem solving, given that the students were not familiar with this style of working, and thus needed individual and group guidance. The teacher-researcher was helped in a few sessions by the thesis advisor and a local academic assistant (who usually handled the camera, but during problem solving sessions, the camera was fixed on the stand, and the academic assistant was free to help the students). The teacher has to ensure that such help is available, if this pedagogy is to be brought into practice.

8.8 Further directions

The proposed pedagogy may have several extensions. The pedagogy is fairly concrete at this stage so it can be directly used in textbook writing. With proper appropriation curriculum designers can use the two conjectures to design gestures, and the characteristics of diagrams proposed in the thesis to teach other branches of science which rely on spatio-temporal content. Teachers should be made aware of the potential of gestures and diagrams, and taught to use thoughtful gestures in classroom, to encourage students to use their body and gestures and to pay more attention to students' spontaneous gestures. They should also know how to use diagrams effectively. Therefore, use of effectiveness of gestures, diagrams and spatial tools in general should be part of teacher education. We hope that this thesis will help science educators and teachers appreciate the purposeful use of gestures in teaching. Interestingly, with appropriate modifications, the pedagogy may be found particularly useful for visually challenged students.

Astronomy is a subject which has popular appeal and it arouses the spontaneous interest of students. This study shows that elementary astronomy is an appropriate subject to expose students to the processes of scientific enquiry including reasoning and problem solving. The reasoning involved in elementary astronomy integrates several topics and in particular provides opportunities to develop visuospatial thinking, which is so far underutilized in science education.

We feel that the perspective of multimodality (Section 2.10) is particularly useful in science learning, for a number of reasons. At a fundamental level, the physical world exists in space and time, hence spatial and temporal cognition is essential and intrinsic to our understanding of physical world. Our vestibular sense provides the only way to experience acceleration, force and 'gravity', the most basic concept in astronomy, and this sensory mode needs to be used in pedagogy.

Experimentation is a component of scientific inquiry which, in its simplest form, uses the senses to understand manipulations of the world. In modern methods of experimentation, where the data are collected indirectly and often in digital form, it becomes useful to convert the data back into visual (graphs, computer simulations) or other sensory forms, in order to apprehend patterns in it. In science pedagogy as well it is important to exploit all the sense modalities. Finally, as argued earlier, for very large distance and time scales it might be possible to link the phenomenon and mental model through actions. Our approach serves to integrate the spatial and temporal aspects of the body-environment interaction.

Diagram-centered pedagogy is quite possible to be integrated into a normal classroom without the 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, both spontaneous and designed, to complement the diagrams, can also be integrated into the classroom discourse. Such a pedagogy provides opportunity for teachers from different disciplines such as, science, mathematics, geography, art and drawing, to collaborate, in order to help students integrate and strengthen knowledge from different areas.

This study may also hold implications for laboratory studies in cognitive psychology, which usually address fairly abstract and content-lean tasks, like mental rotation and scanning, or consider simple two-dimensional mechanical situations. Problems in complex domains and real-life classroom settings may provide useful insights for cognitive psychology. The potential of embodied cognition, multimodality and the study of gesture and diagrams needs to be explored in science education, particularly in areas requiring significant spatial cognition, for example, chemistry, biochemistry, developmental biology, geosciences, mechanics, optics, astronomy, crystallography, etc.. The link between concrete models, activities and experiments on the one hand and abstract science concepts on the other is likely to be facilitated through such embodied modes.

Appendix A

Pre-tests and Post-tests

For diagrams and illustrations in the translations please refer to the respective original Marathi versions of the test which follows the translations.

A.1 Test 1: Observation

A.1.1 English translation of test on Observations

Homi Bhabha Centre for Science Education
Astronomy Education Program

1. List all the things that are seen in the sky. Classify them in the following table.

Table A.1:

Things that are seen in daytime	Things that are seen in both day and night	Things that are seen in night

2 i. Have you seen sunrise? —-
ii. How does the sun look at the time of sunrise?
iii. From where have you see the sun rising? —

iv. What is the direction in which the sun rises? —
v. Does the place of sunrise remain same or changes over the year? —
vi. Does the time of sunrise remain same or changes over the year? —
vii. Have you seen sunset? —-
viii. From where have you see the sun setting? —
ix. What is the direction in which the sun sets? —
x. Does the place of sunset remain same or changes over the year? —
xi. Does the time of sunset remain same or changes over the year? —
xii. Write 3 differences between the setting sun and the sun at noon.
xiii Is the sun overhead every noon? —

Setting sun	Sun at noon

3. In every picture show:

- What is the time in the clock
- Where is the sun in the sky
- The shadow of the pole

a Morning (*Picture*)

b Noon (*Picture*)

c Evening (*Picture*)

d Night (*Picture*)

4 i. Have you seen planets in the sky?
ii. Name the planets which you have seen.

5. Write 3 differences between day and night **6.** Describe the stars which are seen in the night. Write their names if you know any.

Day	Night

7. Have you seen shooting star? How does it look?

8. Have you seen any of the constellations or zodiac signs in the sky?
Name those which you have seen.

9. The sky seen yesterday night at 10 O'clock from window of my house is shown in the following picture. (*Picture*)
i. Would the sky be same at 4 o'clock in dawn?
ii. Would the 3 stars be at the same position at 4 am?
iii. Would the sky look same everyday at 10 o'clock from my window?

10 i. Are there stars in sky in daytime?
ii. Have you seen stars in the sky at daytime?
iii. Explain your answer.

11 i. Do we see the moon every night in the sky?
ii. Have you seen the moon in the daytime? If you have seen it, draw its picture.
(*Space*)
iii. Does the shape of moon change every night or it remain same?
If it changes, draw the change over full cycle
iv. Name the direction in which the moon rises?
(*Space*)
v. Does the moon rises at same time every day or the rising time changes?
vi. Name the direction in which the moon sets?
vii. Does the moon set at the same time every day or does the setting time change?

12 i. What does 'horizon' mean?
ii. Where did you see the largest horizon from?

iii How was its shape?

Table A.2: Subsection numbers in Chapter 6 and corresponding Question numbers in Test 1 (Observation).

Analysis Subsection		Question Number
6.1.1	General observations	1, 12
6.1.2	Sun and Day-night	2, 3, 5
6.1.3	Planets, Stars, Constellations and other night sky objects	4, 6, 7, 8, 9, 10
6.1.4	The Moon	11

A.1.2 Original Marathi test on Observations

होमी भाभा विज्ञान शिक्षण केंद्र

(टाटा मूलभूत संशोधन संस्था)

वि. ना. पुरव मार्ग, मानखुर्द, मुंबई ४०००८८

खगोलशास्त्र शिक्षण उपक्रम

अंतिम परिक्षा १

नाव : **इयत्ता ८ वी**

शाळेचे नाव : **दिनांक :** /०८

१. आकाशात दिसणाऱ्या सर्व वस्तूंची खालील तक्त्यात यादी करा.

दिवसा दिसणाऱ्या वस्तू	दिवसा व रात्री दोन्ही वेळेस दिसणाऱ्या वस्तू	रात्री दिसणाऱ्या वस्तू

२i. तुम्ही सूर्योदय बघितला आहे का? ____

ii. सूर्योदयाच्या वेळी सूर्य कसा दिसतो?

iii. तुम्ही सूर्य कुठून उगवतांना पाहिला आहे?

iv. सूर्य उगवतो ती दिशा कोणती? ____

v. सूर्योदयाची वेळ रोज एकच असते की रोज बदलते? ____

vi. सूर्योदयाची जागा रोज एकच असते की रोज तिच्यात थोडा बदल होतो? ____

vii. तुम्ही सूर्यास्त बघितला आहे का? ____

viii.तुम्ही सूर्य कुठे मावळतांना पाहिला आहे?

ix. सूर्य मावळतो ती दिशा कोणती? ____

x. सूर्यास्ताची वेळ रोज एकच असते की रोज थोडी बदलते? ____

xi. सूर्यास्ताची जागा रोज एकच असते की रोज तिच्यात थोडा बदल होतो? ____

xii. सूर्यास्ताच्या वेळेचा सूर्य आणि भर दुपारचा सूर्य यांच्यातले ३ फरक लिहा.

सूर्यास्ताच्या वेळेचा सूर्य	भर दुपारचा सूर्य

xiii.रोज दुपारी सूर्य डोक्यावर येतो का? ____

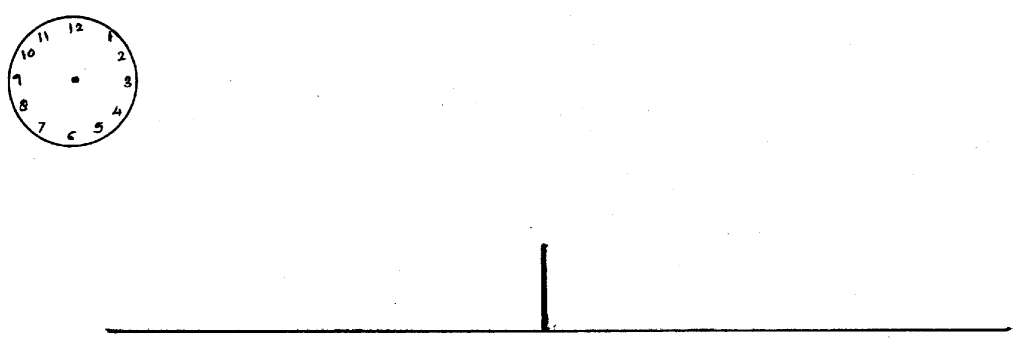
३. प्रत्येक चित्रात:

i. घड्याळात किती वाजले आहेत ते दाखवा.

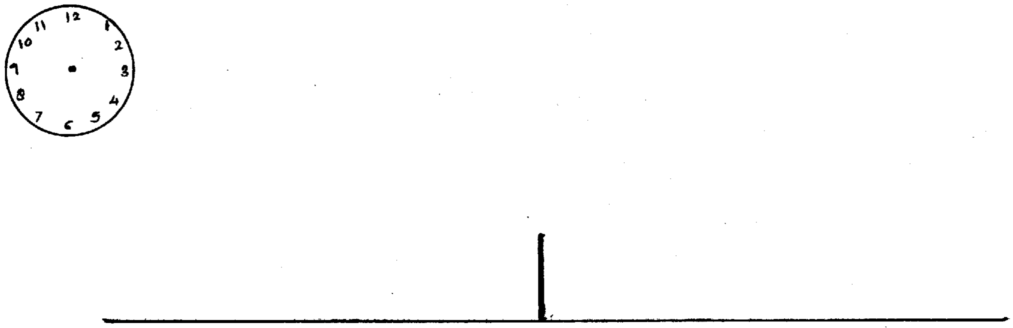
ii. आकाशात सूर्य कुठे आहे ते दाखवा.

iii. खांबाची सावली दाखवा.

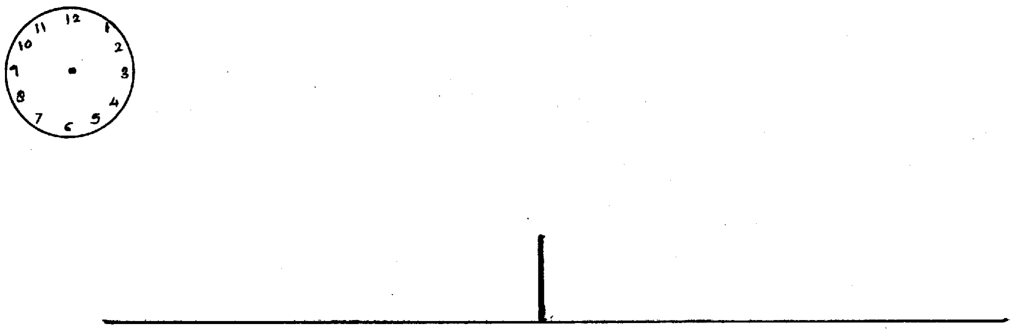
सकाळ



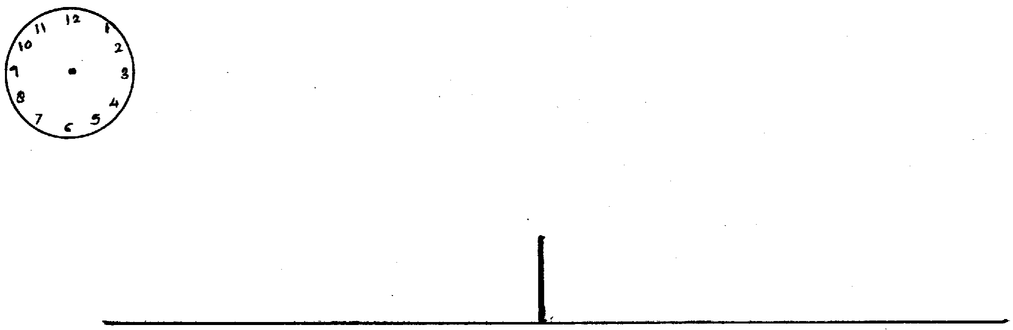
दुपार



संध्याकाळ



रात्र



४ i. तुम्ही आकाशात ग्रह पाहिले आहेत का? ____

ii. त्यांची नावे सांगा.

५. दिवस आणि रात्रीमधले ३ फरक लिहा:

दिवस	रात्र

६i. तुम्ही कधी आकाशातले तारे मोजले आहेत का? _______

६ii. आकाशात किती तारे दिसतात?

६iii. रात्री आकाशात दिसणाऱ्या ताऱ्यांचे वर्णन करा.

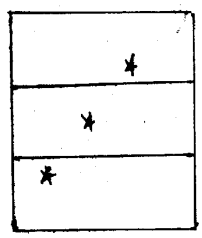
६iv. तुम्हाला ओळखता येणाऱ्या ताऱ्यांची नावे सांगा.

७. तुटता तारा तुम्ही पाहिला आहे का? _______
तुटता तारा कसा दिसतो?

८ i. आकाशातील निरनिराळी नक्षत्रे किंवा राशी तुम्ही पाहिल्या आहेत का? ___

ii. जे पाहिले आहेत त्यांची नावे लिहा.

९.   काल रात्री १० वाजता माझ्या घराच्या खिडकीतून दिसलेल्या आकाशाचे हे चित्र आहे.



i.   पहाटे ४ वाजता खिडकीतून असेच आकाश दिसेल का? ____

ii.   ३ तारे त्याच जागी असतील का? ____

iii.   एका महिन्यानंतर रात्री १० वाजता खिडकीतून असेच आकाश दिसेल का? ___

१०i. दिवसा तारे आकाशात असतात का? ____

ii.   तुम्ही कधी दिवसा आकाशात तारे बघितले आहेत का? ____

iii.   हो किंवा नाही उत्तराचे स्पष्टीकरण द्या.

११ i. रोज रात्री चंद्र आकाशात असतो का? ____

ii. तुम्ही दिवसा चंद्र बघितला आहे का?
बघितला असला तर त्याचे चित्र काढा.

iii. चंद्राचा आकार रोज सारखाच असतो की बदलतो? ___

iv. बदलत असेल तर कसा बदलतो ते चित्र काढून दाखवा. आकारांना नावे द्या.

iv. चंद्र उगवतो ती दिशा कुठली? ___

v. चंद्र रोज एकाच वेळी उगवतो की उगवण्याची वेळ रोज बदलते? ___

vi. चंद्र मावळतो ती दिशा कुठली? ___

vii. चंद्र मावळायची वेळ बदलते की रोज तीच असते? ___

१२ i. क्षितिज म्हणजे काय?

ii. सर्वात मोठे क्षितिज तुम्ही कुठून बघितले?

iii. त्याचा आकार कसा होता?

Shamin 29 Feb 2008

A.2 Test 2: Textbook Facts

A.2.1 English translation of test on Textbook Facts

Homi Bhabha Centre for Science Education
Astronomy Education Program

1. What do you mean by earth?

2. Match the pairs from 2 groups:

Earth	
Sun	Planet
Jupiter	Satellite
Pole Star	Star
Moon	
Sirius	

3. Fill in the blanks
i. Shape of the earth is —–.
(like egg, like ladu, like plate, like bowl)
ii. There are —– Planets in the solar system. iii. Their names are:

4. Draw a picture of the earth. Show the axis of rotation of earth in it. Also show the North Pole, the South Pole and the Equator in the same diagram and name it. (*Space*)

5. Does the earth move? —–
If yes, describe the motion of the earth.

6. How much time does the earth take to complete one rotation around its axis? —–

7. We know that the earth revolves around around the sun while rotating around its axis. Draw a diagram of the sun and the earth and show in it the earth's orbit of

revolution around the sun. In the same diagram show the moon and its orbit.
(*Space*).

8. How much time does the earth take to complete one revolution around the sun?
—–

9. How much time does the moon take to complete one revolution around the earth?
—–

10. Classify into luminous and non-luminous:
sun, earth, mirror, moon, electric bulb, flame, planets, fire-fly, stars

11. Order the following from the nearest to the farthest:
sun, moon, firing, Pole star

12. Order the following from the smallest to the largest:
Jupiter, sun, moon, earth, shooting star

Table A.3: Subsection numbers in Chapter 6 and corresponding Question numbers in the Test 2 (Textbook facts).

Analysis Subsection		Question Number
6.2.1	The earth	1, 3i, 4, 5, 6, 8
6.2.2	The solar system	2, 3ii, iii, 7
6.2.3	Terms related to astronomy	9
6.2.4	Sizes and distances	10, 11

A.2.2 Original Marathi test on Textbook Facts

होमी भाभा विज्ञान शिक्षण केंद्र

(टाटा मूलभूत संशोधन संस्था)

वि. ना. पुरव मार्ग, मानखुर्द, मुंबई ४०००८८

खगोलशास्त्र शिक्षण उपक्रम

अंतिम परीक्षा २

नाव: **इयत्ता ८ वी.**

शाळेचे नाव: **दिनांक**: /०८

१. पृथ्वी म्हणजे काय?

२. दोन गटातील शब्दांच्या जोड्या जुळवा:

i.	पृथ्वी	
ii.	सूर्य	ग्रह
iii.	गुरू	तारा
iv.	ध्रुव	उपग्रह
v.	चंद्र	
vi.	व्याध	

३. रिकाम्या जागा भरा:

i. पृथ्वीचा आकार _ _ _ _ _ _ _ _ _ _ आहे.
(थाळीसारखा, वाटीसारखा, लाडूसारखा, अंड्यासारखा)

ii. सूर्यमालेत _ _ _ _ _ _ _ ग्रह आहेत.

Iii. या ग्रहांची नावे आहेत :

४. i. पृथ्वी हालते का? _ _ _ _ _

ii. जर हालत असेल तर पृथ्वीच्या हालचालीचे वर्णन करा.

५. पृथ्वीचे चित्र काढा. त्यात पृथ्वीचा अक्ष दाखवा.
उत्तर ध्रुव, दक्षिण ध्रुव, विषुववृत्त काढून नावे द्या.
त्याच चित्रात पृथ्वी स्वतःभोवती फिरते हे दाखवा.

६. पृथ्वीला स्वतःभोवती एक फेरी पूर्ण करायला किती वेळ लागतो? _ _ _ _ _

७. पृथ्वी स्वतःभोवती फिरता फिरता सूर्याभोवती फिरते हे आपल्याला माहित आहे. एका चित्रात सूर्य आणि पृथ्वी काढून पृथ्वीची सूर्याभोवती फिरण्याची कक्षा दाखवा. त्याच आकृतीत चंद्र दाखवून चंद्राची कक्षा दाखवा.

८. पृथ्वीला सूर्याभोवती एक फेरी पूर्ण करायला किती वेळ लागतो?

९. स्वयंप्रकाशी आणि परप्रकाशी अशा २ गटांमध्ये वर्गीकरण करा:
सूर्य, पृथ्वी, आरसा, बल्ब, ग्रह, दिव्याची ज्योत, काजवा, तारे, ढग, चंद्र

स्वयंप्रकाशी	परप्रकाशी

१०. अंतरानुसार क्रम लावा: पृथ्वीच्या जवळ असणाऱ्या वस्तू आधी आणि लांब असणाऱ्या वस्तू नंतर या क्रमाने लिहा.
सूर्य, चंद्र, वीज, ध्रुवतारा

११. लहान-मोठेपणानुसार क्रम लावा: आधी लहान आणि नंतर मोठ्या वस्तू लिहा.
गुरू, सूर्य, चंद्र, पृथ्वी, तुटता तारा

A.3 Test 3: Indigenous Knowledge

A.3.1 English translation of test on Indigenous Knowledge

1 i. Name some festivals that we celebrate on full moon day
ii. Name some festivals that we celebrate on new moon day
iii. Name some festivals that we celebrate on *Dwitiya*.
iv. Name some festivals that we celebrate on *Chaturthi*.
v. Name some festivals that we celebrate on *Panchami*.
vi. Name some festivals that we celebrate on *Ashtami*.
vii. Name some festivals that we celebrate on *Dashami*.
Draw the shape of the moon on these days.
2. Write the names of Marathi months.
3. Write the names of *Nakshtras* that you know.
4. Write the names of zodiac signs that you know.
5. Have you heard the phrase *starting of a Nakshatra*? What does it mean?
6. Have you heard that the sun is entering in certain constellation? what does that mean?
7. What does it mean when we say that somebody is born under a certain zodiac sign?
8. Do zodiac signs, constellations, planets and shooting stars affect human life? If yes, how do they affect?

Table A.4: Subsection numbers in Chapter 6 and corresponding Question numbers in Test 3 (Indigenous knowledge).

Analysis Subsection		Question Number
6.3.1	Festivals and Phases of the Moon	1
6.3.2	Naming the examples (names) of terms	2, 3, 4
6.3.3	Familiarity with terms and their Meaning	5, 6, 7
6.3.4	Scientific Attitude	8

A.3.2 Original Marathi test on Indigenous Knowledge

होमी भाभा विज्ञान शिक्षण केंद्र

(टाटा मूलभूत संशोधन संस्था)

वि. ना. पुरव मार्ग, मानखुर्द, मुंबई ४०००८८

खगोलशास्त्र शिक्षण उपक्रम

अंतिम परीक्षा ३

नाव : **इयत्ता ८ वी**

शाळेचे नाव : **दिनांक : ०८**

१i. पौर्णिमेला साजऱ्या करण्यात येणाऱ्या सणांची नावे लिहा.

ii. आमावास्येला साजऱ्या करण्यात येणाऱ्या सणांची नावे लिहा.

iii. द्वितीयेला साजऱ्या करण्यात येणाऱ्या सणांची नावे लिहा.

iv. चतुर्थीला साजऱ्या करण्यात येणाऱ्या सणांची नावे लिहा.

v. पंचमीला साजऱ्या करण्यात येणाऱ्या सणांची नावे लिहा.

vi. अष्टमीला साजऱ्या करण्यात येणाऱ्या सणांची नावे लिहा.

vii. दशमीला साजऱ्या करण्यात येणाऱ्या सणांची नावे लिहा.

प्रत्येक तिथी (दिवशी) च्या चंद्राचे चित्र काढा.

