An indigenous approach to elementary astronomy - how cognitive research can help

We report a study on Grade 8 students' understanding of elementary astronomy. We aim to use recent research in visuospatial reasoning to develop a locally appropriate low-cost teaching methodology for elementary astronomy. Our Experimental sample is drawn from students of three different schools (tribal, rural, urban-slum) in educationally disadvantaged areas in the State of Maharashtra, India. The study consists of three parts: (1) investigation of students' initial knowledge, (2) exposure of 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. We present the rationale and general features of the pedagogical sequence which we developed with the aim to help students use visuospatial reasoning to explain daily astronomical phenomena. We also report some preliminary findings about students' development.

Astronomy in middle school

School science introduces elementary astronomy with the aim of scientific literacy. It includes the heliocentric model of the solar system and explanation of daily astronomical phenomena such as day and night, seasons, phases of the moon and eclipses. But 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 [15, 1]. 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, etc. is common among school students and among adults [21, 1, 19]. One reason might be, such explanations require considerable amount of abstraction of the real situation including simplifications and assumptions, choosing appropriate parts and variables of the model etc., a feature, in fact, of any scientific reasoning. Another reason, which might be specific to these kinds of problem, is that one has to be familiar in handling images which might require cognitive tools such as drawing (mapping 3-d on 2-d, symbolizing dynamic aspects in static diagrams and retrieving them at the appropriate point, choosing an appropriate point of view, etc.). We [13] have found that architects who were well equipped with drawing techniques were much better at explaining phases of the moon than were adults who held Master's degrees in physics. Another study has documented that visuospatial abilities may affect knowledge about astronomy significantly and positively [7].

In India, astronomy is taught as a part of geography. It is possible that geography teachers are not well-prepared to deal with the content of astronomy. Textbooks recount explanations of phenomena, but more in an informative fashion rather than as reasoned arguments. The use of diagrams is limited and not very carefully done [11]. Teaching is driven by the limited expectations from students in examinations, in which neither is knowledge probed in detail nor are 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.

Selection of sample

Our aim was to select student samples representative of the socio-economically deprived majority population of India. According to the 2001 census [3], more than 72% of the Indian population lives in villages. More than 8% of the population is 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. Students do not have access to extra science books, educational videos or computers; in fact they often come to class without minimal tools such as pencils, erasers or notebooks.

Considering this population profile, 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 Experimental and Control samples; in the urban school the Control sample was selected from the same school. The representation of girls in both Experimental and Control Groups was around 30% because of higher drop-out rate among girls.

Rural sample

The rural sample is from a village in south-western Maharashtra. This being one of the relatively 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 total population 4428 (according to the 2001 census) and area 12.84 sq. Km. (including the area of 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 among 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 [9]. 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 held in the local temple, was chosen for the experimental group and another which has its own small building served in our control group.

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 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 alcohol, but most of them are still not settled. There are around 30 lakh nomadic tribals in Maharashtra in whom the percentage of education is less than 0.1% [18]. So most of the students are first-generation learners. Residential schools devoted to nomadic tribes have been operational in this area since 1988. Run by socially progressive organisations 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 were chosen: one for the Experimental sample and another for Control.

Urban-slum sample

The third school serves a suburban slum area of Mumbai, 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 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 Control group. The rural and tribal Experimental and Control samples consisted of an entire class in each school.

Local learning opportunities (rural and tribal samples)

Although all the samples are deprived of formal 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:

- 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 their 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 Indian calendars to regulate agricultural activity and festivals. As a result perhaps, astrology plays an important role in their lives. 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.

We carried out a preliminary investigation with students at different grade levels in order to get a broad view of their range of development over the school years. This sample consisted of students who were about to finish Grade 4 (end of primary school) and Grade 7 (end of middle school). The tests were also administered to a few students from Grades 3 and 5. The one-year pedagogy sequence was started only for students who were about to complete Grade 7. At the end of the intervention, these students had reached the end of their Grade 8. The assessment of our intervention was carried out using post tests on three (tribal, rural and urban) Experimental groups and three Control groups of Grade 8 students. In this paper we discuss performance of the Experimental groups only, over the pretests and during the intervention.

