Citation: Padalkar, S. and Subramaniam, K. (2007) Reasoning processes underlying the explanation of the phases of the moon, Proceedings of Episteme-2, 121-125.

Reasoning Processes Underlying the Explanation of the Phases of the Moon.

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Explaining why the phases of the moon occur is a difficult problem for students and adults even after undergoing relevant instruction and even though they have the correct mental model of the Sun - Earth - Moon system. This study explores how qualified young adults explain the moon's phases, how they change the explanation when faced with inconsistency, and the strategies that they use to arrive at a correct and complete explanation. This process is seen to involve visuospatial reasoning based on mental models. Through detailed individual interviews, we analysed the strategies adopted by subjects qualified in physics and students of a 'Master of Design' programme with prior qualification in architecture. The architects, who were more familar with visualization techniques could solve the problem more quickly and accurately. The strategies used by these two groups were also found to be different. Making diagrams and reasoning using diagrams were found to be critical elements of a successful strategy.

Objectives and significance of the study

The study aims to characterize the reasoning process underlying the explanation of the moon's phases and the change in explanation when confronted by inconsistency. From earlier literature it is clear that the explaining the moon's phases is typically difficult for school and college students and that many of them propose alternative mechanisms to explain this phenomenon. Many students and adults (varying from 38% to 70% of the sample in different studies) think that the phases of the moon occur due to the shadow of the earth following on the moon. (We shall call this the 'eclipse mechanism' hereafter.) Other alternative explanations such as 'cloud covers the moon', 'planet or the sun casts a shadow on the moon' have also been found among school students. In one study, grade 3 students who underwent instruction developed the following alternative explanation: the phases of the moon are related to one's position on the spherical earth (Stahly et al., 1999). Knowledge of elementary astronomy is a part of basic scientific literacy. Hence the widespread existence of misconceptions about a salient, everyday phenomenon is a cause of concern. The studies referred to indicate that producing a clear and correct explanation is difficult for students as well as adults in spite of this topic being taught in school science. Some reasons could be that it involves complex reasoning or that the culture of science learning does not foster links what is learnt and what is observed. Hence the need to study the kind of reasoning which is essential for such problems and to develop tools and instruction material that facilitates such reasoning.

Underlying theoretical framework

Note that in the studies mentioned earlier, typically the subjects had undergone relevant instruction at some point of their education. Almost all of the older students and adults knew the correct model (that the earth rotates around the sun in a year and the moon rotates around the earth in about a month) based on which the phases of the moon are explained. Still due to the complexity of the problem, the explanations were wrong. Hence this phenomenon is different from that of holding alternative mental models on which a number of studies have focused. The present study tries to understand, given that the mental model is correct, what are the explanations offered by subjects and how do subjects change these explanations when inconsistencies are pointed out.

The mental model includes the spatial and temporal properties of the system, in this case, the Sun - Earth - Moon system. The nature of reasoning required to solve the problem of the moon's phases involves relating the spatial properties of objects such as shape, position and motion to arrive at conclusions. The reasoning may be described as visuospatial reasoning. Visuospatial reasoning is different from deductive and inductive reasoning, which need premises expressed with symbols (verbal / mathematical language) and are hence propositional, while visuospatial reasoning is nonpropositional. In the context of the problem identified for study, the following questions were of interest to us. How and when do people use visuospatial reasoning? What mental tools do they use? What kind of skills are helpful for such reasoning? What are the other devices which help or encourage visuospatial reasoning?

Research design and procedure

Several informal interviews, conducted before the main study, indicated that the eclipse mechanism was almost always proposed to explain the moon's phases. The method adopted in the study was to interview a small sample of individual subjects and involved eliciting an initial explanation of the phases, and then inducing the correct explanation through suggestions and hints. Based on pilot interviews we developed a questionnaire and two hint sheets requiring written responses and an interview schedule.