२. मराठी महिन्यांची नावे लिहा.

३. तुम्हाला माहित असलेल्या नक्षत्रांची नावे लिहा.

४. तुम्हाला माहित असलेल्या राशींची नावे लिहा.

५. 'नक्षत्र लागणे' हा वाक्-प्रचार तुम्ही ऐकला आहे का? त्याचा अर्थ काय?

६. 'सूर्य अमुक नक्षत्रात प्रवेश करतो' असे तुम्ही कधी ऐकले आहे का? त्याचा अर्थ काय?

७. एखाद्याचा जन्म अमुक राशीत झाला म्हणजे काय?

८. राशी, नक्षत्र, ग्रह, तुटते तारे यांचा माणसांच्या आयुष्यावर परिणाम होतो का? होत असेल तर काय परिणाम होतो?

A.4 Test 4: The Sun-Earth Model

A.4.1 English translation of test on The Sun-Earth Model

1. If you are convinced the the earth is spherical, give 3 convincing reasons to believe that the earth is spherical.

2. Daw a picture of the earth. Draw pictures of small human beings ( ) to show the where on the earth human beings live.

(*Space*)

3. Draw one more diagram of the earth and show the direction of rain falling on every place on the circumference of the diagram.

(*Space*)

4a. Why does the sun appear to be moving?

b. Where is the sun at the night

(*Space*)

5. Draw a diagram and explain how day and night occur.

(*Space*)

6. If the earth stops rotating around its axis, what will happen?

7. What changes will take place in the motion of the sun, the moon, stars if the earth stops rotating around its axis?

8. Draw a diagram of the earth and its orbit as seen from above the North pole. Show the position of the sun in the diagram. Hash using tilted lines [///] the parts on the earth which are in the night.

(*Space*)

9. Draw a diagram of the earth if it is seen from exactly in the plane of the equator. Draw the axis of rotation of the earth and the equator. Draw a person ( ) on equator.

(*Space*)

Draw a line of horizon for that person. Show ‘Up’, ‘Down’, ‘North’ and ‘South’ directions for that person. At what angle would a person standing on the equator see the Pole Star?

10. Why do we have summer and winter in India? Explain with the help of a diagram.

(*Space*)

11. Answer the questions using the given diagrams.

(a) (*Diagram*)

i. Name the stars which person X would be able to see?

ii. Where would person X see the Polestar?

iii. Where would the person X come after 12 hours due to Rotation of the earth?

(b) (*Diagram*)

i. Which Marathi month is going on on the earth?

ii. Which *Nakshatra* would people on the earth see (overhead) at the midnight?

iii. In which *Nakshatra* is the sun?

(c) (*Diagram*)

i. Is the sun exactly overhead for a person on the equator?

ii. If not, the sun is in which direction of zenith?

iii. Person i which hemisohere would have sun overhead?

iv. Which season is going on in the South hemisphere?

* The pre-test contains Questions 1 to 7. The post-test contains all the questions.

Table A.5: Subsection numbers in Chapter 7 and corresponding Question numbers in Test 4 (The sun-earth model).

Analysis Subsection		Question Number
7.1.1	Round earth + Gravity	1, 2, 3
7.1.2	The rotating earth	4, 5, 6, 7, 9, 11.1
7.1.3	Revolution of the earth	8, 10, 11.2, 11.3

A.4.2 Original Marathi test on The Sun-Earth Model

होमी भाभा विज्ञान शिक्षण केंद्र

(टाटा मूलभूत संशोधन संस्था)

वि. ना. पुरव मार्ग, मानखुर्द, मुंबई ४०००८८

खगोलशास्त्र शिक्षण उपक्रम

अंतिम परीक्षा ४

नाव : **इयत्ता ८ वी**

शाळेचे नाव : **दिनांक :** ०८

१. पृथ्वी गोळ्यासारखी गोल आहे हे जर तुम्हाला पटले असेल तर ते पटवून देणारी ३ कारणे लिहा.

२. पृथ्वीची आकृती काढून तिच्यावर माणसे कुठे रहातात ते माणसांची छोटी चित्रे ( ) काढून दाखवा.

त्यापैकी दोन माणसांच्या क्षितिजाच्या रेषा काढा. दोन्ही माणसांच्या वर आणि खाली या दिशा दाखवा.

३. पृथ्वीची अजून एक आकृती काढा. तिच्या परीघावर प्रत्येक ठिकाणी पाऊस कसा पडत असेल त्याची दिशा दाखवा.

४. सूर्य हालतांना का दिसतो?
रात्री सूर्य कुठे असतो?

५. आकृती काढून दिवस-रात्र कसे होतात ते समजाऊन सांगा.

६. पृथ्वी स्वतःभोवती फिरायची थांबली तर काय होइल?

७. पृथ्वी स्वतःच्या अक्षाभोवती फिरायची थांबली तर सूर्य, चंद्र, तारे यांच्या हालण्यात काय फरक होइल?

८. उत्तर ध्रुवाकडून बघताना पृथ्वी आणि तिची कक्षा कशी दिसेल ते दाखवणारी आकृती काढा. आकृतीमध्ये सूर्य कुठे आहे ते दाखवा. पृथ्वीचा अक्ष दाखवा. पृथ्वीवर ज्या भागात रात्र आहे त्या भागात तिरक्या रेषा [///] मारा.

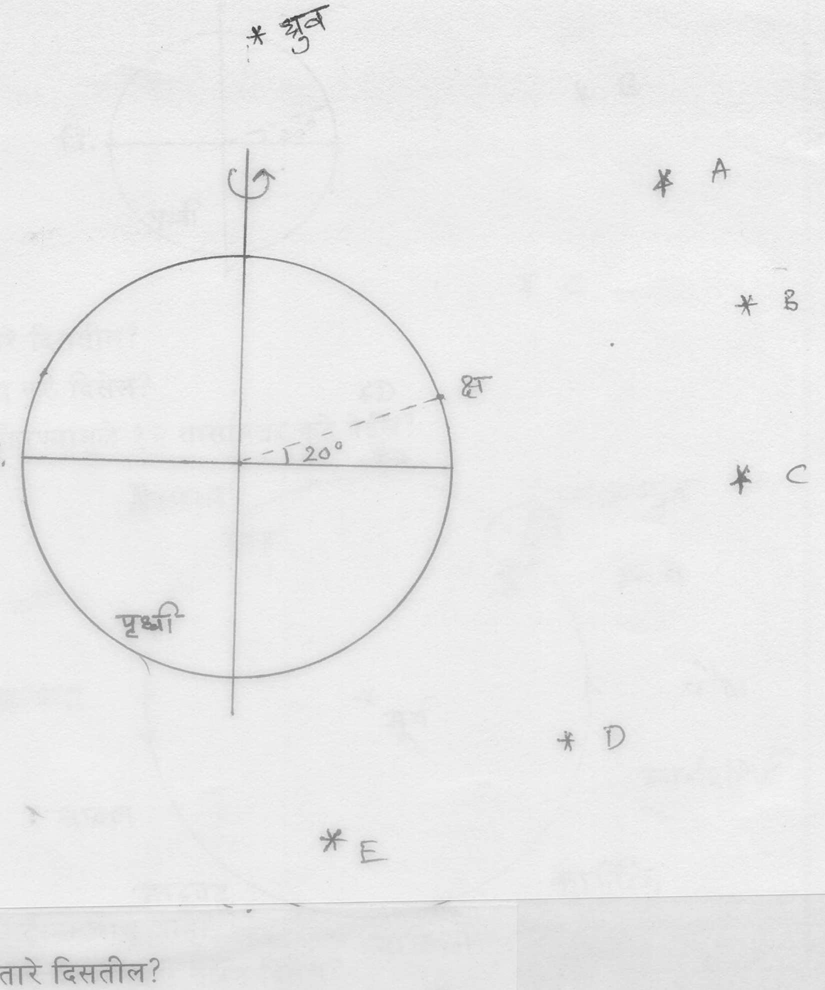
९. बरोब्बर विषुववृत्ताच्या बाजूने बघताना पृथ्वी कशी दिसेल त्याची आकृती काढा. पृथ्वीच्या फिरण्याचा अक्ष आणि विषुववृत्त काढा. विषुववृत्तावर एक माणूस (♀) काढा.

त्या माणसाची क्षितीजाची रेषा काढा. माणसाची वरची, खालची, उत्तर आणि दक्षिण दिशा दाखवा. विषुववृत्तावर उभ्या राहिलेल्या या माणसाला ध्रुव तारा किती अंशांवर दिसेल?

१०. भारतात उन्हाळा आणि हिवाळा का होतात हे आकृतीच्या मदतीने समजावून सांगा.

११. खालील आकृत्यांवरून विचारलेल्या प्रश्नांची उत्तरे लिहा:

1.

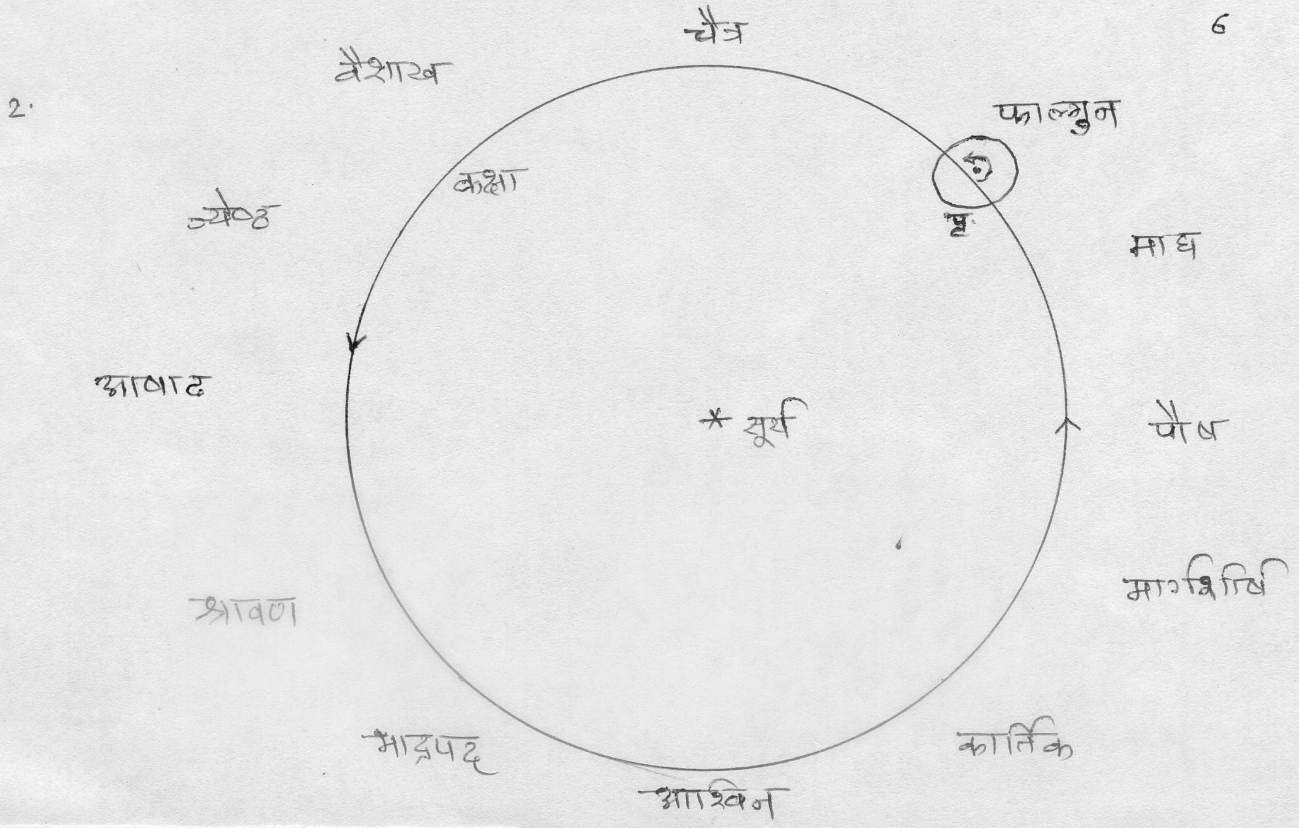


i. क्ष या व्यक्तीला कुठले तारे दिसतील?

ii. क्ष या व्यक्तीला ध्रुव तारा कुठे दिसेल? (दिशा, अंश)

iii. क्ष ही व्यक्ती पृथ्वीच्या फिरण्यामुळे १२ तासांनंतर कुठे येईल?

2.

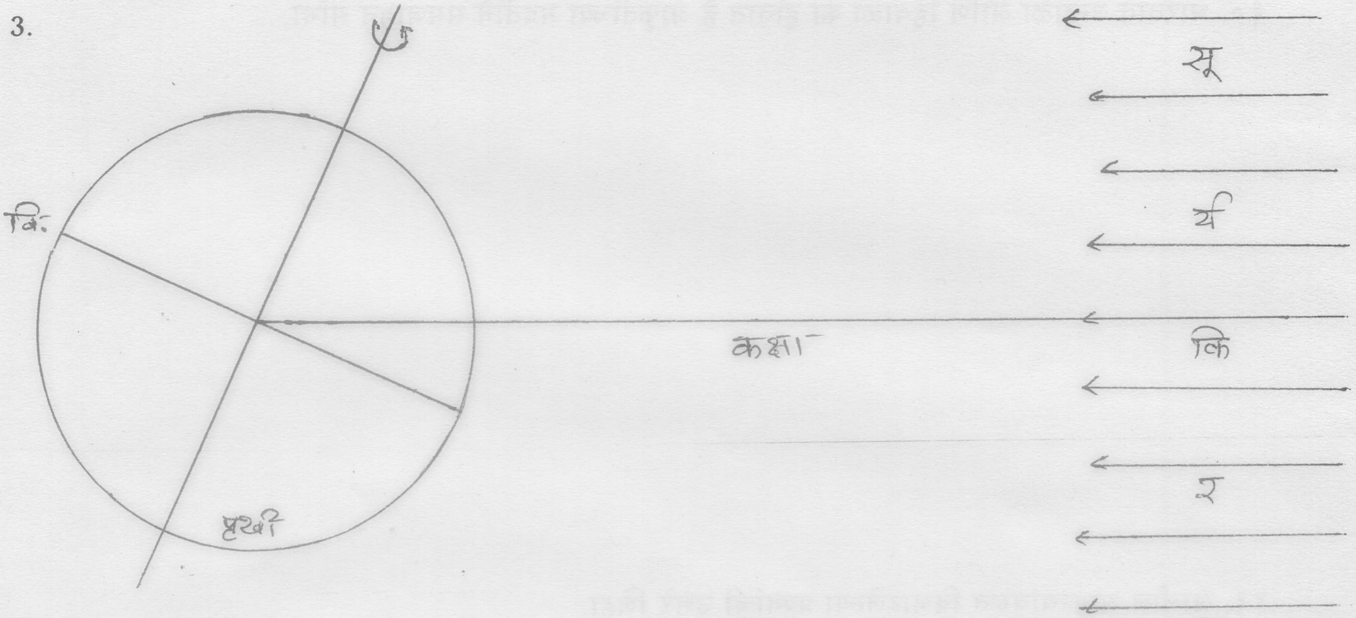


i. पृथ्वीवर कुठला मराठी महीना चालू आहे?

ii. पृथ्वीवरच्या माणसांना मध्यरात्री कुठले नक्षत्र दिसेल?

iii. सूर्य कुठल्या नक्षत्रात आहे?

3.



i. सूर्य विषुववृत्तावरील माणसाच्या बरोब्बर डोक्यावर आहे का?

ii. नसेल तर डोक्याच्या कुठल्या दिशेला आहे?

iii. भर दुपारी कुठल्या गोलार्धातिल माणसाच्या डोक्यावर सूर्य येईल?

iv. दक्षिण गोलार्धात कुठला ऋतू सुरू आहे?

Shamin 29 Feb 2008

A.5 Test 5: The Moon

A.5.1 English translation of test on The Moon

Homi Bhabha Centre for Science Education
Astronomy Education Program

1. Prove that the earth is round using following observations.
i) A photograph of the earth taking from the space-ship.
ii) Lunar eclipse.
iii) The difference in the stars if one goes far away towards north or south.
iv) A ship in the sea approaching the coast.
v) (Other)

2. What is the shape of the moon?

3. You know that the shape of the moon appears to be changing everyday. This is called 'phases of the moon'. Draw and explain how the shape of the moon changes everyday.
Name the phases.

4 i. How many days are there between two (consecutive) full moons?
ii. How many days are there between two (consecutive) *Chaturthis* (4th day either from Full moon or from New moon)?
iii. How many days are there between two (consecutive) half moons?
(*Space*)

5. With the help of diagram explain why do we have phases of moon.
(*Space*)

6. Explain with the help of diagram how does the lunar eclipse occurs. Write the information about the lunar eclipse.
(*Space*)

7. Explain with the help of diagram how does the solar eclipse occurs. Write the information about the solar eclipse.
(*Space*)

8. We can sea only one face of the moon from the earth. What should be the time period of rotation and revolution of the moon so that this happens. Explain your answer with the help of diagram.
(*Space*)

9. The time period of revolution of the moon is of 27 days. But to see the moon at same place at the same time again from the earth, it takes 29 days. Why does this happens?
(*Space*)

* The pre-test does not contain question 1. The post-test contains all the questions.

Table A.6: Subsection numbers in Chapter 7 and corresponding Question numbers in Test 5 (The moon).

Analysis Subsection		Question Number
7.2.1	The spherical earth	1
7.2.2	Factual information and observations about the moon	2, 3, 4
7.2.3	Explanations of phenomena related to the moon	5, 6, 7, 8, 9

A.5.2 Original Marathi test on The Moon

होमी भाभा विज्ञान शिक्षण केंद्र

(टाटा मूलभूत संशोधन संस्था)

वि. ना. पुरव मार्ग, मानखुर्द, मुंबई ४०००८८

खगोलशास्त्र शिक्षण उपक्रम

अंतिम परीक्षा ५

नाव: **इयत्ता ८ वी.**

शाळेचे नाव: **दिनांक**:

१) खालील निरिक्षणे वापरून पृथ्वी गोल आहे हे सिद्ध करा:

1. पृथ्वीचा यानातून काढलेला फोटो.

2. चंद्रग्रहण.

3. पृथ्वीवर उत्तरेला किंवा दक्षिणेला लांबपर्यंत चालत गेल्याने ताऱ्यांमध्ये होणारा फरक.

4. समुद्रातून किनाऱ्याकडे येणारे जहाज.

5.

२) चंद्राचा आकार कसा आहे?

३) चंद्राचा आकार रोज बदलल्यासारखा दिसतो हे तुम्हाला माहीत आहे. यालाच आपण चंद्रकला म्हणतो. रोज आकार कसा बदलतो त्याचे (चंद्रकलांचे) चित्र काढून वर्णन करा.
आकृतीच्या खाली तुम्हाला माहीत असणाऱ्या कलांची नावे लिहा.

४ i) दोन पौर्णिमांमध्ये किती दिवसांचे अंतर असते? _________

४ ii) दोन चतुर्थींमध्ये किती दिवसांचे अंतर असते? _________

४ iii) दोन अष्टमींमध्ये किती दिवसांचे अंतर असते? _________

(3)

५) चंद्रकला कशामुळे होतात ते आकृती काढून समजावून सांगा.

(4)

६) चंद्रग्रहण कशामुळे होते ते आकृती काढून समजावून सांगा. चंद्रग्रहणाविषयी तुम्हाला काय काय माहिती आहे ते लिहा.

(5)

७) सूर्यग्रहण कशामुळे होते ते आकृती काढून समजावून सांगा. सूर्यग्रहणाविषयी तुम्हाला काय काय माहिती आहे ते लिहा.

८) पृथ्वीवरून चंद्राचा कायम एकच गोलार्ध दिसतो. असे होण्यासाठी चंद्राचा परिभ्रमण काळ व परिवलन काळ कसा असला पाहिजे? तुमचे उत्तर आकृती काढून समजावून सांगा.

९) चंद्राचा परिभ्रमण काळ २७ दिवस आहे. पण पृथ्वीवरून चंद्र पुन्हा त्याच वेळी, त्याच ठिकाणी दिसण्यासाठी २९ दिवस लागतात. असे का होत असेल?

Appendix B

Pedagogic Questionnaires for Guided Collaborative Problem Solving

Table B.1: Subsection numbers in Chapter 6 and corresponding Questionnaire numbers in 'Guided Collaborative Problem Solving'.

Analysis Subsection		Questionnaire Number
6.1	Parallel Rays: Parallel ray approximation for a distant light source	1, 2
6.2	Shadows: Correlating shadows with angles of elevation of a light source	3, 4
6.3	Rotating Earth: Correlating global cues with local directions and angles of elevations; time differences	5, 6, 7, 8
6.4	Star-month: Observed night sky *Nakshatra* and indigenous calendar	9
6.5	Seasons: Day-night and north-south elevations of the sun during solstices and equinoxes	10

Annotated translations of problem situations used in five sessions of guided collaborative problem solving are given next. For diagrams and illustrations in the translations please refer to the respective original Marathi versions of the test which follows the translations.

B.1 Session 1: Parallel rays

Parallel ray approximation for a distant light source.

B.1.1 English translations of pedagogic questionnaires

Homi Bhabha Centre for Science Education
Astronomy Education Program

Questionnaire 1: Measurement of angles between successively less divergent lines leading to parallel lines
Measure the angle between the given pair of lines and write the measure of the angle:
(Diagram: Four pairs of lines (a, b, c, d) subtending successively decreasing angles; case d being that of parallel lines)

Questionnaire 2: Drawing rays from the sun at increasingly larger distances to notice almost parallel nature of rays near the earth
A picture of the sun is given below. Dray the rays for this sun:
Pictures of the sun and the earth are given below. In each picture draw sun-rays going in all directions. Then colour only those rays which fall on the earth.
Write the measure of the maximum angle between the coloured rays in each diagram.
(Diagram: Three figures (a, b, c) with successively increasing distance between the sun and the earth)
Does the maximum angle between the rays increase or decrease on increasing the distance between the sun and the earth?
The actual distance between the sun and the earth is several times larger than shown. If we draw the sun and the earth at the distance they really are, what would be the angle between the rays?