Testing prior knowledge

Based on our informal assessment of these samples (as described in the previous section) and one open-ended discussion session in each class, we prepared four tests, one each on: observations, textbook information, cultural information and conceptual understanding. The tests were followed by individual interviews of a selected subsample to probe their models in detail. The analysis of pre-test responses of Grade 7 students is summarised here. Qualitative details of the first four points along with percentages of students' correct and faulty responses are documented in [12].

1. Although most students could state a few observational facts, detailed and careful observations were rare. This was an unexpected finding especially for the rural and tribal samples.

2. Students' scores in textbook information were highest among all four tests. Students were well familiar with terms used in textbook, but a few very useful concepts, such as horizon and axis of rotation, were not introduced in the textbook.

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.

4. Students had erroneous models of the earth such as flat earth (2%), hollow earth (15%) and spherical earth without gravity integrated with it (60%). For classification scheme see [16]. Students did not have 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.

5. From statistics for scores in pretests we found that all the distributions are normal (so t-tests can be used for comparison although the sample sizes are small).

6. Tribal students scored significantly higher than urban students on the cultural information test, which was not surprising, but counter to our expectations the rural students' scores in the cultural information test were not significantly higher than those of urban students.

7. Tribal students scored higher than the rural students on observation, but again, no significant difference was found between the rural and urban students' scores on observation.

8. Taking all tests together, the tribal students scored higher than the rural students.

Cognitive consideration in astronomy learning

Given the background of astronomy education in India and the socio-economic context and prior knowledge of our student samples, we explore how cognitive considerations could help us develop an indigenous approach to elementary astronomy.

The search for explanation of natural phenomena is at the core of scientific investigation, and is often believed to form the core of science education as well. Constructing a mental model and explaining observations based on it is a classic mode of scientific discovery [10]. The place of mental models and of visualization in scientific discovery as well as in science education is addressed in the literature [5, 14]. The study of reasoning using nonconventional cognitive 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, often in combination with propositions and symbols. Model-based visuospatial reasoning we consider 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 [10, 13].

From these studies, we conjecture that tools which help us understand and represent space and motion might help in explaining astronomical phenomena; and astronomical phenomena might, in turn, help in developing spatial reasoning competencies. Diagrams are one of the well documented tools for representing and organizing space [20]. 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 [20, 8]. 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 considering the large range of sizes combined with distances that are literally "astronomical" in comparison with the sizes of objects in the solar system.

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 might provide a good link between models and diagrams. Body gestures have been shown to contribute to our understanding of space and motion [20]. The body being our prime source of understanding space and motion, 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 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.

Next we describe some features of our pedagogy which was based on the above two conjectures.

Pedagogy

Our intervention was divided in to three parts (cycles) of about 10 classroom sessions of one and half hour each. There was a gap of about 5 months between any two teaching cycles. We thought that this gap might be useful for students to think over the taught content, carry out new observations on the gradually changing sky, and thus to come up with new questions and clearer understanding. Students were asked to take careful notes of 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 cycles. These we thought would remind them of the content of the earlier cycle as well as prepare them for the next cycle.

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 cycles.

The pedagogy of the first cycle is described in detail elsewhere [11]. Here we list some general features of the pedagogy of all three cycles, whose overall aim was to construct a working mental model of the sun-earth-moon system and a rough model of the solar system. Students were also expected to explain and predict the phenomena based on the sun-earth-moon system. The pedagogy used 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.

- Outdoor observations of shadows (from which we made inferences about the sun), moon and stars were conducted during the three cycles. Students were provided star charts of the entire year to help them identify the stars. Tools such as a simple gnomon and an astrolabe were prepared by the students and used for observations.