B.1.2 Original Marathi pedagogic questionnaires

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(टाटा मूलभूत संशोधन संस्था)

वि. ना. पुरव मार्ग, मानखुर्द, मुंबई ४०००८८

खगोलशास्त्र शिक्षण उपक्रम

प्रश्न-संच - १

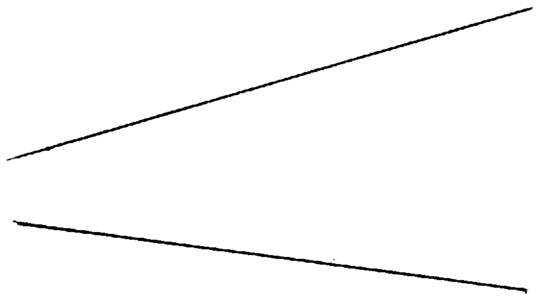
ऑगस्ट २००७

नाव: **इयत्ता ८ वी.**

शाळेचे नाव: **दिनांक:**

१) खालील रेषाममधील कोन मोजून कोनाचे माप लिहा:

a)



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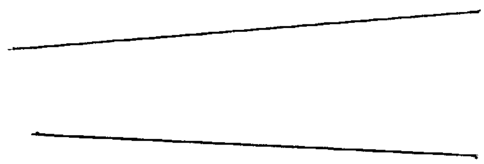
b)



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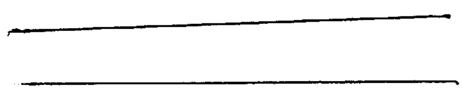
c)



d)

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खगोलशास्त्र शिक्षण उपक्रम

प्रश्न-संच - २

ऑगस्ट २००७

नाव: **इयत्ता ८ वी.**

शाळेचे नाव: **दिनांक:**

खाली सूर्याचे चित्र दिले आहे. या सूर्याची किरणे काढा:

खाली सूर्य आणि पृथ्वी यांची चित्रे दिली आहेत. प्रत्येक चित्रात पहिल्यांदा सूर्याची सर्व दिशांना जाणारी सूर्याची किरणे काढा. मग त्यातली पृथ्वीवर पडणारी किरणे रंगीत पेन्सिलीने ठळक करा.

प्रत्यक आकृतीत रंगीत किरणांमधला जास्तीत जास्त कोन किती अंशाचा आहे ते मोजून लिहा.

a)

b)

c)

सूर्य आणि पृथ्वी मधले अंतर वाढल्यावर किरणांमधला कोन वाढत गेला की कमी होत गेला?

सूर्य आणि पृथ्वी मधील खरे अंतर अजून अनेक पटींनी जास्त आहे. जर खरोखर तितक्या अंतरावर सूर्य आणि पृथ्वी काढली तर किरणांमधला कोन किती अंशाचा होइल?

B.2 Session 2: Shadows

Correlating shadows with angles of elevation of a light source.

B.2.1 English translations of pedagogic questionnaires

Questionnaire 3: Shadows cast by parallel rays of light at different inclinations to the ground or earth

1. Two sticks erected on the ground are shown in the following picture. The direction of sun-rays has also been shown.
Draw the shadow of the first stick.
Now draw more sun-rays. (Remember; the sun-rays falling on the earth are parallel.)
Now draw the shadow of the second stick.
(Diagram: Two sticks erected on the ground)

2. Now the two sticks are erected on a slope. The direction of the sun-rays is shown. Now draw the shadows of these two sticks.
(Diagram: Two sticks erected on the slope of ground)

3. Similar two sticks are erected at two different positions on the earth. Now, if the direction of sun-rays is as shown in the picture, draw shadows of both the sticks.
(Diagram: Two sticks erected at two different positions on the earth separated by a longitudinal angle of $80°$*)*

Questionnaire 4: Drawing angle of elevation of a point or parallel ray source at different inclinations to the ground or the earth

1. Two friends, Bimm and Kimm are shown in the picture below. The shadow of Bimm in the morning sun-light is shown in the diagram. Draw the shadow of Kimm at the same time.
(Diagram: Two boys standing on the ground and shadow of one of them)

2. There is a lamp-post between two of them. Draw the shadows of Bimm and

Kimm due to the lamp at night. Draw shadows at night in the same diagram by using coloured pencil.
(Diagram: Two boys standing on the ground and a lamppost in the middle)

3. Kimm sees the star Sirius at 40° as shaown in the diagram. Draw at what angle Kimm would see the star Sirius.
(Diagram: Two boys standing on ground and a ray from Sirius at an angle of 40° *above horizon)*

4. After few days Kimm went to another place to live. The positions of Bimm and Kimm on the earth are shown in the diagram below. The direction in which Kimm sees the star Sirius from the new place is shown in the diagram. Can you show the direction in which Bimm would see the star Sirius?
(Diagram: Earth as seen from the north pole; Bimm and Kimm separated by a longitudinal angle of 70°*)*

B.2.2 Original Marathi pedagogic questionnaires

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प्रश्न-संच - ३

ऑगस्ट २००७

नाव: **इयत्ता ८ वी.**

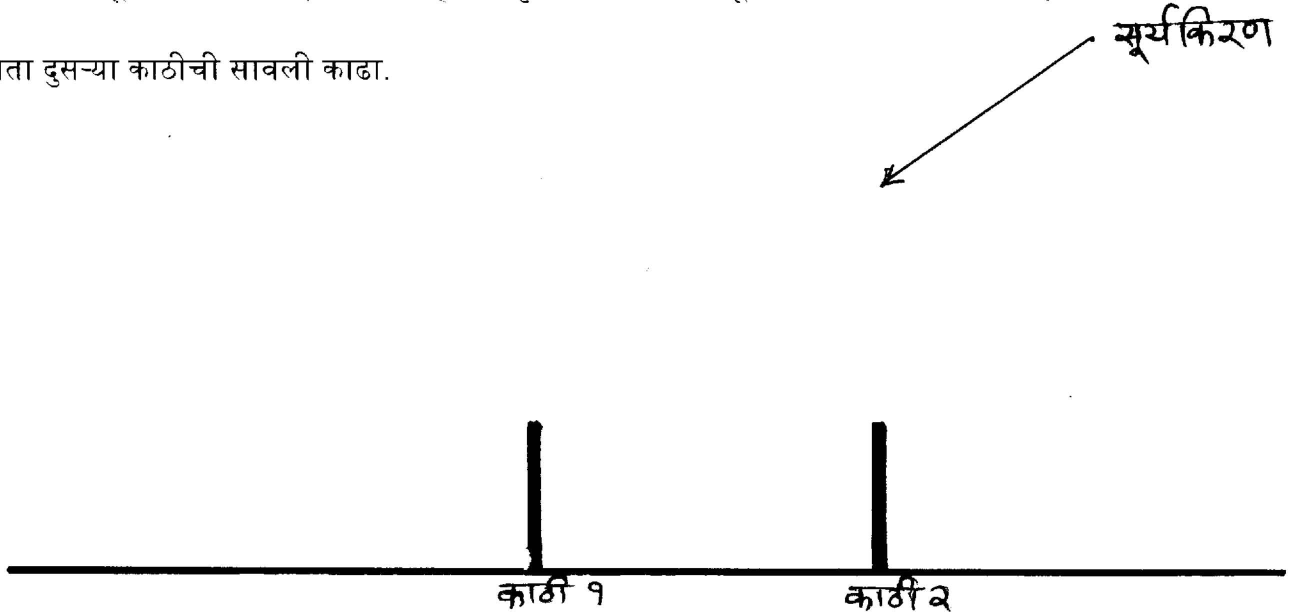
शाळेचे नाव: **दिनांक:**

खाली दिलेल्या चित्रात मैदानात रोवलेल्या दोन काठ्या दाखवलेल्या आहेत; त्याचप्रमाणे सूर्यकिरणांची दिशा दाखवली आहे.

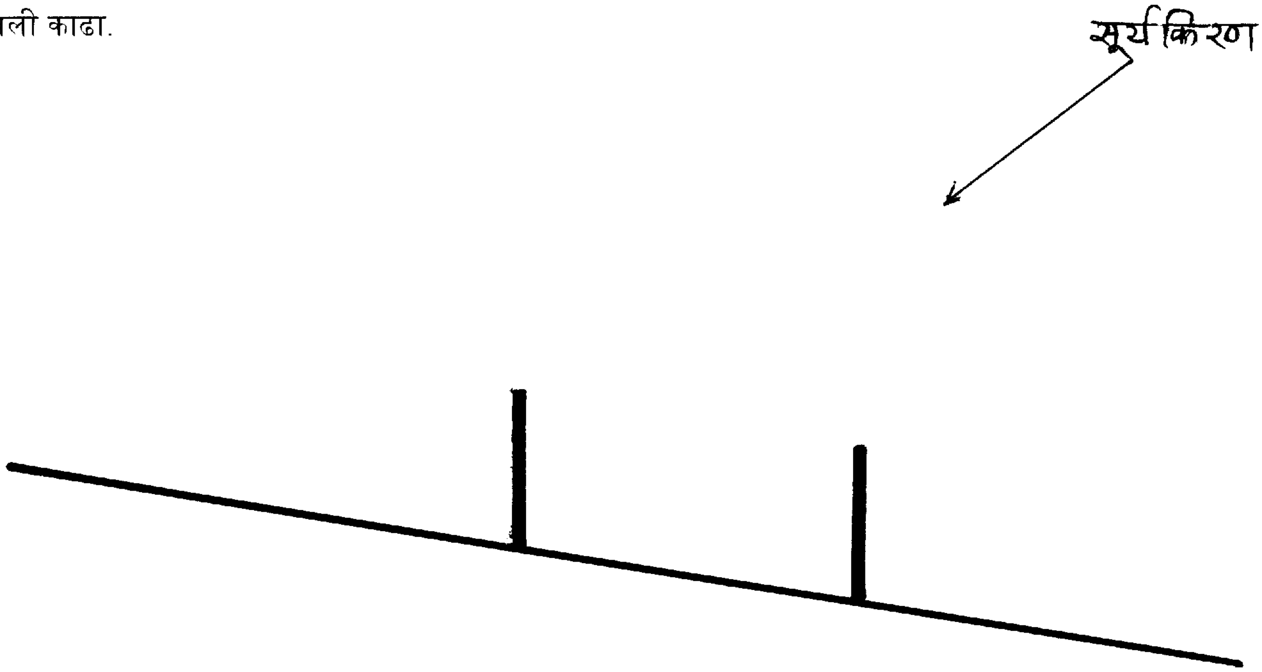
आधी पहिल्या काठीची सावली काढा.

आता इतर सूर्यकिरणे काढा. (लक्षात आहे ना? पृथ्वीवर पडणारी सूर्यकिरणे समांतर असतात.)

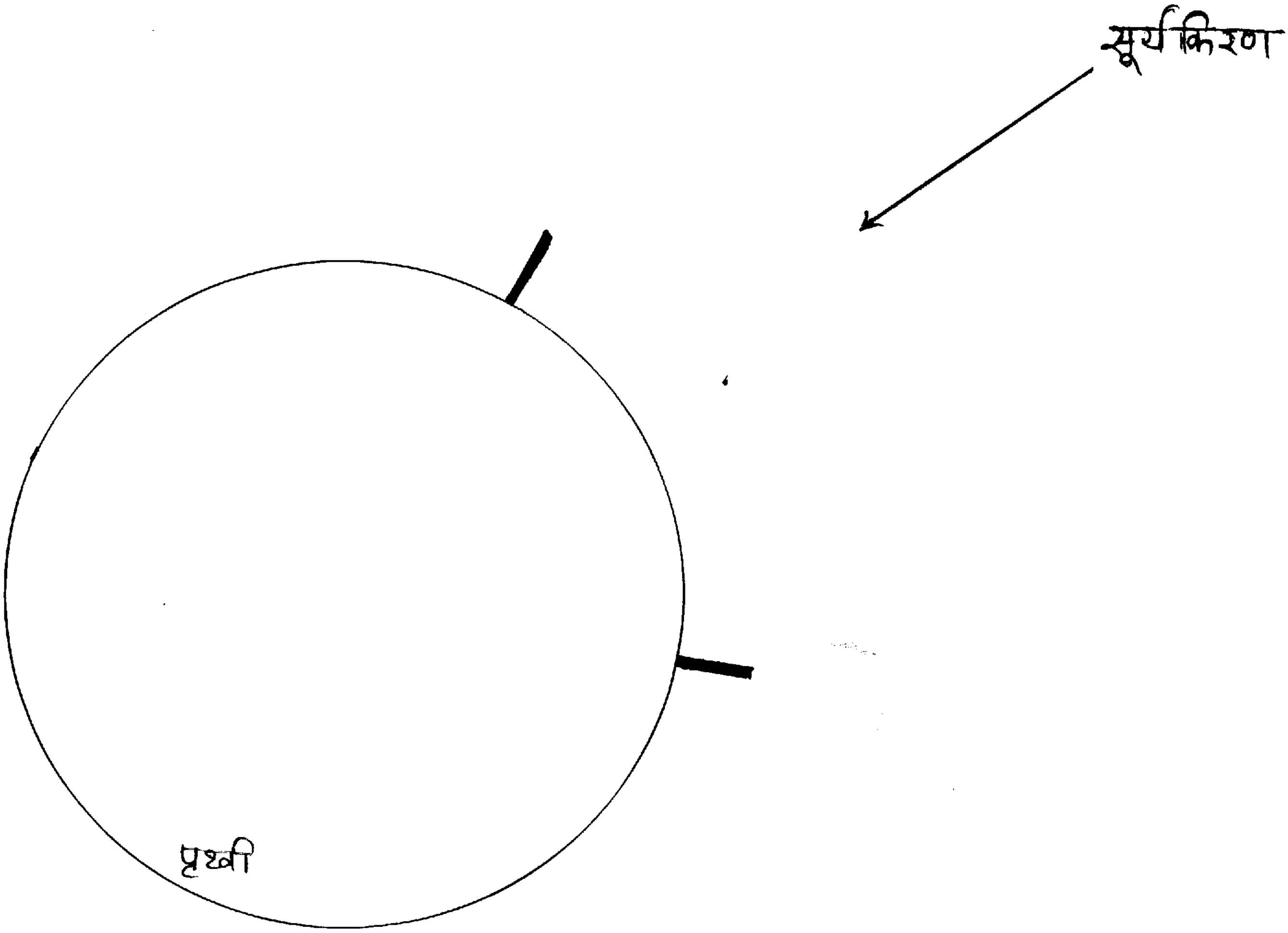
आता दुसऱ्या काठीची सावली काढा.



आता दोन काठ्या एका उतारावर रोवलेल्या आहेत. सूर्यकिरणांची दिशा दाखवली आहे. आता या दोन काठ्यांची सावली काढा.



तशाच दोन काठ्या खाली दाखवल्याप्रमाणे पृथ्वीवर दोन ठिकाणी रोवल्या. आता चित्रात दाखवल्या प्रमाणे सूर्यकिरणांची दिशा असली तर काठ्यांची सावली काढा.



होमी भाभा विज्ञान शिक्षण केंद्र

(टाटा मूलभूत संशोधन संस्था)

वि. ना. पुरव मार्ग, मानखुर्द, मुंबई ४०००८८

खगोलशास्त्र शिक्षण उपक्रम

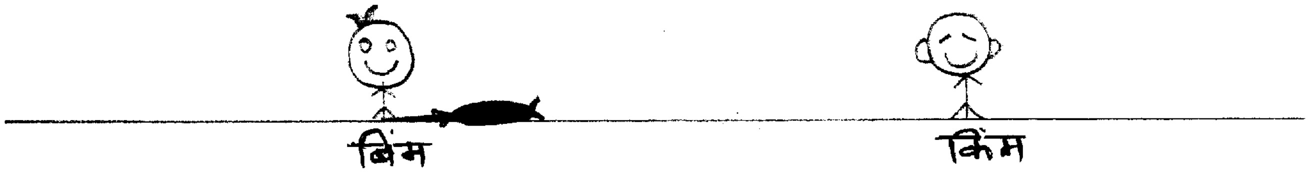
प्रश्न-संच - ४

ऑगस्ट २००७

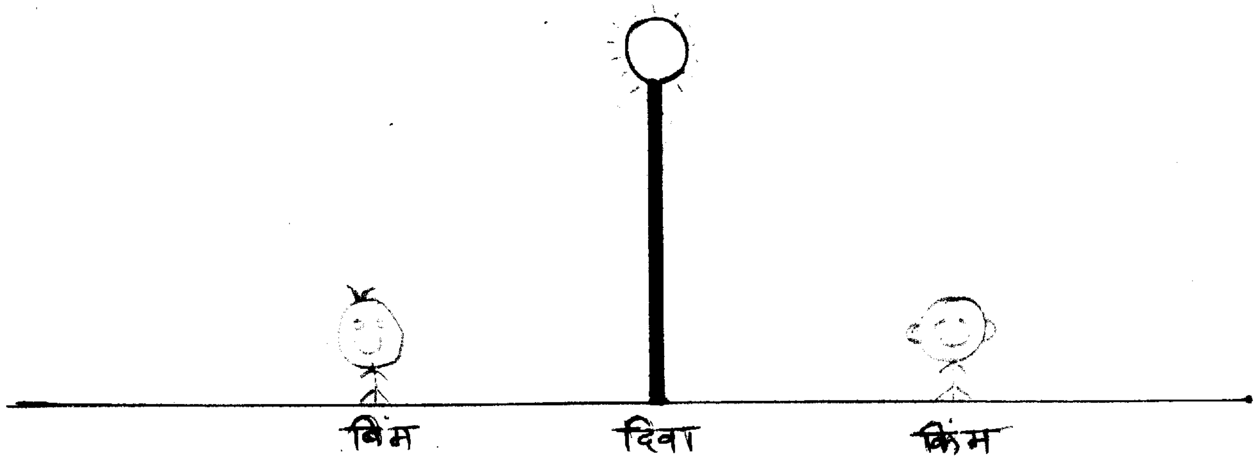
नाव: **इयत्ता ८ वी.**

शाळेचे नाव: **दिनांक:**

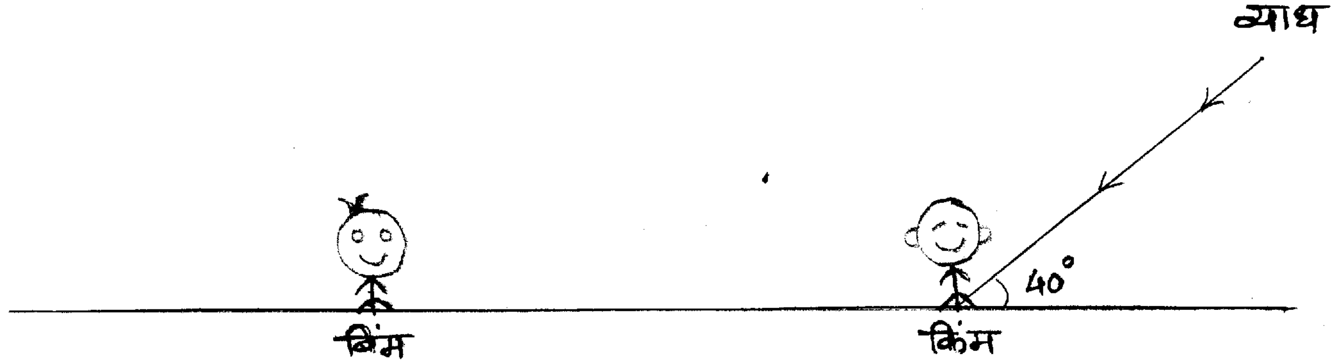
खाली दिलेल्या चित्रात बिंम आणि किंम असे २ दोस्त आहेत. सकाळी सूर्यप्रकाशात बिंमची सावली कशी पडते ते आकृतीत दाखवले आहे. त्याच वेळी बिंमची सावली कशी पडेल ते काढून दाखवा.



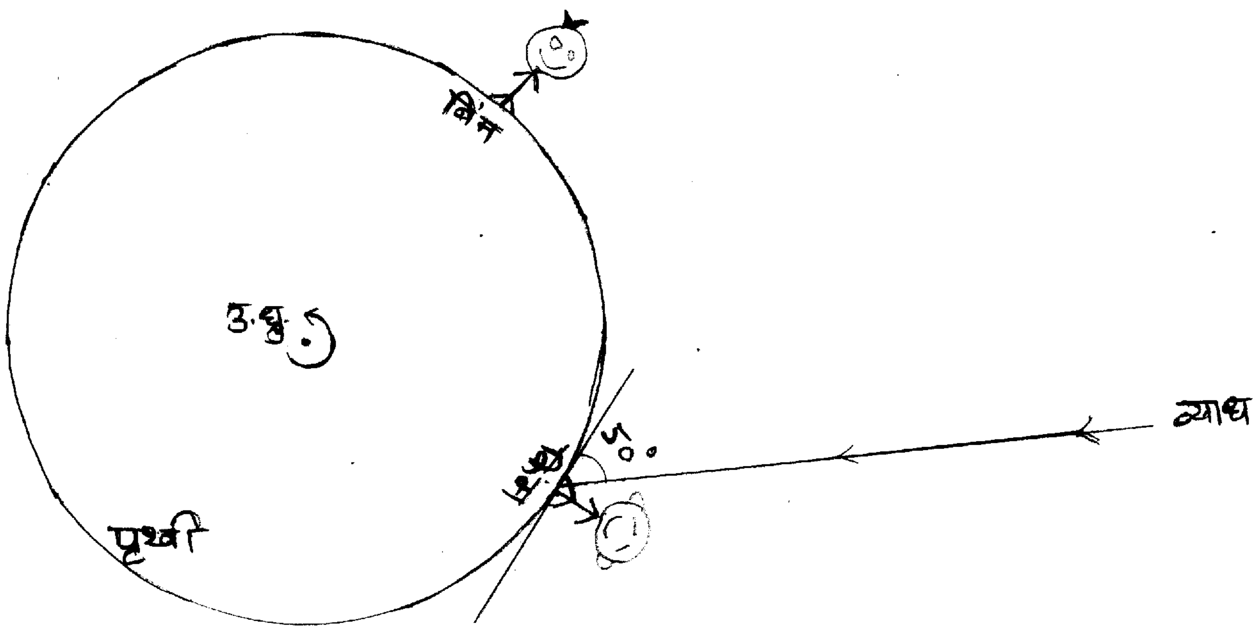
त्यांच्या दोघांच्या मध्ये दिवा आहे. रात्री त्या दिव्यामुळे त्या बिंम आणि किंमची सावली कशी पडेल ते काढून दाखवा. रात्रीच्या सावल्या त्याच आकृतीत रंगित पेन्सिलीने काढा.



किंमला 'व्याध' तारा आकृतीत दाखवल्या प्रमाणे 40^0 वर दिसतो. बिंमला व्याध तारा किती अंशावर दिसेल ते काढून दाखवा.



काही दिवसांनंतर किंम दुसऱ्या गावाला राहायला गेला. खाली दिलेल्या आकृतीत बिंम आणि किंमची पृथ्वीवरची जागा दाखवली आहे. नव्या जागेवरून किंमला व्याध तारा कुठल्या दिशेला दिसला ते दाखवले आहे. बिंमला व्याध तारा कुठल्या दिशेला दिसेल तुम्ही दाखवू शकाल का?



B.3 Session 3: Rotating earth

Correlating global cues with local directions and angles of elevations; time differences

Questionnaires 5 to 8: Local time at different locations of the earth, position of celestial bodies at each of these positions and changes in the positions of celestial bodies as a result of rotation of the earth.

B.3.1 English translations of pedagogic questionnaires

Questionnaire 5: Determining local directions at a point on the equator, given the global direction of the sun

In the following diagram, a picture of a girl called Rinku is to be drawn at such a place that it is 12 O' clock in the noon for Rinku.

(Diagram: Earth as seen from the north pole and sun-rays from the right side)

Draw a line of horizon for Rinku in this diagram.

Now indicate the East and the West directions of Rinku on that line.

Questionnaire 6: Determining local directions at a diametrically opposite point on the equator and locating stars at given angles of elevation from this point

1. Now, in the following diagram, a picture of Sonu, sister of Rinku, is to be drawn at such a place that it is midnight for Sonu.

Draw a line of horizon for Sonu.

Now indicate the East and the West directions of Sonu on that line.

(Diagram: Earth as seen from the north pole and sun-rays from the right side)

2. Now Sonu sees the star *Magha* overhead from her current place. Draw the rays coming from star *Magha* to Sonu.

(Remember; the rays falling from any star on the earth are parallel.)

3. At the same time, Sonu sees the star *Rohini* at 20° above the Western horizon. Draw the rays coming from star *Rohini* to Sonu in the same diagram.

4. At the same time, Sonu sees the star *Swati* at 45° above the Eastern horizon. Draw the rays coming from star *Swati* to Sonu in the same diagram.

Questionnaire 7: Determining local directions at three different points on the equator and locating stars at given angles of elevation from these point; time zone differences

Now, Mithu, brother of Rinku and Sonu, is standing at such a position that the sun is just setting for him on the western horizon in the evening. Draw picture of Mithu in following diagram.
Draw a line of horizon for Mithu.
Now draw the East and West directions of Mithu in the same diagram.
(Diagram: Earth as seen from the north pole and sun-rays from the right side)
Now predict, where would following stars be seen to Mithu, using the diagram (If Mithu would not be able to see the star, then write 'will not be seen').
1. Where will Mithu see the star *Magha*?
2. Where will Mithu see the star *Rohini*?
3. Where will Mithu see the star *Swati*?
4. After how much time would Mithu see the sky that is currently visible to Sonu?
5. After how much time would Sonu see the sky that is currently visible to Mithu?

Questionnaire 8: Same as Q7 above, six hours later

Draw a diagram, similar to above diagram, which shows the positions of Rinku, Sonu and, Mithu after 6 hours. Draw stars *Magha, Rohini* and *Swati* in it.
(Diagram: Earth as seen from the north pole and sun-rays from the right side)
1. Where will Sonu see the star *Magha*?
2. Where will Sonu see the star *Rohini*?
3. Where will Sonu see the star *Swati*?
4. Where will Sonu see the sun?
5. What is the time for Mithu according to this diagram?

B.3.2 Original Marathi pedagogic questionnaires

होमी भाभा विज्ञान शिक्षण केंद्र

(टाटा मूलभूत संशोधन संस्था)

वि. ना. पुरव मार्ग, मानखुर्द, मुंबई ४०००८८

खगोलशास्त्र शिक्षण उपक्रम

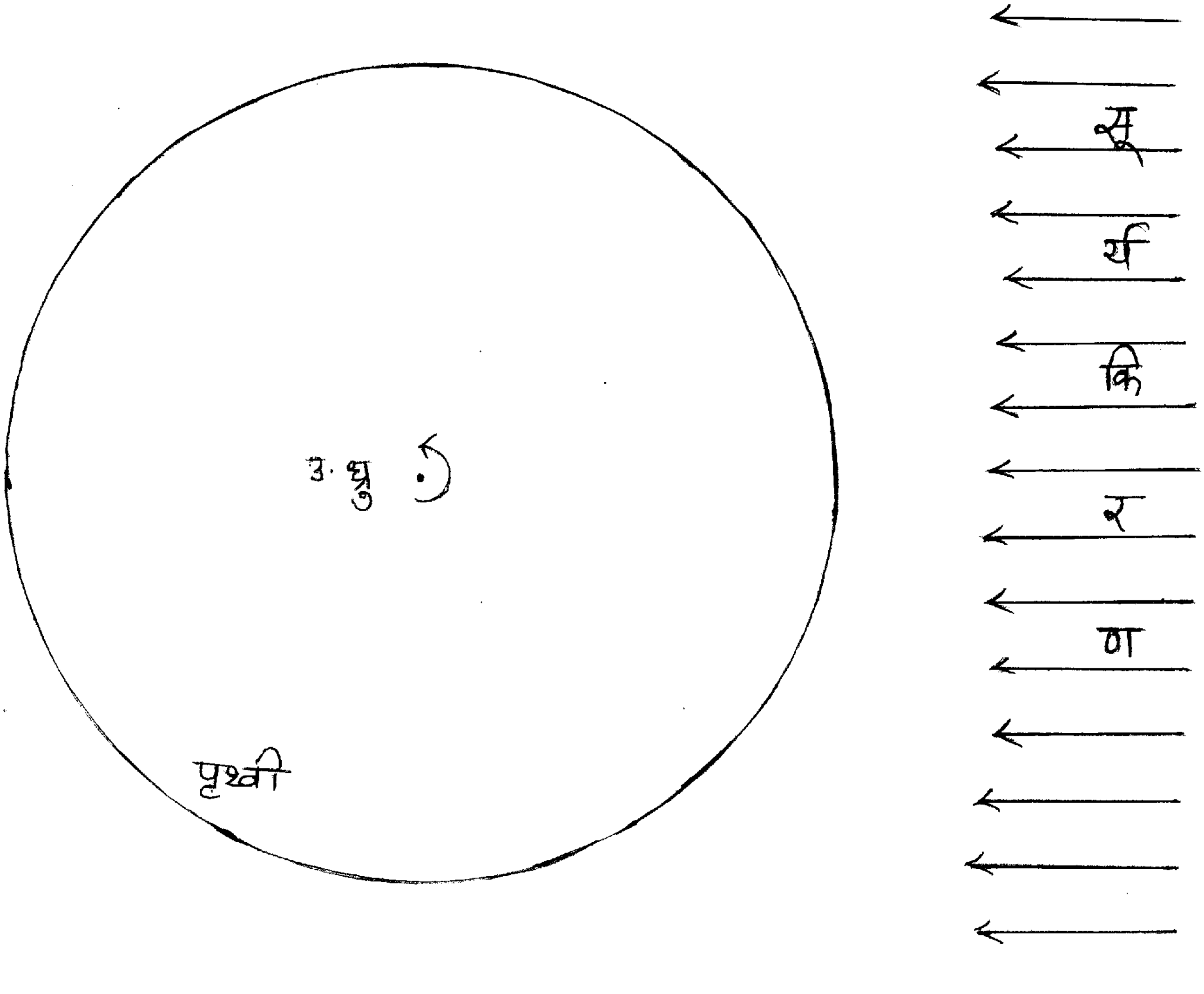
प्रश्न-संच -५

ऑगस्ट २००७

गटाचे नाव: **इयत्ता ८ वी.**

शाळेचे नाव: **दिनांक:**

खाली दिलेल्या आकृतीमध्ये रिंकू या मुलीचे चित्र ( ) अशा ठिकाणी काढायचे आहे, की रिंकूचे दुपारचे बारा वाजले असतिल.



आता त्याच आकृतीत रिंकूची जमिनीची रेषा काढा.

आता त्या रेषेवर रिंकूची पूर्व दिशा कुठली आणि पश्चिम दिशा कुठली ते दाखवा.

होमी भाभा विज्ञान शिक्षण केंद्र

खगोलशास्त्र शिक्षण उपक्रम

प्रश्न-संच -६

ऑगस्ट २००७

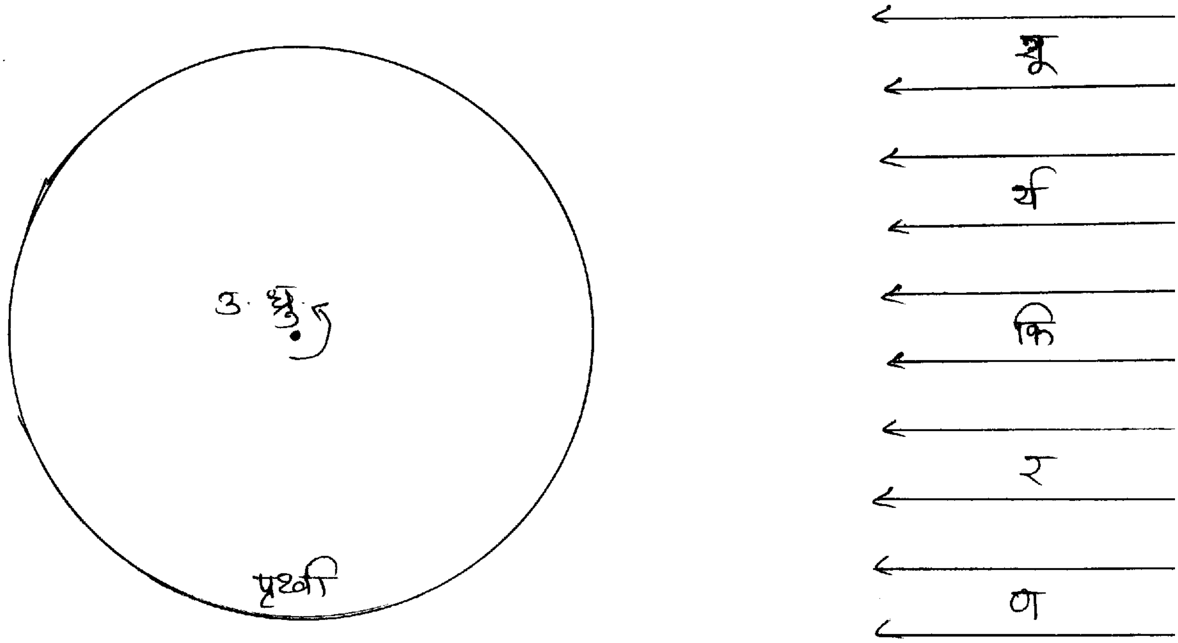
गटाचे नाव: | **इयत्ता ८ वी.**

शाळेचे नाव: | **दिनांक:**

आता दिलेल्या आकृतीमध्ये रिंकूच्या बहिणीचे, सोनूचे चित्र ( ) अशा ठिकाणी काढायचे आहे, की सोनूची मध्यरात्र असेल.

सोनूची जमिनीची रेषा काढा.

आता त्या रेषेवर सोनूची पूर्व दिशा कुठली आणि पश्चिम दिशा कुठली ते दाखवा.



आता सोनू ज्या ठिकाणी आहे, तिथून तिला 'मघा' तारा बरोबर डोक्यावर दिसतो. वरील आकृतीत 'मघा' ताऱ्यापासून सोनू कडे येणारी किरणे दाखवा.

(लक्षात आहे ना? कुठल्याही ताऱ्यापासून पृथ्वीवर पडणारी किरणे समांतर असतात.)

त्याच वेळी सोनूला 'रोहिणी' चा तारा पश्चिमेच्या क्षितीजावर 20° वर दिसतो. त्याच आकृतीत 'रोहिणी' ताऱ्यापासून सोनू कडे येणारी किरणे दाखवा.

त्याच वेळी सोनूला 'स्वाती' तारा पूर्वेच्या क्षितीजावर 45° वर दिसतो. त्याच आकृतीत 'स्वती' ताऱ्यापासून सोनी कडे येणारी किरणे दाखवा.

होमी भाभा विज्ञान शिक्षण केंद्र

खगोलशास्त्र शिक्षण उपक्रम

प्रश्न-संच -७

ऑगस्ट २००७

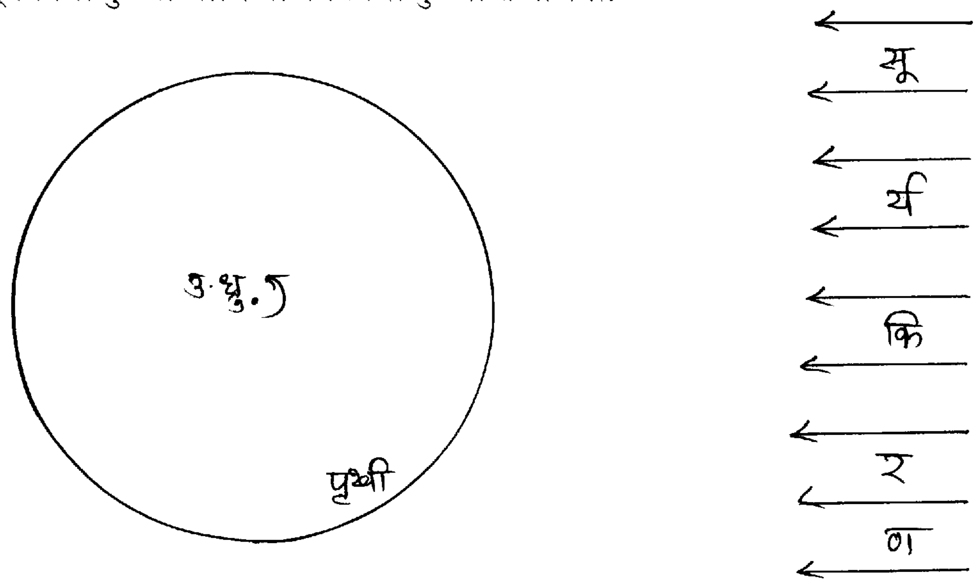
गटाचे नाव: **इयत्ता ८ वी.**

शाळेचे नाव: **दिनांक:**

आता रिंकू आणि सोनूचा भाऊ मिठू हा अशा ठिकाणी उभा आहे की त्याच्या पश्चिमेला सूर्य मावळत असून नुकती संध्याकाळ होत आहे. खाली दिलेल्या आकृतीत मिठूचे चित्र काढा.

मिठूची जमिनीची रेषा काढा.

आता त्या आकृतीत मिठूची पूर्व दिशा कुठली आणि पश्चिम दिशा कुठली ते दाखवा.



मिठूला खालील तारे कुठे (कुठल्या दिशेला व किती अंशावर) दिसतील ते आकृतीच्या मदतीने सांगा. (जर तारा दिसणार नसेल तर 'दिसणार नाही' असे लिहा.)

यासाठी आधी तुम्हाला सोनू आणि तिला तीनही तारे कुठे दिसत असतील ते काढून घ्यावे लागेल.

मिठू ला 'मघा' तारा कुठे दिसेल? ___________

मिठू ला 'रोहिणी' तारा कुठे दिसेल? ___________

मिठू ला 'स्वाती' तारा कुठे दिसेल? ___________

आत्ता सोनूला जसे आकाश दिसते आहे तसे आकाश मिठूला अजून किती वेळाने दिसेल? ___________

आत्ता मिठूला जसे आकाश दिसते आहे तसे आकाश सोनूला अजून किती वेळाने दिसेल? ___________

होमी भाभा विज्ञान शिक्षण केंद्र
खगोलशास्त्र शिक्षण उपक्रम

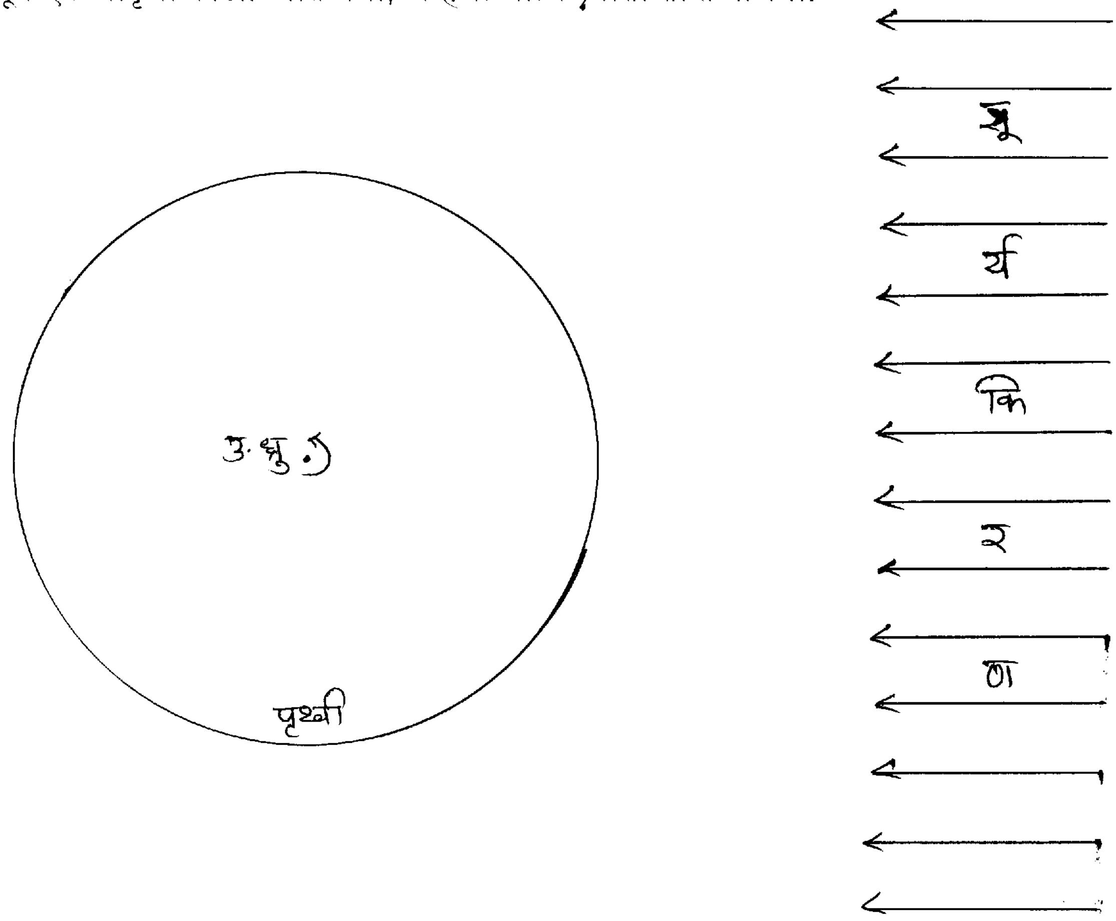
प्रश्न-संच -८

ऑगस्ट २००७

गटाचे नाव: **इयत्ता ८ वी.**

शाळेचे नाव: **दिनांक:**

सहा तासांनंतर रिंकू, सोनू आणि मिठू च्या जागेत काय फरक पडला असेल ते एकत्रीतपणे दाखवणारी वरच्यासारखी अजून एक आकृती काढा. त्यात मघा, रोहिणी आणि स्वाती तारा दाखवा.



सोनू ला 'मघा' तारा कुठे दिसेल? ___________

सोनू ला 'रोहिणी' तारा कुठे दिसेल? ___________

सोनू ला 'स्वाती' तारा कुठे दिसेल? ___________

सोनू ला सूर्य कुठे दिसेल? ___________

त्या आकृतीप्रमाणे 'मिठू' ची कुठली वेळ असेल? ___________

B.4 Session 4: Star-month

Observed night sky *nakshatra* and indigenous calendar (Indigenous calendar and observational astronomy)

B.4.1 English translations of pedagogic questionnaires

Questionnaire 9: Relation between the visible sky at a given point on the earth's orbit and the *nakshatra* (star group) and month named in the indigenous calendar

The sun, earth and the orbit of the earth are shown in the following diagram. The stars are very far than they are shown in the diagram.

(Diagram: The earth and its orbit as seen from above north pole; location of some stars and constellations indicated in indigenous terminology)

1. From which side do we have to view (the model) to see the given picture?

2. Which stars would a person on the earth see at night?

3. Would the person on the earth be able to see the stars on the other side of the sun in daytime?

4. Would the person be able to see the stars on the other side of the sun, even for a short while, at any time during complete day?

5. Which Marathi month and *Nakshatra* is going on on the earth?

B.4.2 Original Marathi pedagogic questionnaires

होमी भाभा विज्ञान शिक्षण केंद्र

(टाटा मूलभूत संशोधन संस्था)

वि. ना. पुरव मार्ग, मानखुर्द, मुंबई ४०००८८

खगोलशास्त्र शिक्षण उपक्रम

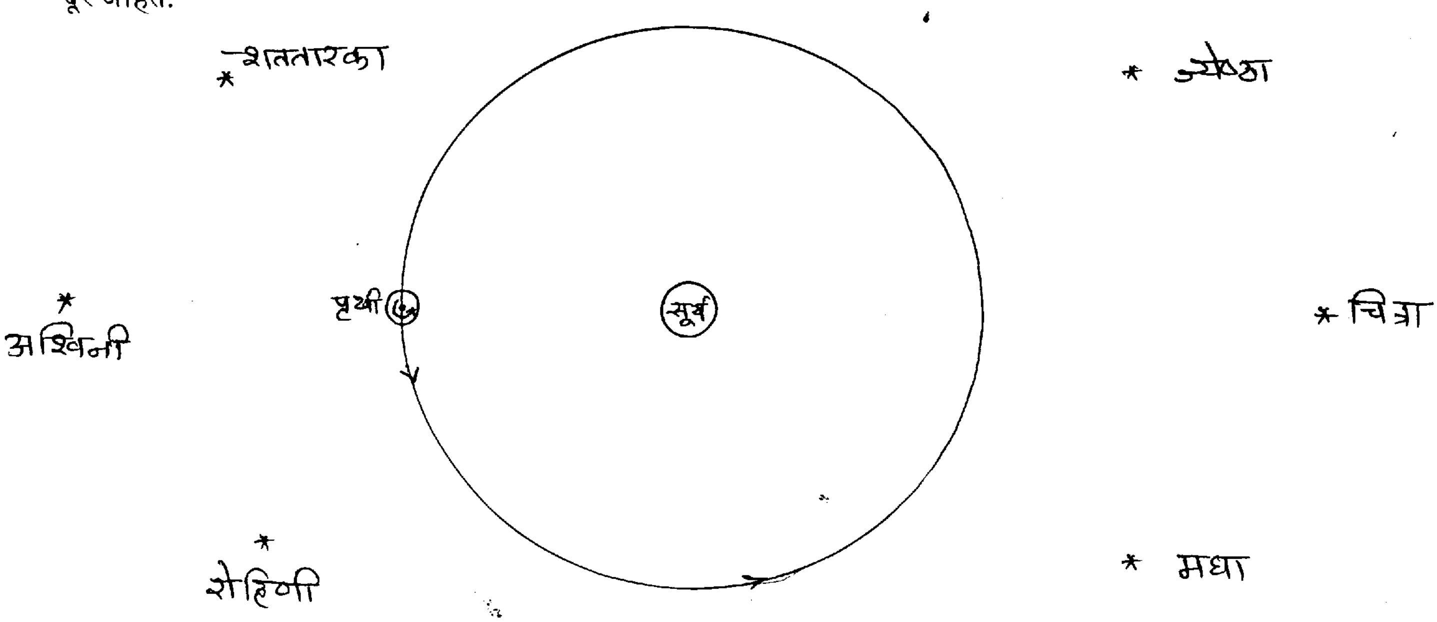
प्रश्न-संच ९

ऑगस्ट २००७

गटाचे नाव: **इयत्ता ८ वी.**

शाळेचे नाव: **दिनांक:**

खालील आकृतीत सूर्य, पृथ्वी आणि पृथ्वीची कक्षा दाखवली आहे. आकृतीतले तारे, दाखवले आहेत त्यापेक्षा खूप दूर आहेत.