- Students were given photographs of the sun, earth, moon and solar system (model). Activities using concrete models, gestures and role-play were conducted in groups or individually.

- Students were given a copy of the local calendars to help them connect observation with indigenous knowledge. These calendars are combinations of Gregorian calendars and a particular Indian calendar, derived from the almanac called *"Chaitry Panchang"* [4]. These calendars are commonly available. All the urban and most of the rural households in our sample owned a copy of these calendars. They are used in determining festivals and other social as well as the (often related) agricultural practices around the year. These calendars document many observational facts such as the times of sunrise and sunset, moonrise and moonset on few a days, phase of the moon, in which constellation the moon would be seen, etc.. We wanted students to use these calendars for their observations.

- Students were given total of 13 questionnaire to solve in the groups of three in the classroom. Video data of one of the groups was taken to study their argumentation.

- Supportive activities included reading and discussing material based on historical development of the round earth and of the heliocentric model (in groups), 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 [2]), recounting mythological stories related to stars or festivals (festivals being associated with astronomical observations), watching an animated film on the solar system, etc.

The first cycle dealt only with the earth, its roundness and rotation. These ideas were sufficient to explain the change in apparent position of the celestial bodies due to change

in position on the globe, as also their daily apparent motion [11]. The second cycle 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. The third cycle dealt with the sun-earth-moon system and hence explanation of phases of the moon and eclipses.

Some preliminary results

We give some informal observations about students' visuospatial thinking during the intervention:

- Students were taught (through activities and visual/ gestural/ diagrammatic arguments) that rays coming to the earth from far-away sources could be considered parallel (ratio of the size of the earth to the distance to the source is very small and hence, the angle subtended is negligible). Activities to prove that sun-rays are parallel were also carried during the class. This assumption is crucial in explanation of many facts such as seasons on the earth and the apparent position of a star in the sky. Students learnt after some practice to use this assumption for the sun rays but they seemed quite unable and unwilling, during problem-solving, to consider rays from a (point-like) star to be parallel [11].

- Students usually found it easy to give a qualitative answer (eg. rough direction of rays from a celestial object) through gestures and mental visualization. But giving an accurate quantitative answer (such as the exact angle of position of a celestial object above the horizon) was found to be difficult, even after much practice in measurement of angles.

- Similarly, they could give a qualitatively correct descriptions or proof of the observations (eg. phases of the moon) but geometrical descriptions and diagrammatic proofs of the same phenomena were difficult to understand.

- When students were given a problem situation without any diagram, it was difficult for them to initiate a solution. But if a skeletal diagram was provided, they did begin to think, although only a few ultimately took a correct path towards the solution. Thus choosing the appropriate portion and aspect of a mental model was perhaps a barrier. Again given a diagram, if step-by-step questions were asked, many students, though not all, could construct an argument. Arguments involving multiple steps of reasoning are inevitable in this subject but they do pose a challenge for pedagogy.

- To our disappointment very few students began using gestures on their own, although gestures were a major part of the pedagogy. The reasons may lie in cultural and classroom practices along with the relevant cognitive processes.

After the third contact sessions the pre test questionnaires were repeated as post tests. One extra questionnaire was added to address content that was new in Grade 8 and was covered in our pedagogic sequence. The same tests were also conducted on the Control groups. Analysis of this data is in progress. A preliminary comparison of pre tests and post tests in the Experimental groups shows that scores on the post tests are

statistically higher than those on pre tests at 99% level of confidence on all individual tests as well as on the total scores, with the exception of the tribal sample on the cultural information test.

Conclusion

Based on cognitive considerations we have developed a pedagogy that we hope is appropriate for the low-resource situation present in most Indian schools. Our study is in a preliminary stage and much of the data is yet to be analysed. We hope that this account of our rationale will be of interest to researchers and teachers in astronomy education as also to cognitive scientists looking for applications of their ideas to education.

Acknowledgments

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