१) वर काढलेले चित्र कुठल्या बाजूने बघतांना दिसेल?

२) पृथ्वीवरच्या माणसाला रात्री कुठले तारे दिसतात?

३) दिवस असतांना सूर्याच्या पलिकडचे तारे त्याला दिसतील का?

४) पृथ्वीवरच्या माणसांना पूर्ण दिवसभरात सूर्याच्या पलिकडचे तारे थोडा वेळ तरी दिसतील का?

५) दिलेल्या आकृतीत कुठला मराठी महिना व नक्षत्र चालू आहे?

B.5 Session 5: Seasons

Day-night and North-South elevations of the sun during solstices and equinoxes (explanation of occurrence of seasons)

B.5.1 English translations of pedagogic questionnaires

Questionnaire 10: Day-night at the poles and elevation of the sun at the equator during the summer and winter solstices

1. The following diagram represents the earth and its orbit as seen from within the plane of the earth's orbit. The line of the orbit and direction of the sun-rays are shown.
Now draw an axis of the earth making an angle of 66.5° to the line of the orbit.
Indicate the North pole and the South pole.
Draw the equator making an angle of 90° with the axis.
Indicate the Northern and Southern hemispheres in the diagram.
The angle between the parallel sun-rays and the axis of the earth is 66.5°. Indicate the day and night occurring due to these sun-rays.
(Diagram: Earth; Line indicating plane of orbit; sun-rays from right parallel to this line)
Now, draw a person on the equator in this diagram. For this person, is the sun exactly overhead, or towards North of zenith, or towards South of zenith?
If the earth completes one rotation around itself in 24 hours, there will be some parts on which sun-light will not fall. Which are these parts? Colour these parts blue.
If the earth completes one rotation around itself in 24 hours, there will be some parts on which sunlight will fall all the time. Colour these parts red.
Which hemisphere (Northern or Southern) will have more sunshine according to this diagram?
Which hemisphere will be warmer?
Which hemisphere will be cooler?
Which season would be going on in the Northern hemisphere?
Which season would be going on in the Southern hemisphere?

2. You know that the earth revolves around the sun. The above picture depicts the position in the month of June and the following picture shows the position of the earth after six months, which is in the month of December.
(Diagram: June (left of the sun) and December (right of the sun) positions of the earth as seen along plane of orbit)
Based on this picture, complete the following diagram for the month of December.
Draw the axis of the earth making an angle of 66.5° to the line of the orbit.
Indicate the North Pole and the South Pole.
Draw the equator making an angle of 90° with the axis.
Indicate the Northern and Southern hemispheres in the diagram.
(Diagram: Earth; line indicating plane of orbit; sun-rays from left parallel to this line)
Indicate the day and night occurring due to these sun-rays.
Now, draw a person on the equator in this diagram. For this person, the is sun exactly overhead or towards North of zenith or towards South of zenith?
If the earth completes one rotation around itself in 24 hours, there will be some parts on which sun-light will not fall. Colour these parts blue.
If the earth completes one rotation around itself in 24 hours, there will be some parts on which sun-light will fall all the time. Colour these parts red.
Which hemisphere (Northern or Southern) will have more sunshine according to this diagram?
Which hemisphere will be warmer?
Which hemisphere will be cooler?
Which season would be going on in the Northern hemisphere?
Which season would be going on in the Southern hemisphere?

Questionnaire 11: Day-night on earth and North-South elevations of the sun in the two hemispheres at the time of equinox

3. In the following diagram, assume that the sun is exactly in front of the earth outside the plane of this paper.
(Diagram: Earth with equator and axis at 66.5° *to the line indicating plane of the orbit)*
From the part of the earth which we can see, if there is any part which is in darkness,

colour it blue.
In the part of the earth which we can see:
Is it daytime everywhere in the Northern hemisphere?
Is it daytime everywhere in the Southern hemisphere?
Which hemisphere (Northern or Southern) will have more sunshine according to this diagram?
Which hemisphere will be warmer?
Which hemisphere will be cooler?
Which season would be going on in the Northern hemisphere?
Which season would be going on in the Southern hemisphere?
In which month would this situation occur? **4**. Indicate whether the following statements (or diagrams) are right or wrong:

i In December, it is winter in the Northern hemisphere.

ii Following diagram: *(Diagram with direction of axis of rotation of the earth changed after 6 months. See previous and modify.)*

iii Seasons occur due to change in the distance between the earth and the sun.

iv It is winter in the Southern hemisphere when it is summer in the Northern hemisphere.

v Polar region are lit for six months and dark for the remaining six months

vi In polar regions, the earth takes more then 24 hours to move around itself.

vii It never gets dark on some parts on the earth.

B.5.2 Original Marathi pedagogic questionnaires

होमी भाभा विज्ञान शिक्षण केंद्र

(टाटा मूलभूत संशोधन संस्था)

वि. ना. पुरव मार्ग, मानखुर्द, मुंबई ४०००८८

खगोलशास्त्र शिक्षण उपक्रम

प्रश्न-संच १०

ऑगस्ट २००७

गटाचे नाव: **इयत्ता ८ वी.**

शाळेचे नाव: **दिनांक:**

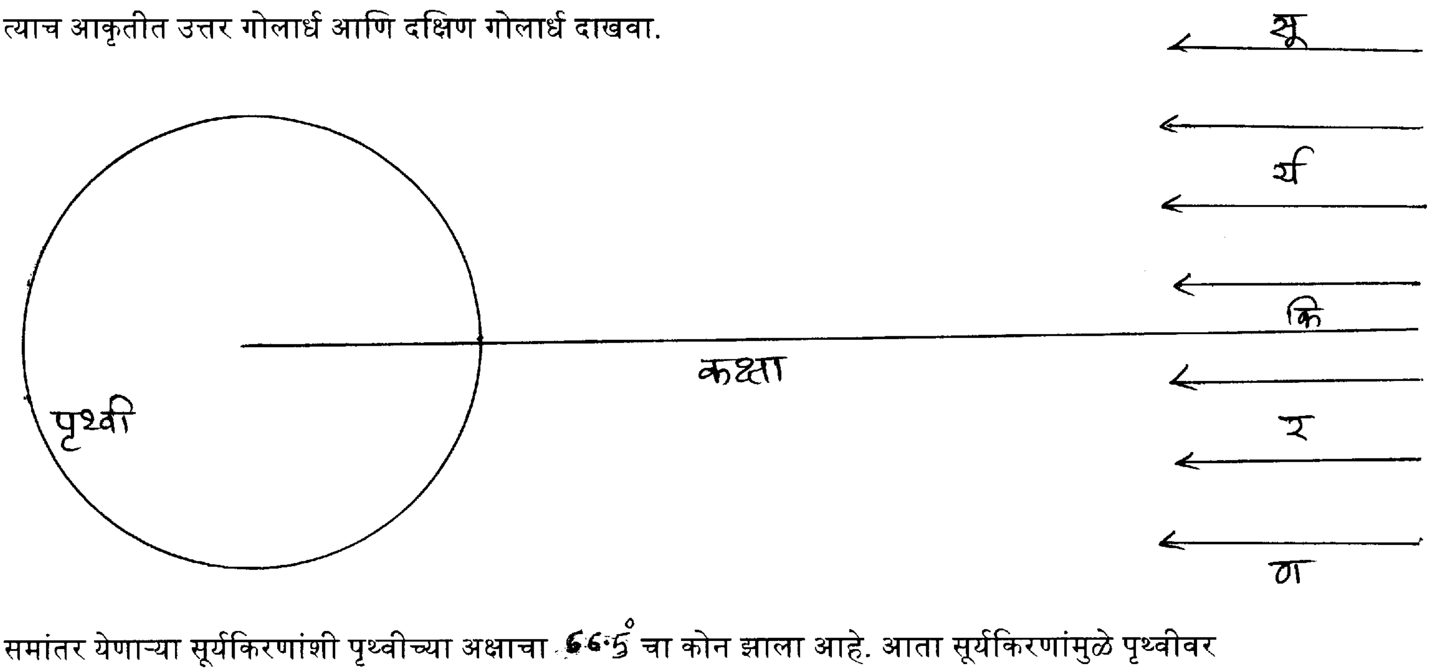
१) खाली पृथ्वीच्या कक्षेच्या प्रतलाच्या बाजूने बघितले तर जसे दिसेल त्याची एक आकृती दिली आहे. तिच्यात कक्षेची रेषा आणि सूर्यकिरणांची दिशा दाखवली आहे.

आता कक्षेच्या रेषेला 66.5^0 चा कोन करून पृथ्वीचा अक्ष दाखवा.

उत्तर ध्रुव आणि दक्षिण ध्रुव दाखवा

अक्षाला 90^0 चा कोन करून विषुववृत्त दाखवा.

त्याच आकृतीत उत्तर गोलार्ध आणि दक्षिण गोलार्ध दाखवा.



समांतर येणाऱ्या सूर्यकिरणांशी पृथ्वीच्या अक्षाचा 66.5^0 चा कोन झाला आहे. आता सूर्यकिरणांमुळे पृथ्वीवर झालेले दिवस आणि रात्र दाखवा.

आता त्याच आकृतीत विषुववृत्तावर एक माणूस दाखवा. सूर्य या माणसाच्या बरोबर डोक्यावर आहे, डोक्याच्या उत्तरेला आहे की दक्षिणेला?

पृथ्वीने 24 तासात स्वत:भोवती एक फेरी पूर्ण केली तरी काही भागात सूर्यप्रकाश पडणारच नाही. हे भाग कोणते?

त्या भागांना निळा रंग द्या.

पृथ्वीने 24 तासात स्वत:भोवती एक फेरी पूर्ण केली तरी काही भागात दिवसभर प्रकाश पडतच राहील. अशा भागाला लाल रंग द्या.

या आकृतीत उत्तर गोलार्धात जास्त उन्ह असेल की दक्षिण गोलार्धात? ___________________

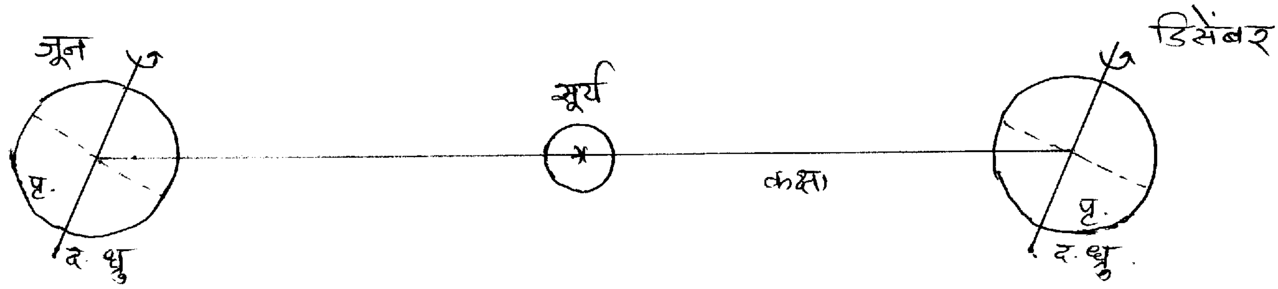
कुठल्या गोलार्धात जास्त उकाडा असेल? ___________________

कुठल्या गोलार्धात जास्त थंड असेल? ___________________

उत्तर गोलार्धात कोणता ऋतू चालू असेल? ___________________

दक्षिण गोलार्धात कोणता ऋतू चालू असेल? ___________________

२) पृथ्वी सूर्याभोवती फिरते हे तुम्हाला माहीत आहे. वर जुन महीन्यातले चित्र काढले असून त्यानंतर सहा महीन्यांनी, म्हणजे डिसेंबरमध्ये पृथ्वी कुठे असेल याचे चित्र खाली दाखवले आहे.



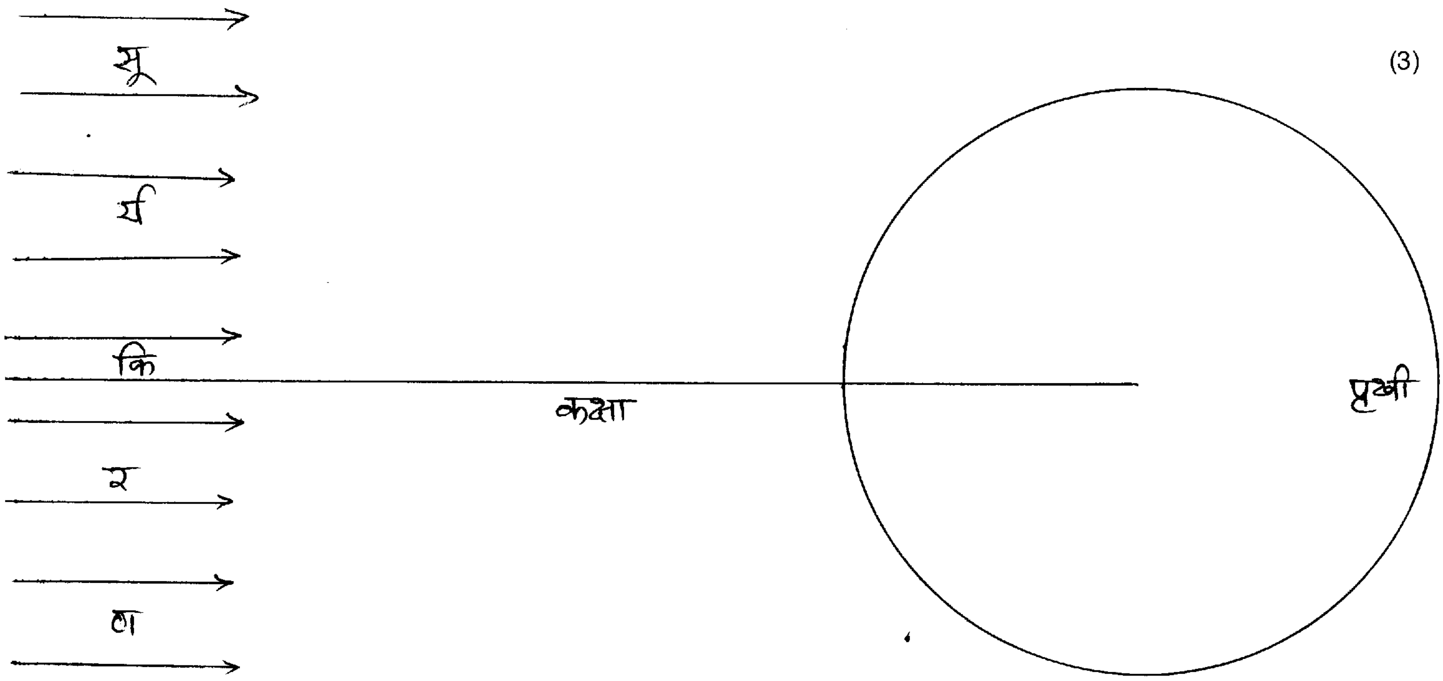
या चित्रावरून आता डिसेंबर महीन्यातील आकृती पूर्ण कारा:

कक्षेच्या रेषेला 66.5^0 चा कोन करून पृथ्वीचा अक्ष दाखवा.

उत्तर ध्रुव आणि दक्षिण ध्रुव दाखवा

अक्षाला 90^0 चा कोन करून विषुववृत्त दाखवा.

उत्तर गोलार्ध आणि दक्षिण गोलार्ध दाखवा.



सूर्यकिरणांमुळे पृथ्वीवर झालेले दिवस आणि रात्र दाखवा.

आता त्याच आकृतीत विषुववृत्तावर एक माणूस दाखवा. सूर्य या माणसाच्या बरोबर डोक्यावर आहे, डोक्याच्या उत्तरेला आहे की दक्षिणेला?

पृथ्वीने 24 तासात स्वत:भोवती एक फेरी पूर्ण केली तरी काही भागात सूर्यप्रकाश पडणारच नाही. अशा भागाला रंग निळा द्या.

पृथ्वीने 24 तासात स्वत:भोवती एक फेरी पूर्ण केली तरी काही भागात दिवसभर प्रकाश पडतच राहील. अशा भागाला लाल रंग द्या.

या आकृतीत उत्तर गोलार्धात जास्त उन्ह असेल की दक्षिण गोलार्धात? ____________________

कुठल्या गोलार्धात जास्त उकाडा असेल? ____________________

कुठल्या गोलार्धात जास्त थंडी असेल? ____________________

उत्तर गोलार्धात कोणता ऋतू चालू असेल? ____________________

दक्षिण गोलार्धात कोणता ऋतू चालू असेल? ____________________

होमी भाभा विज्ञान शिक्षण केंद्र

खगोलशास्त्र शिक्षण उपक्रम

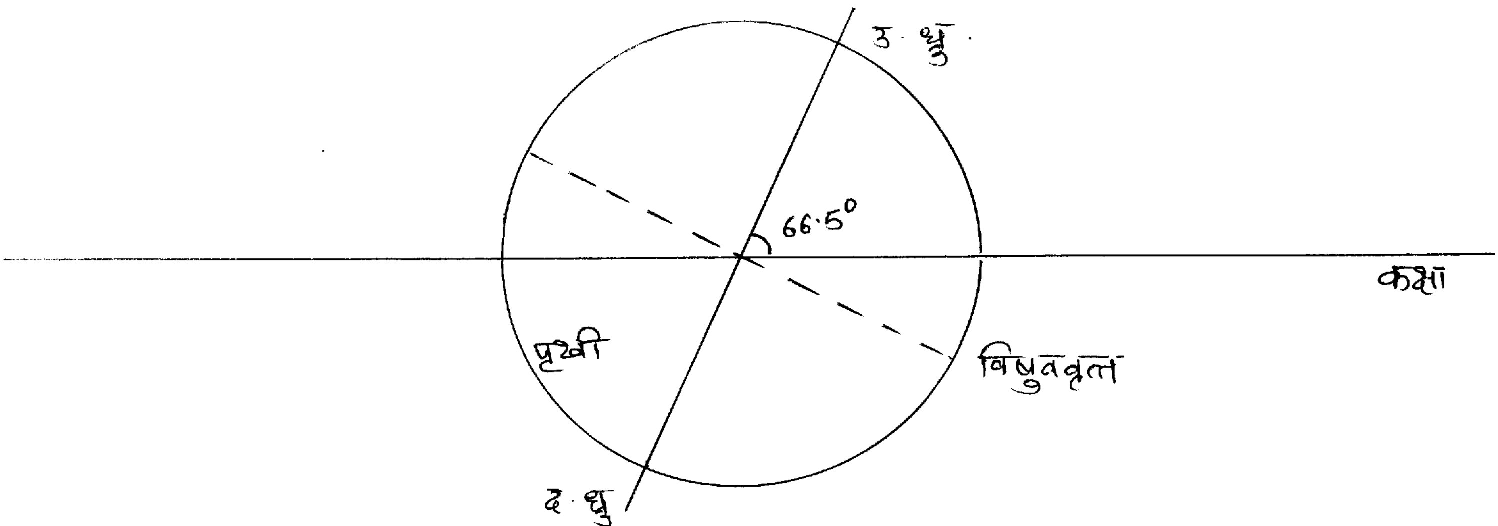
प्रश्न-संच ११

ऑगस्ट २००७

गटाचे नाव: **इयत्ता ८ वी.**

शाळेचे नाव: **दिनांक:**

३) खालील आकृतीत सूर्य कागदाच्या प्रतलाच्या बाहेर पृथ्वीच्या बरोबर समोर आहे असे समजा.



आता आपल्याला पृथ्वीचा जो भाग दिसतो आहे त्यापैकी जर कुठल्या भागावर प्रकाश पडत नसेल तर तो भाग निळ्या रंगाने रंगवा.

उत्तर गोलार्धात सर्वत्र दिवस आहे का? ____________________

दक्षिण गोलार्धात सर्वत्र दिवस आहे का? ____________________

या आकृतीत उत्तर गोलार्धात जास्त उन्ह असेल की दक्षिण गोलार्धात? ____________________

कुठल्या गोलार्धात जास्त उकाडा असेल? ____________________

कुठल्या गोलार्धात जास्त थंडी असेल? ____________________

उत्तर गोलार्धात कोणता ऋतू चालू असेल? ____________________

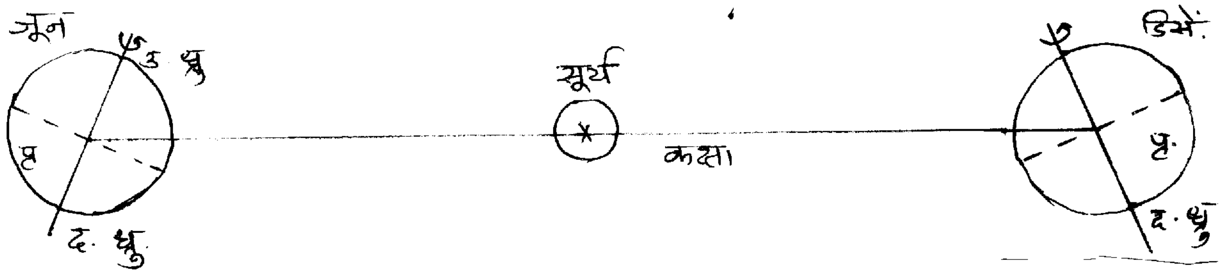
दक्षिण गोलार्धात कोणता ऋतू चालू असेल? ____________________

अशी स्थिती कुठल्या महीन्यात असेल?

४) चूक की बरोबर सांगा:

i) डिसेंबर मध्ये उत्तर गोलार्धात हिवाळा असतो. ______________

ii) खालील आकृती: ______________



iii) पृथ्वीचे सूर्यापासून अंतर बदलल्यामुळे पृथ्वीवर ऋतू होतात. ______________

iv) उत्तर गोलार्धात जेव्हा उन्हाळा सुरू असतो तेव्हा दक्षिण गोलार्धात हिवाळा चालू असतो. ______________

v) ध्रुवीय प्रदेशात सहा महीने अंधार आणि सहा प्रकाश असतो. ______________

vi) ध्रुवीय प्रदेशात पृथ्वीला स्वत:भोवती फिरायला 24 तासांपेक्षा जास्त वेळ लागतो. ______________

vii) पृथ्वीवरील काही भगांमध्ये काधीच रात्र होत नाही. ______________

B.6 Part III: Questionnaire for revision

B.6.1 English translations of pedagogic questionnaire

1. Write the names of elephant, giraffe, kakakua and kangaroo in the given map where these animals live. (*World map*)
Draw the picture of each animal at the appropriate place in the diagram of the earth provided below. Determine the directions Up, Down, East and West for each animal. (*Diagram*)
Determine the time of the day (dawn, noon, evening, night) for each animal and write down what might each animal be doing at that time.
Elephant: Giraffe: Kakakua: kangaroo:

2. The following diagram shows how the flag-pole in our front lawn looks from the space. (The height of the pole is increased so that we will be able to see it). Draw the diagram of the flag pole and its shadow on the lawn at the same time.
(*2 Diagrams*)

3. Two children Manya and Banti are shown in the given diagram.
(*Diagram*)
Draw the line of horizon for both.
Determine Up, Down, East and West directions for each.
With the help of diagram determine the direction and angle at which the sun will be seen to each child.
Draw tilted lines [///]on the part where it is night on the earth.
Draw how the sun will appear to move to Banti in the following diagram.
(*Diagram*)

4. Position of a girl called Renuka is shown in the following diagram.
(*Diagram*)
Is Renuka in Northern hemisphere or in Southern hemisphere?
Draw the line of horizon for Renuka.
Determine the Up, Down, North and South directions for her.

Is the sun exactly overhead for Renuka?
If the sun is not overhead, then in which direction of the zenith of Renuka?
In the given diagram, is it summer or winter at the position where Renuka stands?
Draw the apparent motion of the sun as seen be Renuka.

B.6.2 Original Marathi pedagogic questionnaire

होमी भाभा विज्ञान शिक्षण केंद्र

(टाटा मूलभूत संशोधन संस्था)

वि. ना. पुरव मार्ग, मानखुर्द, मुंबई ४०००८८

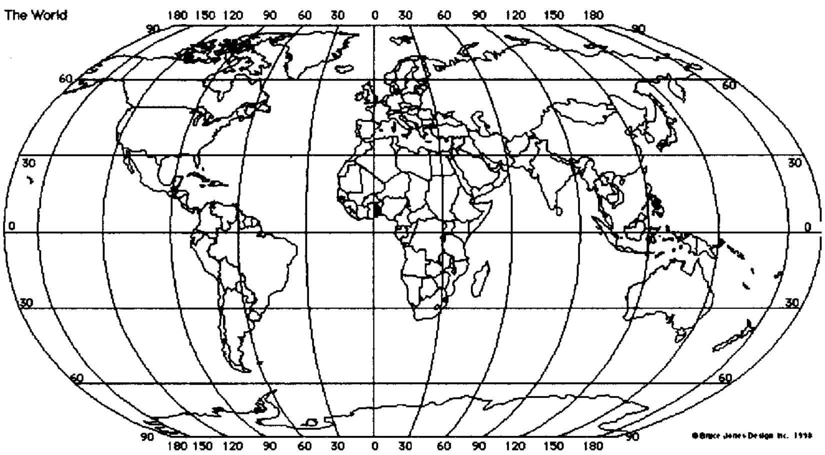
खगोलशास्त्र शिक्षण उपक्रम

प्रश्नसंच १२

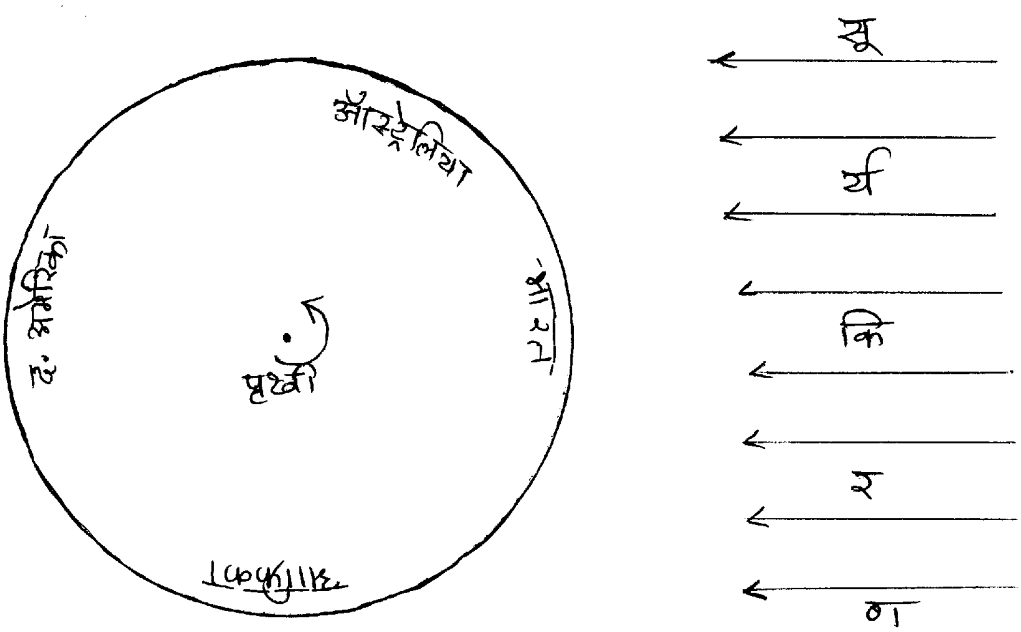
नाव: **इयत्ता ८ वी.**

शाळेचे नाव: **दिनांक:**

१. खाली देलेल्या नकाशात हत्ती, जिराफ, काकाकुआ आणि कांगारू हे प्राणी जिथे रहातात तिथे त्यांचे नाव लिहा:



खाली दिलेल्या पृथ्वीच्या आकृतीत प्रत्येक प्राण्याचे योग्य ठिकाणी चित्र काढा. प्रत्येक प्राण्यासाठी वर, खाली, पूर्व व पश्चिम दिशा ठरवा.



(2)

त्यापैकी प्रत्येक प्राण्याची कुठली वेळ (पहाट, दुपार, संध्याकाळ, रात्र) चालली असेल ते ठरवून त्याच्याइथल्या वेळनुसार तो प्राणी काय करत असेल ते सांगा.

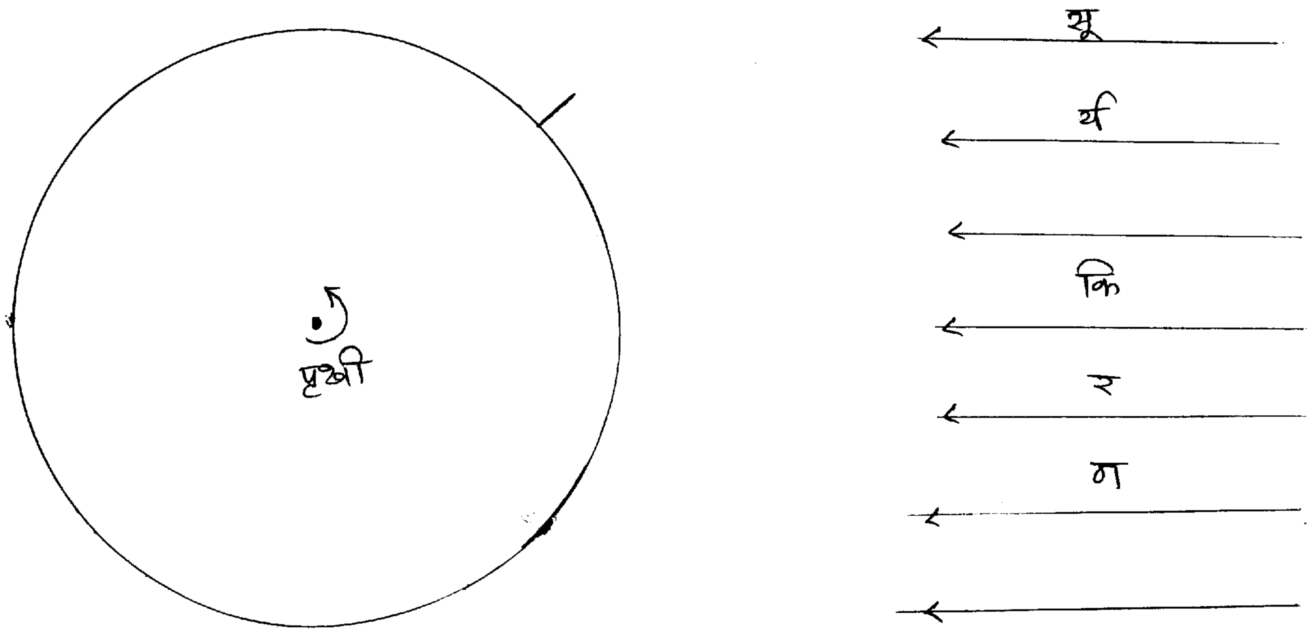
हत्ती:

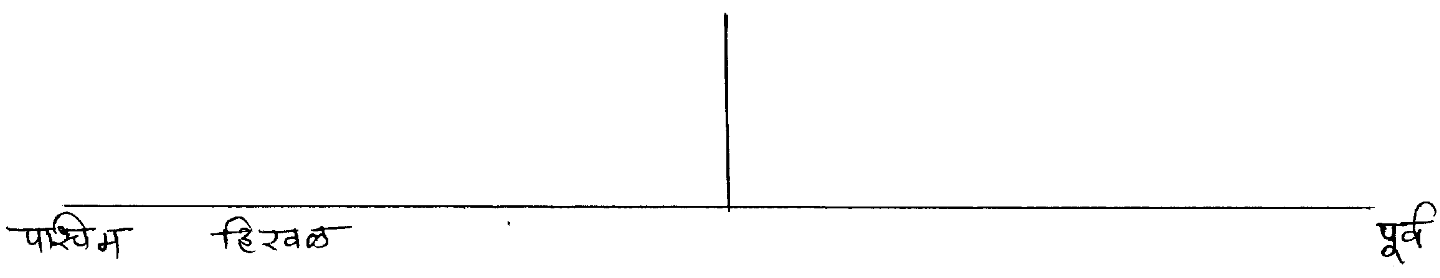
जिराफ:

काकाकुआ:

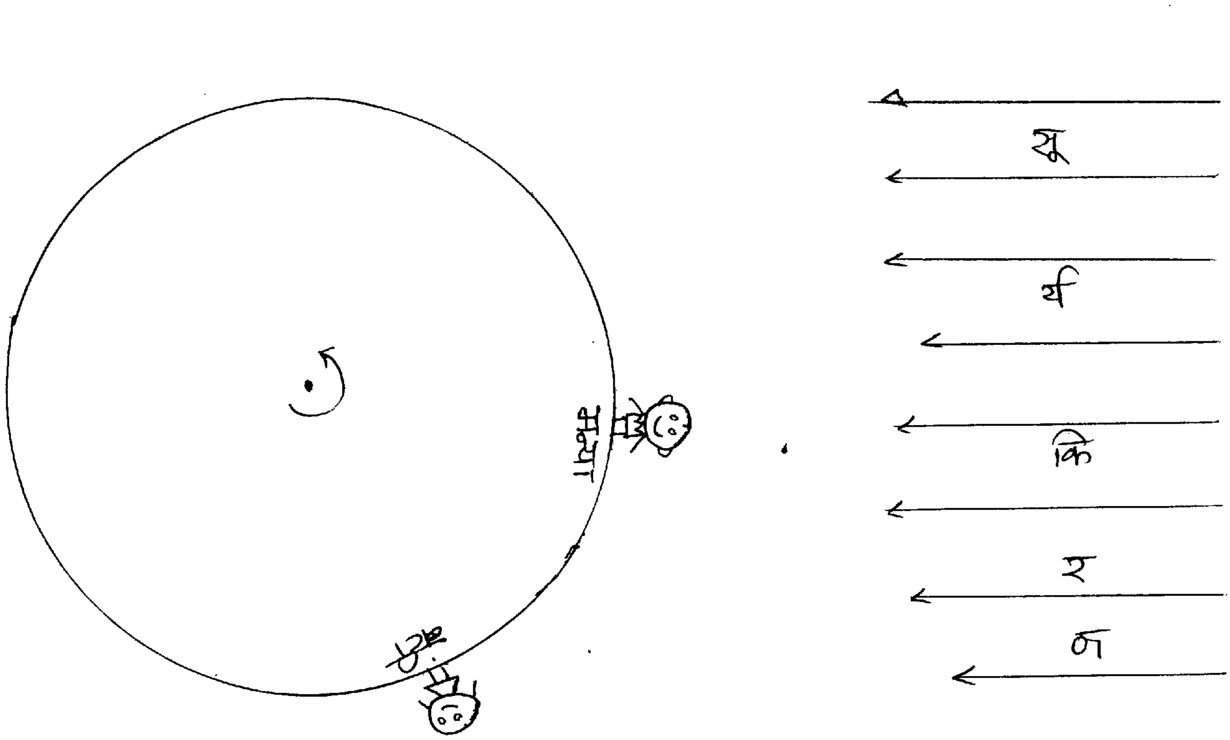
कांगारू:

२. अवकाशातून बघताना पृथ्वीवर, आपल्या समोरच्या हिरवळीवर रोवलेला झेंड्याचा खांब कसा दिसेल याची आकृती दिली आहे. (आपल्याला दिसावा म्हणून खांबाचा आकार मोठा केला आहे.) त्याच वेळेस आपल्याला समोरच्या हिरवळीवरचा खांब आणि त्याची सावली कशी दिसेल याची आकृती काढा:

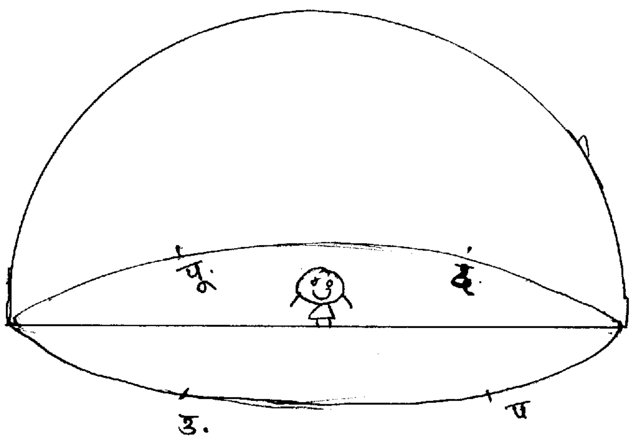




३. खाली दिलेल्या आकृतीत मन्या आणि बंटी अशी दोन मुले आहेत.

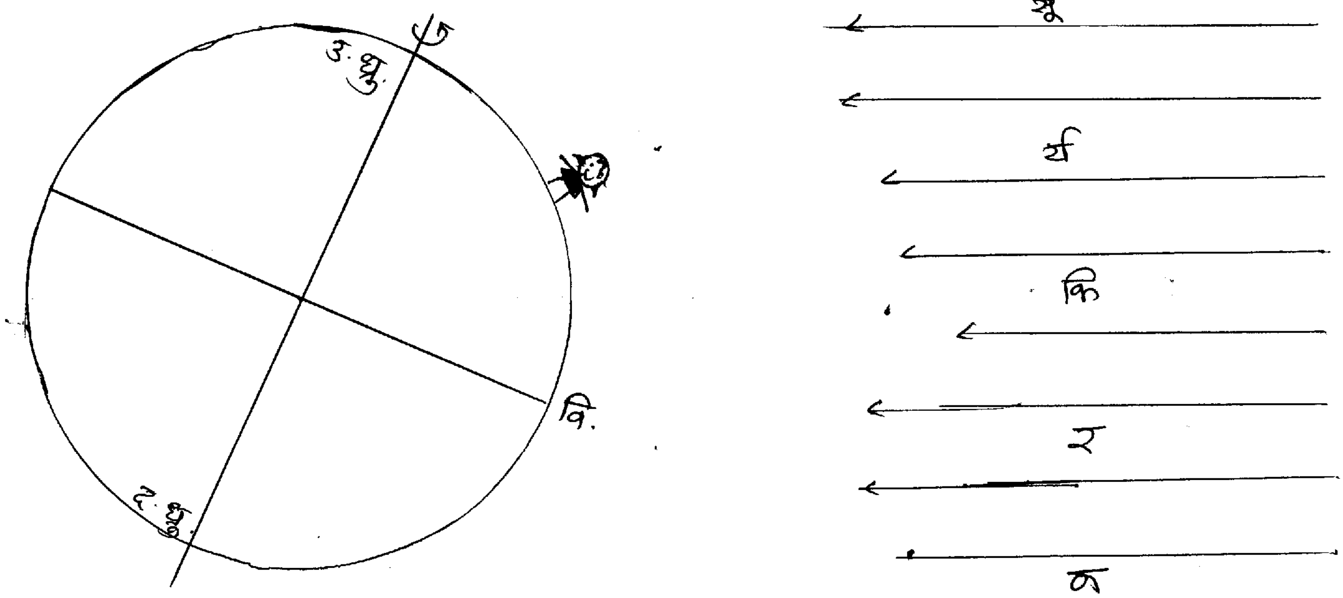


दोघांसाठी क्षितीजाच्या रेषा काढा.
प्रत्येकाची वर, खाली, पूर्व व पश्चिम दिशा ठरवा.
आकृतीच्या मदतीने प्रत्येकाला सूर्य कुठल्या दिशेला किती अंशावर दिसल ते सांगा.
आकृतीतिल पृथ्वीवर ज्या भागात रात्र आहे तिथे तिरक्या रेषा ▨ मारा.
खालच्या आकृतीत बंटीला सूर्य कसा हालतांना दिसेल ते दाखवा:

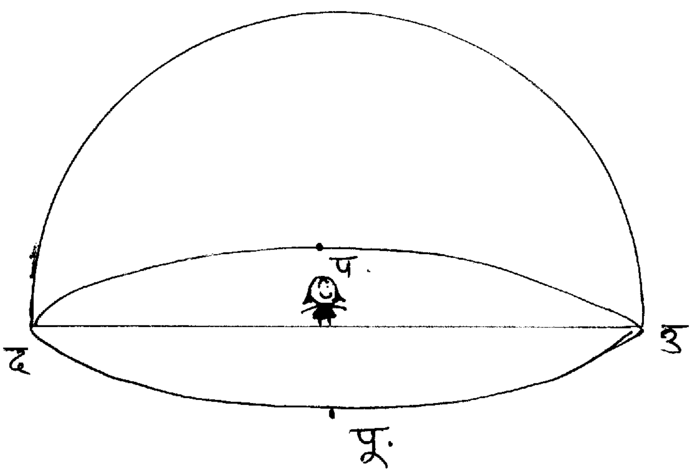


(4)

४. खालील आकृतीत रेणुका नावाच्या मुलीची जागा दाखवली आहे.



रेणुका उत्तर गोलार्धात आहे की दक्षिण गोलार्धात?
रेणुकासाठी क्षितीजाची रेषा काढा.
तिची वर, खाली, उत्तर व दक्षिण दिशा ठरवा.
सूर्य रेणुकाच्या बरोबर डोक्यावर आहे का?
नसेल तर डोक्याच्या कुठल्या दिशेला आहे?
या आकृतीमध्ये रेणुका जिथे आहे तिथे उन्हाळा चालू आहे की हिवाळा?
खालिल आकृतीत रेणुकाला सूर्य कसा हालतांना दिसेल ते काढा:



Appendix C

Homework

Homework sets 1, 2 and 3 were given between Part I and II of the intervention and the homework sets 4, 5 and 6 were given between parts II and III of the intervention.

Homework 1: The earth and the space (4 pages)
Question 1. Drawing diagram of the earth, its elements and positioning human beings on the earth. Determining their directions and drawing their horizon.
Question 2. Matching the pairs of celestial bodies and their examples.
Question 3. Explanation of apparent motion of the stars across the sky over night.
Question 4. Drawing shadow of the stick in four different conditions.
Question 5. Questions on locations of countries and continents to be answered by observing the world map or globe.

Homework 2: Lines, shapes and objects (4 pages)
Questions 1-4. Parallel lines and angles made by a secant.
Question 5. Geometry of circle: radius, diameter, circumference, area
Question 6 & 7. examples of approximately 1, 2 and 3 dimensional objects.
Question 8. Drawing axis of rotation for different objects.

Homework 3: Measurement (4 pages)
Question 1. Units of length, their conversion
Question 2. Perimeter and area of a square.
Question 3. Diameter, Perimeter, volume and density of the earth
Question 4-6. Calculation: ratios of mass of the earth to mass of the sun, radius of

the earth to the radius of the sun, radius of the earth to radius of the earth's orbit.

Homework 4: (2 pages)
Parallel lines, angles, circle
Multiplication and division by multiples of 10 and powers of 10 to be solved orally.[5pt]
Homework 5: Revision of the sun-earth system (3 pages)
Question 1. Two evidences of the spherical shape of the earth.
Question 2. Shape of different celestial bodies.
Question 3. The earth and the sun-earth system from three different perspectives.
Question. Factual questions on sun-earth model.
Question 4, 5 & 6. Diagrams of sun-earth system from different perspectives (top, oblique, side).
Question 7. Explanation of parallel ray assumption.
Question 8. Time zones on the earth and local noon in different locations in India.

Homework between Part II and III of the intervention included observations of the moon. Two observation charts were provided to the class.
Moon observation chart 1: Overnight observations (1 page)
Moon observation chart 2: For a month (4 pages so that observations of 30 days could be taken). Only first page is given here as a sample.

Homework 6: (3 pages)
Questions based on overnight observations of the moon
Factual questions about the moon, dimensions and distances. Answers to be found from textbooks and written down. Rations of sizes of celestial bodies and distances between them to be calculated.
Questions about time of moonrise and moonset to be found from calendar.
Common alternative conceptions about moon to be judged correct or incorrect.

For diagrams see the original Marathi versions http://www.hbcse.tifr.res.in/data/pdf/vthinking/homeworks-original-marathi-versions

Appendix D

Spatial Tasks

D.1 Part 2

ST1: Suppose you go far away from the earth and sun in a spaceship. Imagine what you will see there. Draw a picture of what you imagine.

ST2: Fold a sheet of paper as shown below and draw the picture of the object that you get.

ST3: If you fold the paper as shown in the picture, what will the resultant pattern look like? Choose from the options given below.

ST4

1. What is the angle between the index finger and the middle finger if they are stretched and kept as far as possible? Trace the lines of the fingers on paper and measure the angle using a protractor.

2. What is the angle between any two blades of a fan which has 3 blades? You need not actually measure the angle in this case.

3. If we are turning the page of a book which is kept on the bench, by what angle do we turn the page?

4. What is the angle between the hour hand and minute hand when it is 3 o'clock? Find two other times when the angle between hour hand and the minute hand is the same as the angle between them at 3 o'clock.

ST5

1. If you rotate the digit “3" (3) by 180°, which Marathi digit will you get? (Ans: 6)

2. If you rotate the letter “p" by 180°, which letter will you get? (Ans: d)

3. Rotate the letter “D" anti-clockwise by 90° and join the letter “J" under it. Which shape does the resulting figure look like? (Ans: An umbrella)

4. Which is the digit which remains as it is even if you rotate it through any angle?(Ans: O)

ST6: Draw the picture which will be next in the sequence given below.

ST7

1. How will be the shadow of a cylindrical tiffin box, if light shines on it from the top? How will the shadow of the same box look like if the light is coming exactly from the side? Draw the pictures of shadows in the both cases.

2. When light falls on a wooden object from the side the shadow that we get is triangular in shape. But if the light falls from the top of the object the shadow we get is circular. Draw this object.

ST8: How would following things will look if you see them from three different perspectives?

	A bucket	A bowl
Top view		
Top + Side view		
Side view		

ST9: Mark the option which will complete the given picture.

ST10: A plan view of a garden is given below. You are standing at the main gate, facing the garden at the position marked ‘U’. Answer the following questions with reference to the map.

i. In which direction with respect to you is the water tank?

ii. While going towards the water tank, where does the first road on your right-hand side lead to?

iii. What is present on the left hand side to the road while going towards the water-tank?

iv. From where you are standing, how will you go towards the swings and slides from the main main gate?

v. Your little sister is standing at the position marked ‘X’ on the map. Give her instructions to reach you.

ST11: A small calf went grazing for the first time and got lost. Now he is not able to find the way back. Help the calf to find the way to the cowshed.

ST12

a. Draw the map of your school campus. The school building, hostel, kitchen etc in the map should be roughly according to the their relative shapes and sizes. Draw the maps carefully because they will be used in planning some improvements of the campus.

b. Explain the way to your home from the school by drawing a neat map. Show the main landmarks on the way in your map. Write your name in the square which indicates your house. I may come to your house using this map, so draw the map carefully.

D.2 Part 3

ST1: Fold the given paper according to the instructions to get a world map on the globe.

ST2: Suppose, we fold the paper as shown below and cut the dark part. Then we unfold the paper. Draw a picture to show how the cut will look like.

ST3

1. Draw a larger Rangoli which is the same shape as the given Rangoli.

2. Neatly draw the grid of points for a Rangoli neatly. Draw any Rangoli pattern which you know in that grid.

ST4

1. Identify which of the following things are rotating clockwise and ones rotating anticlockwise.

2i. What English word can be formed from following: Half circle - “Right angle - Full circle - Half circle - K"

2ii. Rotate the letter “C" in the clockwise direction by 90°. Now rotate the letter “T" by 180° and join it under the rotated C°. What shape do you get?

2 iii. How will the digit “5" look if you rotate it by 90° clockwise?

2 iv. If there are parallel lines in the following letters, make the parallel lines bold.

3. Draw two parallel lines 3 cm away from each other.

Draw pictures of 3 objects which contain parallel lines. Make the parallel lines bold.

4. Draw an acute angle, a right angle and an obtuse angle. Write the measure of each angle. Give an example where you see these angles in your surroundings.

Acute angle Right angle Obtuse angle

ST5: Draw the picture of the shape which will come next in the given sequence of 4 shapes. ST Repetition of ST from cycle 2

ST6

1. Suppose you hold a bangle horizontally in the sunlight:

a. Draw the shadow of the bangle when it is midnoon and the sun is overhead.

b. Draw the shadow of the bangle when the sun is at an angle at the evening.

2. The roof of a house has a circular window so that the sunlight can come in. Draw the pictures of a light beam when it comes through the window in the morning, noon and in evening.

3. A bucket is kept in the sunlight in the morning. Does the sunlight fall directly on the bottom of the bucket?

How should we keep the bucket if we want the sunlight to fall on the bottom of the bucket?

4. A particular kind of glass gets dark when sunlight falls on it. The glass becomes darker if more sunlight falls on it. Three pieces of this glass which have the same area are kept in sunlight at noon in different inclinations.

Shade the darkest glass with a mesh and the moderately dark one with parallel lines. Leave the one which will be least dark blank.

ST7: Following map shows how Patgaon (name of a place) looks, if we see it from an airplane. Help the new people in the town to find out addresses:

1. Instruct Ashwini how to go back to her home from school.
2. Instruct Rohini how to go to the school.
3. Instruct Chitra how to go to the market.
4. Instruct Swati how to go to the bus stop.
5. Instruct Revati, how to go to Ashwini's house.

For diagrams see the original Marathi versions see http://www.hbcse.tifr.res.in/data/pdf/vthinking/spatial-tasks-original-marathi-versions.

Appendix E

Other educational material

The round earth: Interactive reading material on historical development of model of the spherical earth and evidences for spherical shape of the earth.

Revolving of the earth: Interactive reading material on historical development of heliocentric model of the sun-earth system.

Play - Life of Galileo: One page information about Galileo Galilei, and the Play by Bertolt Brecht (Brecht, 1947). Six pages of Marathi translation of the play by Rajiv Naik. The underlined sentences were covered while giving the photocopies to students.

Information Charts

Information Chart 1: Dimensions, rations and important features of the sun-earth system.

Information Chart 2: Relation between Marathi months, sun-*Nakshatra* and gregorian calendar of 2007.

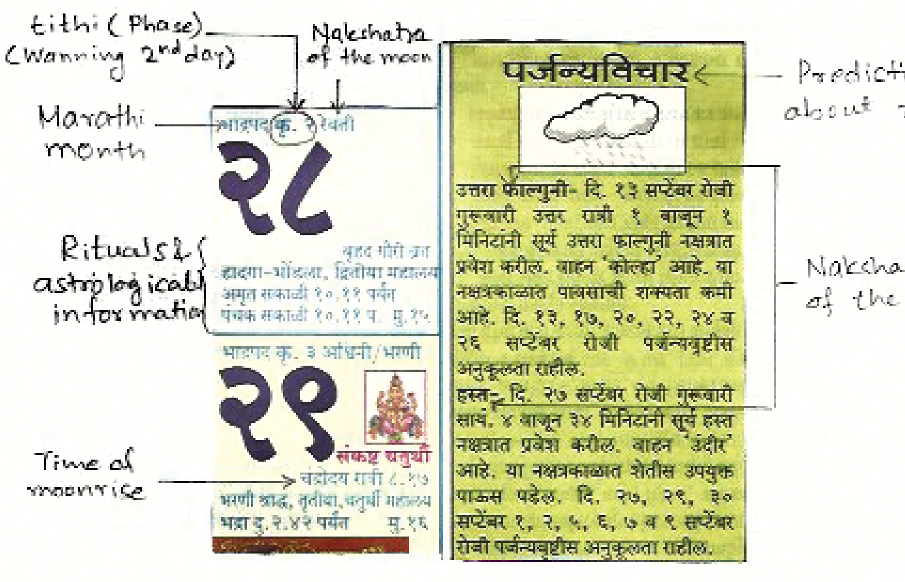
Information Chart 3: Dimensions and time periods of the planets in the solar system.

Information Chart 4: Dimensions, rations and important features of the sun-earth-moon system.

For diagrams see the original Marathi versions at http://www.hbcse.tifr.res.in/data/pdf/vthinking/other-educational-material-original-marathi-versions

Calender

(a) Portable size Shri (17X9 cm) Mahalaxmi calendars were given to groups of students



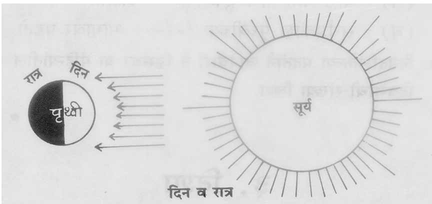
(b) Astronomical notes on wall-calendar (40X28 cm) (28, 29 September 2007)

Figure E.1: A local calendar can connect indigenous knowledge to observational astronomy

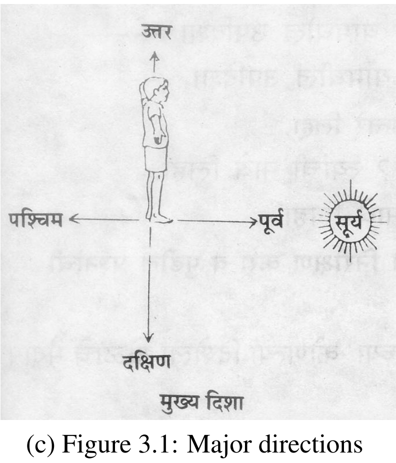
Appendix F

Diagrams from Maharashtra State Textbooks

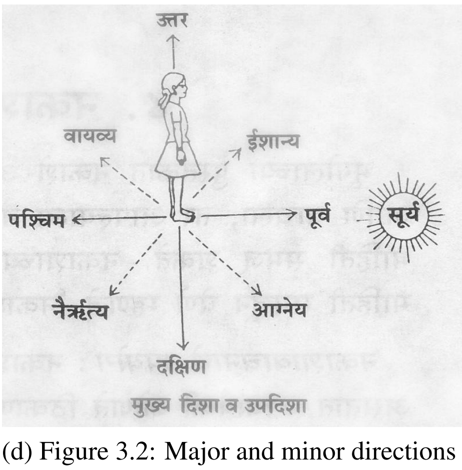
(a) Figure 1.1: Phases of the moon



(b) Figure 2.1: Day and night



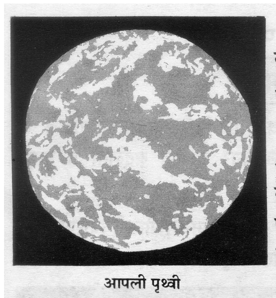
(c) Figure 3.1: Major directions



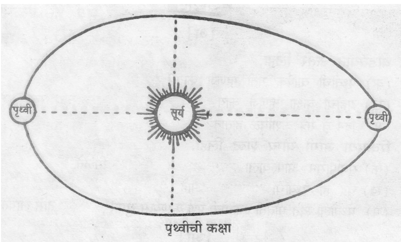
(d) Figure 3.2: Major and minor directions

Figure F.1: Diagrams from Grade 3 Geography textbook

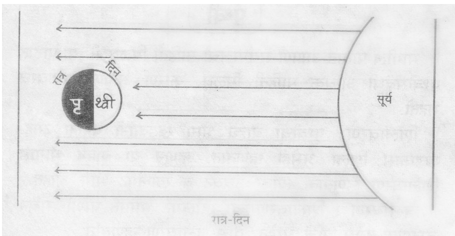
(a) Figure 1.1: Our Solar system



(b) Figure 1.2: Our earth

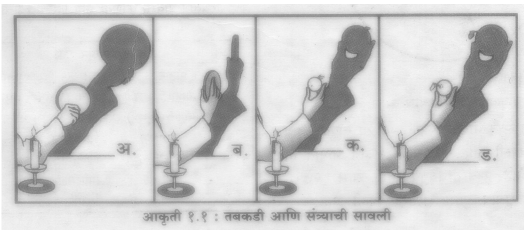


(c) Figure 1.3: Orbit of the earth

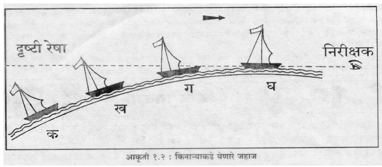


(d) Figure 1.4: Night-day

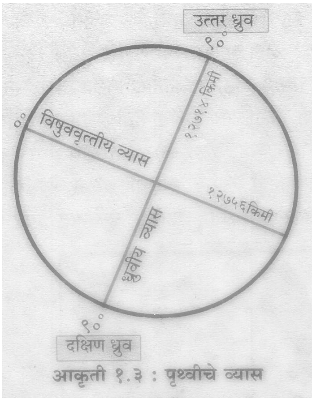
Figure F.2: Diagrams from Grade 4 Geography textbook



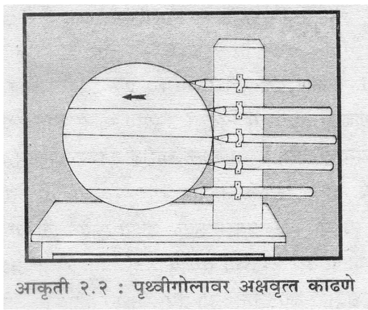
(a) Figure 1.1: Shadow of a plate and an orange



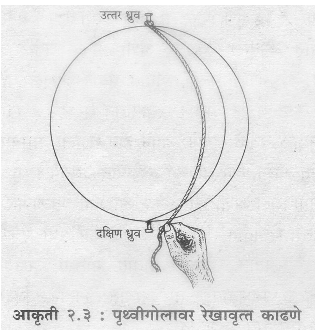
(b) Figure 1.2: A ship approaching an observer



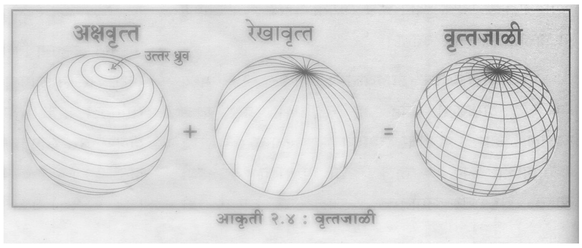
(c) Figure 1.3: Diameters of the earth



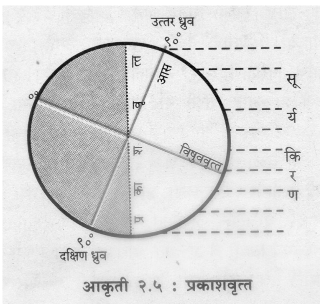
(d) Figure 2.2: Drawing latitudes on a globe



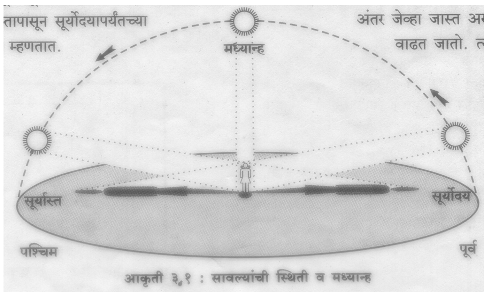
(e) Figure 2.3: Drawing longitudes on a globe



(f) Figure 2.4: Latitudes and longitudes

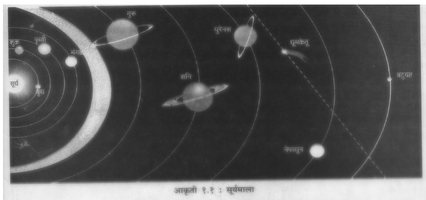


(g) Figure 2.5: The terminator

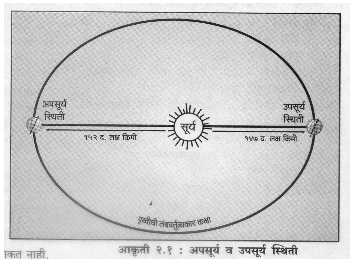


(h) Figure 3.1: Positions of the shadows and noon

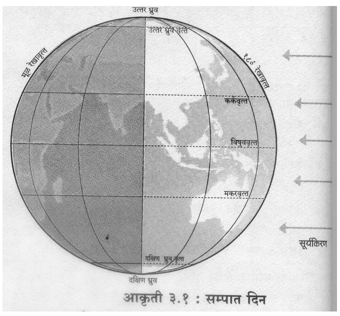
Figure F.3: Diagrams from Grade 5 Geography textbook



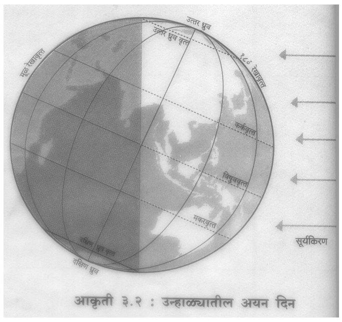
(a) Figure 1.1: Solar system



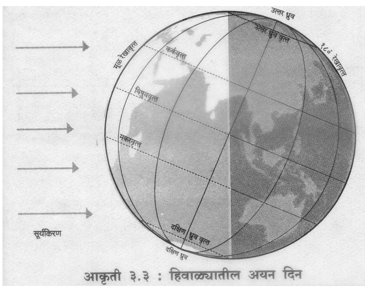
(b) Figure 2.1: Apogee and Perigee positions



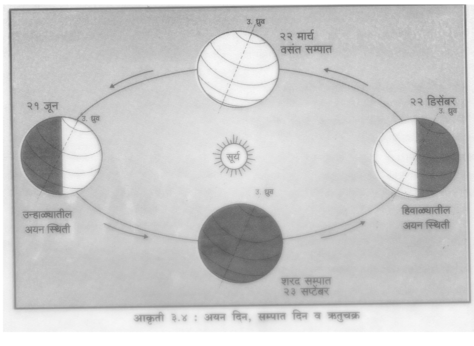
(c) Figure 3.1: The equinox



(d) Figure 3.2: The summer solstice



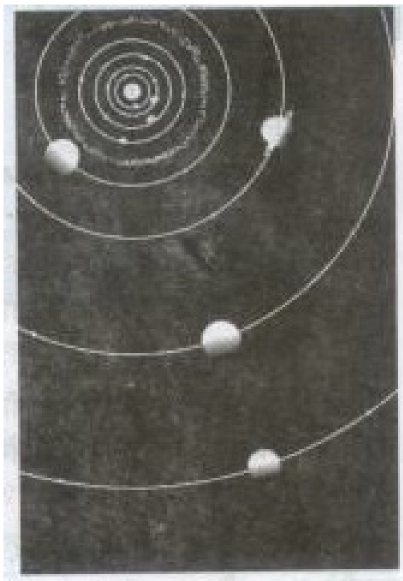
(e) Figure 3.3: The winter solstice



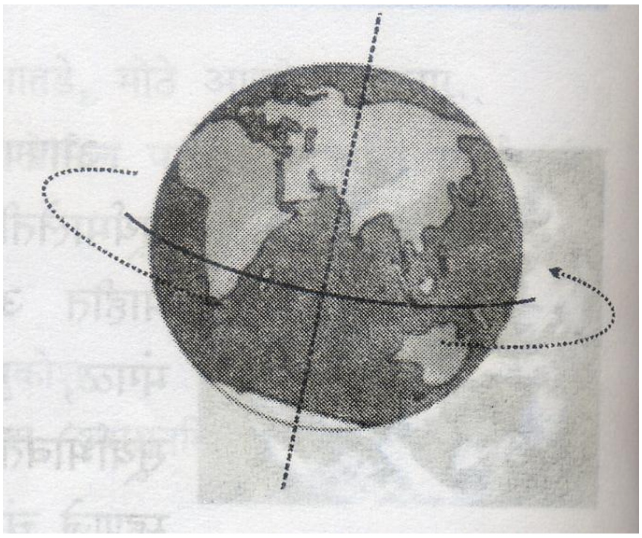
(f) Figure 3.4: Solstice, equnox and cycle of seasons

Figure F.4: Diagrams from Grade 6 Geography textbook

(a) Figure 1.1: Summer solstice - position on 21st June

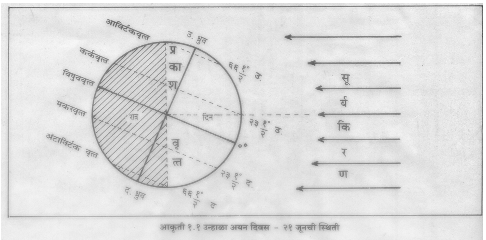


(b) Figure 1.2: Winter solstice - position on 22nd December

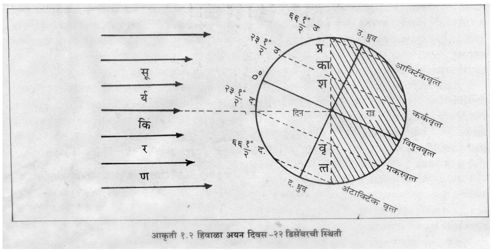


(c) Figure 1.3: Position on 21st March and 22nd September

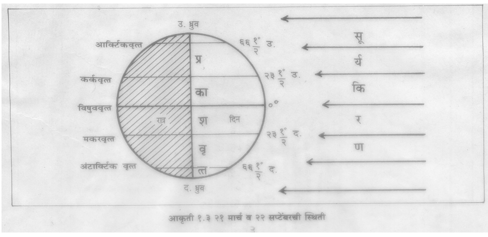
Figure F.5: Diagrams from Grade 6 Science textbook



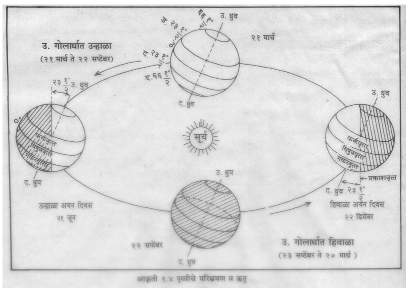
(a) Figure 1.1: Summer solstice - position on 21st June



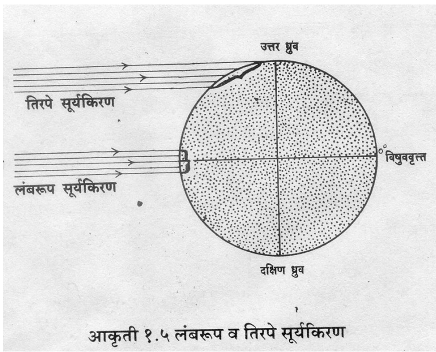
(b) Figure 1.2: Winter solstice - position on 22nd December



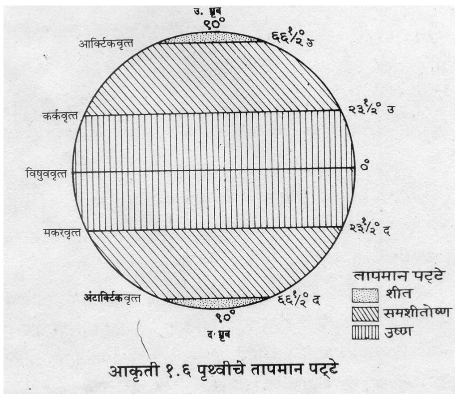
(c) Figure 1.3: Position on 21st March and 22nd September



(d) Figure 1.4: Revolution of the earth and seasons

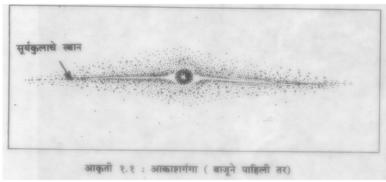


(e) Figure 1.5: Perpendicular and oblique sun-rays

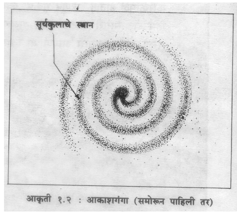


(f) Figure 1.6: Temperature belts on the earth

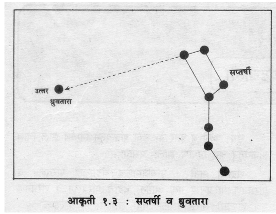
Figure F.6: Diagrams from Grade 7 Geography textbook



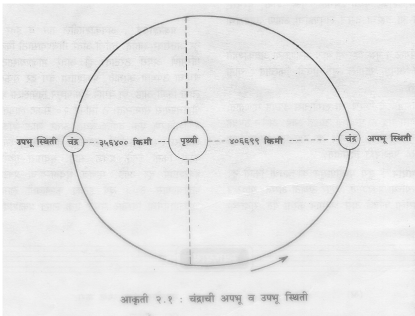
(a) Figure 1.1: Galaxy (if seen from front)



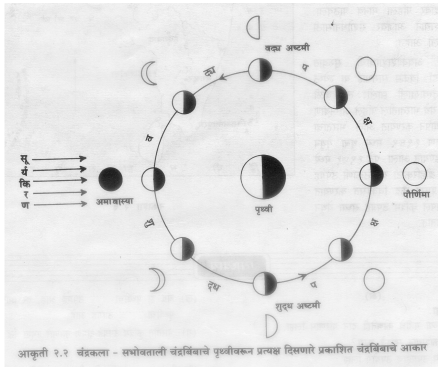
(b) Figure 1.2: Galaxy (if seen from side)



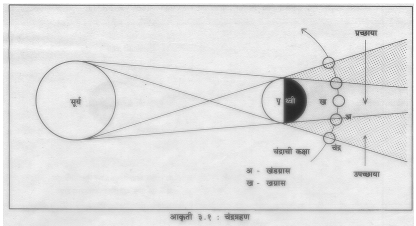
(c) Figure 1.3: The great bear and the Pole star



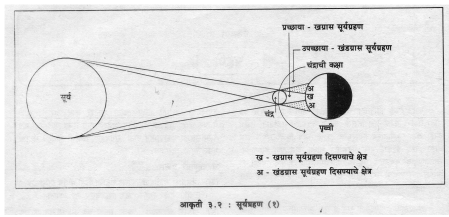
(d) Figure 2.1: Apogee and Perigee positions of the moon



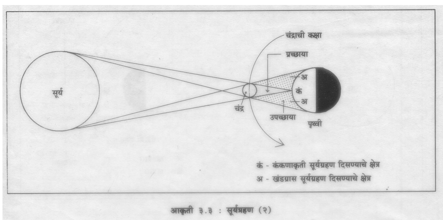
(e) Figure 2.2: Phases of the moon



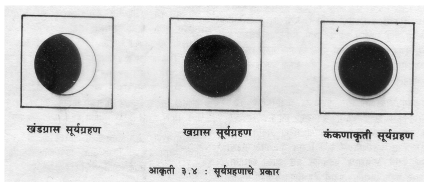
(f) Figure 3.1: Latitudes and longitudes



(g) Figure 3.2: The terminator



(h) Figure 3.3: Positions of the shadows and noon



(i) Figure 3.4: Positions of the shadows and noon

Figure F.7: Diagrams from Grade 8 Geography textbook

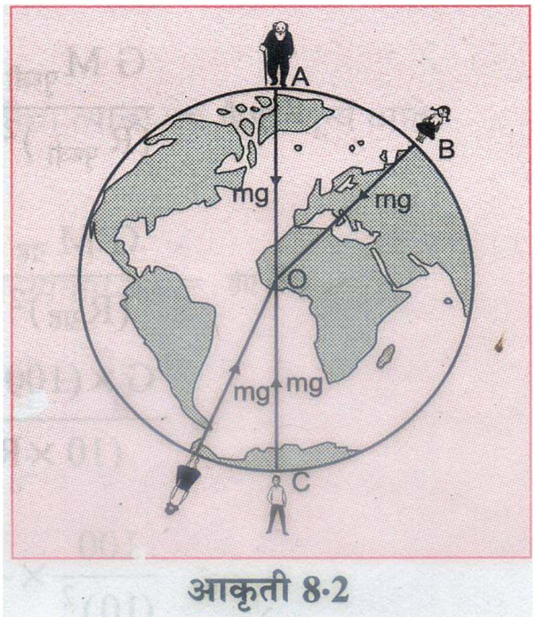


Figure F.8: Diagram from Grade 9 Science textbook

Appendix G

Glossary

G.1 Cognitive science

externalize: verb [trans.] (usu. be externalized)
give external existence or form to
express (a thought or feeling) in words or actions
Psychology project (a mental image or process) onto a figure outside oneself
DERIVATIVES: externalization [noun]
From New Oxford American Dictionary (Provided by OsX)

haptic: adjective technical
of or relating to the sense of touch, in particular relating to the perception and manipulation of objects using the senses of touch and proprioception.
From New Oxford American Dictionary (Provided by OsX)

internalize: verb [trans.]
(Psychology) make (attitudes or behavior) part of one's nature by learning or unconscious assimilation.
acquire knowledge of
DERIVATIVES: internalization [noun]
From New Oxford American Dictionary (Provided by OsX)

kinesthesia (Brit. kinaesthesia): noun
awareness of the position and movement of the parts of the body by means of sensory organs (proprioceptors) in the muscles and joints.
DERIVATIVES: kinesthetic
adjective
From New Oxford American Dictionary (Provided by OsX)

mental imagery
Mental imagery (varieties of which are sometimes colloquially refered to as "visualizing," "seeing in the mind's eye," "hearing in the head," "imagining the feel of," etc.) is quasi-perceptual experience; it resembles perceptual experience, but occurs in the absence of the appropriate external stimuli. It is also generally understood to bear intentionality (i.e., mental images are always images of something or other), and thereby to function as a form of mental representation.
From Stanford Encyclopedia of Philosophy retrieved on 8 Sept. 2010. (http://plato.stanford.edu/entries/mental-imagery/) *First published Tue Nov 18, 1997; substantive revision Fri Apr 2, 2010.*

motor: adjective [attrib.]
giving, imparting, or producing motion or action
(Physiology) relating to muscular movement or the nerves activating it
From New Oxford American Dictionary (Provided by OsX)

perception: noun
the ability to see, hear, or become aware of something through the senses
(Psychology & Zoology) the neurophysiological processes, including memory, by which an organism becomes aware of and interprets external stimuli.
From New Oxford American Dictionary (Provided by OsX)

representation: noun
a thing, esp. a picture or model, that depicts a likeness or reproduction of someone or something

(in some theories of perception) a mental state or concept regarded as corresponding to a thing perceived.
From New Oxford American Dictionary (Provided by OsX)

sensorimotor: adjective
Etymology: sensory + motor
of, relating to, or functioning in both sensory and motor aspects of bodily activity
sensory
adjective
of or relating to sensation or to the senses
conveying nerve impulses from the sense organs to the nerve centers
Merriam Webster online dictionary retrieved on 8 Sept. 2010. (http://www.merriam-webster.com/dictionary/sensorimotor)

spatial cognition
spatial: adjective
of or relating to space
cognition: noun
the mental action or process of acquiring knowledge and understanding through thought, experience, and the senses.
a result of this; a perception, sensation, notion, or intuition.
From New Oxford American Dictionary (Provided by OsX)

visualize: verb [trans.]
1 form a mental image of; imagine
2 make (something) visible to the eye
From New Oxford American Dictionary (Provided by OsX)

G.2 Indigenous astronomy

Tithi (also spelled *thithi*): a lunar day, or the time it takes for the longitudinal angle between the moon and the sun to increase by 12°.

Names of *Tithi*: *Amavasya* (New moon), *Pratipada, Dvitiya, Tritiya, Chaturthi, Panchami, Shashti, Saptami, Ashtami* (Half moon), *Navami, Dasami, Ekadashi, Dvadashi, Trayodasi, Chaturdashi, Pournima* (Full moon)
From wikipedia entry retrieved on 8 Sept. 2010.(http://en.wikipedia.org/wiki/Tithi)
These names translate literally to first, second, third and so on and hence are not difficult to remember.

Names of Marath Months: *Chaitra, Vaishakh, Jyeshtha, Aashadh, Shravan, Bhadrapad, Ashwin, Kartik, Margashirsh, Paush, Magh, Falgun*

Nakshatra: lunar mansion is one of the 27 divisions of the sky, identified by the prominent star(s) in them.
Names of *Nakshatra*: *Ashwini, Bharani, Krittika, Rohini, Mrigashirsha, Ardra, Punarvasu, Pushya, Ashlesha, Magha, Purva-Falguni, Uttara-Falguni, Hasta, Chitra, Swati, Vishakha, Anuradha, Jyeshtha, Mool, Purvashadha, Uttarashadha, Sravan, Dhanishtha, Shatataraka, Purva-Bhadrapada, Uttar-Bhadrapada, Revati*
From wikipedia entry retrieved on 8 Sept. 2010.(http://en.wikipedia.org/wiki/Nakshatra)

Rashi: Zodiac or Star sign
Zodiac: the ring of constellations that lines the ecliptic, which is the apparent path of the Sun across the celestial sphere over the course of the year. The paths of the Moon and planets also lie roughly within the ecliptic, and so are also within the constellations of the zodiac.
From wikipedia entry retrieved on 8 Sept. 2010.(http://en.wikipedia.org/wiki/Zodiac)
Names of *Rashi*: *Mesha, Vrishabha, Mithuna, Karka, Sinha, Kanya, Tula, Vrushchik, Dhanu, Makar, Kumbha, Meena*

Appendix H

Statistics

The following statistical tests were carried out using SPSS version 16.
1. One Sample Kolmogorov-Smirnov Test: To test the normality of total scores for each Grade (Grades 4, 7, 8t, 8t; after collapsing the rural, tribal and urban samples) and each sample (Rural, Tribal, Urban; after collapsing Grades 4, 7, 8t and 8c in each sample) for all tests.

2. Comparison between Grades: Total scores for each grade were compared using:
Paired t-test (Gr7-Gr8t)
Independent sample t-test (Gr4-Gr7, Gr8t-Gr8c)
Mann-Whitney test (Gr8t-8c for Test 5)

3. Comparison of samples: The differences between three samples were compared using:
T-Test (Rural-Tirbal): For Test 2 & Test 3
Mann-Whitney Test (Rural-Tirbal): For Test 1, Test 4 (Q1-7), Test 4, Test 5 (Q2-9) & Test 5
T-Test (Tribal-Urban): For Test 1, Test 2, Test 3 & Test 4 (Q1-7)
Mann-Whitney Test (Tribal-Urban): For Test 4, Test 5 (Q2-9) & Test 5
T-Test (Rural-Urban): For Test 2 & Test 3, Test 4 & Test 5 (Q2-9)
Mann-Whitney Test (Rural-Urban): For Test 1, Test 4 (Q1-7) & Test 5

statistical tables are given here:

One sample Kolmogorov–Smirnov test for Normality

Grade	statistic	Test 1	Test 2	Test 3	Test 4 (Q1-7)	Test 4	Test 5 (Q2-9)	Test 5
4	N	87	88		88			
	Mean	33.25	28.05		15.85			
	SD	8.05	8.53		3.73			
	KS z	0.64	0.48		1.22			
	p	0.81	0.98		0.1			
7	N	66	58	59	54		43	
	Mean	44.7	38.56	24.57	17.18		14.34	
	SD	12.44	10.93	8.68	4.03		7.54	
	KS z	0.77	0.92	0.69	0.71		0.69	
	p	0.59	0.37	0.73	0.7		0.73	
8t	N	53	53	54	54	54	53	53
	Mean	60.4	47.64	32.16	31.7	55.39	22.71	24.56
	SD	17.06	12.37	12.63	9.41	20.26	15.21	16.28
	KS z	0.57	0.91	0.71	0.59	0.65	0.95	0.79
	p	0.9	0.38	0.7	0.88	0.8	0.32	0.57
8c	N	72	80	79	76	76	80	80
	Mean	36.45	36.98	25.17	16.57	24.31	11.04	11.67
	SD	9.07	12.18	7.63	5.66	10.08	8.35	8.39
	KS z	0.49	0.64	0.75	0.57	1.2	1.52	1.49
	p	0.97	0.81	0.63	0.9	0.11	0.02	0.02
Scores of Gr8c are not normaly distributed for Test 5 (Q2-9) and Test 5								

Samples

Rural	N	119	123	92	118	64	83	59
	Mean	41.7	35.99	29.21	19.56	41	18.27	19.72
	SD	17.11	14.84	11.69	9.75	23.39	13.54	16.32
	KS z	1.61	0.61	0.89	1.95	0.9	1.17	1.47
	p	0.01	0.85	0.41	0	0.39	0.13	0.03
Tribal	N	87	85	74	84	57	84	65
	Mean	45.34	37.02	25.7	19.89	30.51	11.69	13.09
	SD	13.26	11.98	7.56	8.32	16.99	7.98	9.2
	KS z	0.89	0.62	0.98	1.16	1.48	1.36	1.45
	p	0.41	0.84	0.3	0.14	0.03	0.05	0.03
Urban	N	72	71	26	70	9	9	9
	Mean	38.35	36.83	22.52	18.79	52.83	22.89	24.56
	SD	13.16	9.96	8.25	5.91	21.1	14.45	15.16
	KS z	0.79	0.76	0.57	1.13	0.8	0.53	0.56
	p	0.57	0.6	0.91	0.16	0.54	0.95	0.91

Paired T test **Gr7_Gr8t**

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Test 1	46.71	49	11.34	1.62
	Test1_t	60.48	49	16.79	2.4
Pair 2	Test 2	39.4	38	10.92	1.77
	Test2_t	51.32	38	10.43	1.69
Pair 3	Test 3	26.49	38	7.14	1.16
	Test3_t	35.12	38	11.31	1.84
Pair 4	Test 4 (Q1-7)	17.78	36	4.1	0.68
	Test4(Q1-7)_t	33.49	36	8.95	1.49
Pair 5	Test 5 (Q2-9)	14.61	40	7.73	1.22
	Test5(Q2-9)_t	24.1	40	15.4	2.43

		N	Correlation	Sig.
Pair 1	T1_T1t	49	0.27	0.06
Pair 2	T2_T2t	38	0.61	0
Pair 3	T3_T3t	38	0.54	0
Pair 4	T4(1-7)_ T4(1-7)t	36	0.32	0.06
Pair 5	T5(2-9)_ T5(2-9)t	40	0.57	0

		Paired Differences							
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
					Lower	Upper			
Pair 1	T1_T1t	-13.77	17.52	2.5	-18.81	-8.74	-5.5	48	0.000
Pair 2	T2_T2t	-11.92	9.4	1.53	-15.01	-8.83	-7.81	37	0.000
Pair 3	T3_T3t	-8.63	9.56	1.55	-11.77	-5.49	-5.56	37	0.000
Pair 4	T4(1-7)_ T4(1-7)t	-15.71	8.56	1.43	-18.6	-12.81	-11.01	35	0.000
Pair 5	T5(2-9)_ T5(2-9)t	-9.49	12.7	2.01	-13.55	-5.43	-4.73	39	0.000

Independent sample T test **Gr4-Gr7**

	Grade	N	Mean	Std. Deviation	Std. Error Mean
Test 1	4	87	33.25	8.05	0.86
	7	66	44.7	12.44	1.53
Test 2	4	88	28.05	8.53	0.91
	7	58	38.56	10.93	1.44
Test 4 ((	4	88	15.85	3.73	0.4
	7	54	17.18	4.03	0.55

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference		
									Lower	Upper
Test 1	Equal varian	9.65	0	-6.9	151	0.000	-11.45	1.66	-14.732	-8.17

	Equal variances not assumed			-6.52	104.87	0.000	-11.45	1.76	-14.935	-7.97
Test 2	Equal varian	3.92	0.05	-6.5	144	0.000	-10.51	1.62	-13.703	-7.32
	Equal variances not assumed			-6.19	101.29	0.000	-10.51	1.7	-13.880	-7.14
Test 4 (	Equal varian	0.18	0.67	-1.99	140	0.048	-1.32	0.66	-2.638	-0.01
	Equal variances not assumed			-1.96	105.61	0.053	-1.32	0.68	-2.666	0.02

Independent sample T test Gr8t-Gr8c

	Grade	N	Mean	Std. Deviation	Std. Error Mean
Test 1	8	53	60.4	17.06	2.34
	1	72	36.45	9.07	1.07
Test 2	8	53	47.64	12.37	1.7
	1	80	36.98	12.18	1.36
Test 3	8	54	32.16	12.63	1.72
	1	79	25.17	7.63	0.86
Test 4 (	8	54	31.7	9.41	1.28
	1	76	16.57	5.66	0.65
Test 4	8	54	55.39	20.26	2.76
	1	76	24.31	10.08	1.16

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Test 1	Equal varian	22.52	0	10.13	123	0.000	23.94	2.36	19.267	28.62
	Equal variances not assumed			9.3	73.56	0.000	23.94	2.58	18.813	29.08
Test 2	Equal varian	0.78	0.38	4.91	131	0.000	10.66	2.17	6.368	14.95
	Equal variances not assumed			4.9	110.29	0.000	10.66	2.18	6.346	14.97
Test 3	Equal varian	9.65	0	3.97	131	0.000	6.99	1.76	3.508	10.46
	Equal variances not assumed			3.64	79.36	0.000	6.99	1.92	3.163	10.81
Test 4 (	Equal varian	17.27	0	11.42	128	0.000	15.13	1.33	12.509	17.75
	Equal variances not assumed			10.54	80.04	0.000	15.13	1.44	12.274	17.99
Test 4	Equal varian	26.3	0	11.53	128	0.000	31.08	2.7	25.745	36.41
	Equal variances not assumed			10.4	71.72	0.000	31.08	2.99	25.120	37.04

Mann Whitney Gr8t-8c

	Grade	N	Mean Rank	Sum of Ranks
Test 5 (	1	80	53.7	4296
	8	53	87.08	4615
	Total	133		
Test 5	1	80	53.38	4270.5
	8	53	87.56	4640.5
	Total	133		

	Test 5 (Without Q1)	Test 5
Mann-Whitney U	1056	1030.5
Wilcoxon W	4296	4270.5
Z	-4.89	-5.01
Asymp. Sig. (2-tailed	0.000	0.000

Independent sample T-test Gr7-Gr8c

	Grade	N	Mean	Std. Deviation	Std. Error Mean
Test 1	7	66	44.7	12.44	1.53
	1	72	36.45	9.07	1.07
Test 2	7	58	38.56	10.93	1.44
	1	80	36.98	12.18	1.36
Test 3	7	59	24.57	8.68	1.13
	1	79	25.17	7.63	0.86
Test 4 (	7	54	17.18	4.03	0.55
	1	76	16.57	5.66	0.65

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Test 1	Equal varian	3.58	0.06	4.48	136	0.000	8.25	1.84	4.603	11.89
	Equal variances not assumed			4.42	118.11	0.000	8.25	1.87	4.549	11.94
Test 2	Equal varian	0.06	0.81	0.79	136	0.434	1.58	2.01	-2.401	5.56
	Equal variances not assumed			0.8	129.86	0.426	1.58	1.98	-2.334	5.49
Test 3	Equal varian	0.84	0.36	-0.43	136	0.666	-0.6	1.39	-3.356	2.15
	Equal variances not assumed			-0.43	115.6	0.672	-0.6	1.42	-3.413	2.21
Test 4 (	Equal varian	7.02	0.01	0.67	128	0.503	0.6	0.9	-1.175	2.38
	Equal variances not assumed			0.71	128	0.479	0.6	0.85	-1.078	2.29

Mann Whitney (Test 5) Gr7-Gr8c

	Grade	N	Mean Rank	Sum of Ranks
Test 5 ('	1	80	55.17	4413.5
	7	43	74.71	3212.5
	Total	123		

Test 5 (Without Q1)	
Mann-Whitney U	1173.5
Wilcoxon W	4413.5
Z	-2.9
Asymp. Sig. (2-tailed	0.004

NPar Tests: Sample 1 (rural) Test 1, 4(Q1-7), 5 not normal
NPar Tests: Sample 2 (tribal) Test 4, 5 (without Q1), 5 not normal
NPar Tests: sample 3 (urban) all normal

T-Test (rural, tirbal)

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Differen ce	Std. Error Differen ce	95% Confidence Interval of the Difference	
									Lower	Upper
Test 2	Equal va	4.26	0.04	-0.53	206	0.6	-1.03	1.94	-4.85	2.8
	Equal variances not assun			-0.55	200.97	0.58	-1.03	1.87	-4.7	2.65
Test 3	Equal va	6.71	0.01	2.23	164	0.03	3.5	1.57	0.4	6.61
	Equal variances not assun			2.33	157.21	0.02	3.5	1.5	0.54	6.47

Test 2: No difference
Test 3: Rural>Tribal

Mann-Whitney Test (rural, tribal)

	Test 1	Test 4 (1-7)	Test 4	Test 5 (2-9)	Test 5
Mann-Whitney U	3959	4494.5	1351.5	2456.5	1525
Wilcoxon W	11099	11515.5	3004.5	6026.5	3670
Z	-2.88	-1.13	-2.45	-3.3	-1.96
Asymp. Sig. (2-tai	0	0.26	0.01	0	0.05

Test 1:tribal > rural
Test 4 (Q1-7): No difference
Test 4: rural > tribal
Test 5 (Q2-9): rural > tribal
Test 5: rural > tribal

T-Test: (tribal, urban)

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Differen ce	Std. Error Differen ce	95% Confidence Interval of the Difference	
									Lower	Upper
Test 1	Equal va	0.16	0.69	3.32	157	0	6.99	2.11	2.83	11.15
	Equal variances not assun			3.32	151.93	0	6.99	2.1	2.83	11.15
Test 2	Equal va	4.09	0.05	0.1	154	0.92	0.19	1.79	-3.34	3.72
	Equal variances not assun			0.11	154	0.92	0.19	1.76	-3.28	3.66
Test 3	Equal va	0.28	0.6	1.8	98	0.07	3.18	1.76	-0.32	6.68
	Equal variances not assun			1.73	40.72	0.09	3.18	1.84	-0.53	6.9
Test 4 (C	Equal va	7.01	0.01	0.92	152	0.36	1.09	1.19	-1.25	3.44
	Equal variances not assun			0.95	148.49	0.34	1.09	1.15	-1.18	3.37

Test 1: tribal>urban
Test 2: No difference
Test 3: No difference
Test 4 (Q1-7): No difference

Mann-Whitney Test (tribal, urban)

	Test 4	5 (Withou	Test 5
Mann-Whitney U	90	184.5	151.5

Wilcoxon W	1743	3754.5	2296.5
Z	-3.11	-2.52	-2.33
Asymp. Sig. (2-ta	0	0.01	0.02

Test 4: urban>tribal
Test 5 (Q2-9): urban>tribal
Test 5: urban>tribal

T-Test (rural, urban)

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Test 2	Equal va	14.29	0	-0.42	192	0.67	-0.84	1.98	-4.74	3.06
	Equal variances not assun			-0.47	187.57	0.64	-0.84	1.79	-4.36	2.68
Test 3	Equal va	1.67	0.2	2.73	116	0.01	6.69	2.45	1.83	11.54
	Equal variances not assun			3.3	56.48	0	6.69	2.03	2.63	10.74
Test 4	Equal va	0.04	0.85	-1.44	71	0.16	-11.83	8.24	-28.26	4.59
	Equal variances not assun			-1.55	10.96	0.15	-11.83	7.62	-28.6	4.94
Test 5 (V	Equal va	0.25	0.62	-0.97	90	0.34	-4.62	4.78	-14.12	4.87
	Equal variances not assun			-0.92	9.59	0.38	-4.62	5.04	-15.92	6.67

Test 2: No difference
Test 3: rural>urban
Test 4: No difference
Test 5 (Q2-9): No difference

Mann-Whitney Test (rural, urban)

	Test 1	st 4 (Q1-	Test 5
Mann-Whitney U	3951.5	3689	197.5
Wilcoxon W	6579.5	10710	1967.5
Z	-0.9	-1.22	-1.23
Asymp. Sig. (2-ta	0.37	0.22	0.22

Test 1: No difference
Test 4 (Q1-7): No difference
Test 5: No difference

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Bad moon rising.

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