Since we had an idea that the problem involves visualization, we were interested in studying how people who are familiar with visualization techniques would solve this problem. So we selected half of the subjects of our sample from students of a course in 'Master of Design'. These students all had a college degree in architecture and had taken the 'visual communication' specialization for their current course.

Sample: In all there were 8 subjects. Selection was based on their prior degree (architecture or physics), gender and convenience. Four subjects were students of Master of design course (Visual Communication Stream) (2 female + 2 male) having bachelor's degree in architecture. The other four subjects had Master's degree in Physics (2 female + 2 male) and were working in the area of physics education.

Method: Subjects were individually administered the written response questionnaire followed by an interview. First the task was explained to the subject. The basic information about the Sun - Earth - Moon system such as sizes, distances, ratios of sizes and distances, time-periods and the angle of inclination of moon's orbit to the ecliptic was provided in the data sheet. Subjects were told that some of the data might be useful but not all of the data was required for solving the problem.

Then the main questionnaire was given followed by hint-sheet/s. The main questionnaire asked for the subjects' explanation of the phases and the exact shape of the phases. The hint sheets, which required written responses, provided questions and hints which would be of help in obtaining the correct explanation.

In the interview, which followed the questionnaire, the first set of questions were aimed at understanding the subjects' initial model and mechanism as found in written response and the representation of the model ('Which view have you drawn? '/ 'Where is the sun', if sun is not in the picture, etc.). The next step was to challenge their proposed explanation. The following questions were asked to challenge the eclipse mechanism:

- Why is the moon not visible at the time of new moon?
- When does the lunar eclipse occur? Why does it happen? How long does it take? How is it different from the phases of the moon? Can you say when an eclipse will occur and why it does not occur as frequently as the full moon and the new moon?

Answers to the above probes made the subjects realize that their explanation mistakenly addressed eclipses rather than phases of the moon.

So to help them to build a new model and to guide their thinking a sequence of hints was also developed for the interviews. These hints were different from those in the hint-sheets given in the questionnaire. A list of hints was prepared in advance and a subset of hints from the hints listed were given to individual subjects, depending on their responses. Direct hints, which were close to the real situation, such as 'an observer standing on a rotating platform with a ball, lit by single distant light', 'Watching a stationary ball lit by single distant light from different angles' or 'Watching a uniformly lit half black and half white ball from different angles' were given first. It was found from pilot interviews that visualizing how faces appear from different angles, (we call such hints "anthropomorphic hints") were more effective than visualizing spheres. So, in the cases where direct hints did not work, anthropomorphic hints such as 'an observer standing at the center of a rotating platform looking at a friend standing at the edge whose face is toward a single distant light' or 'Walking around stationary friend whose face is turned towards a single distant light' were given. The similarity and equivalence of the partial views obtained in different 'hint' situations were probed from time to time during the interview. To determine the correct shape of moon in each of the phases, subjects were asked questions and provided hints depending on their responses in the written hintsheet 2 and in the interview, such as: Think of how the two boundaries that you traced on the sphere intersect. If you look at the sphere from one position, the visible boundary is fixed. Now if you move the boundary between the lit and dark parts, across the surface of the moon, how would the appearance of the boundary change?

Two concrete models, namely, a table tennis ball, painted half black and half white, and two bangles intersecting in diametrically opposite points, were shown to some subjects (depending on their responses) to help explain how the phases are formed.

At the end, subjects were asked a question to test their understanding. The question was, "how will the Earth look from the moon on the day of the full moon/ new moon/ half moon."

Findings

Mental models were correct in the case of all the subjects except for the lack of unfamiliarity with the large scales involved in the problem. Several assumptions and simplifications have to be made to compensate for the difficulties induced by the distance scales and to form an appropriate mental model. Choosing an appropriate point of view is another important step in solving the problem. Seven out of eight subjects started with an eclipse mechanism. After eventually arriving at the correct mechanism, some subjects had difficulty in deriving/ visualizing the shape of the corresponding phase. This may be because of two reasons. First, it was seen that the eclipse mechanism is rooted so deeply that it reappeared many times during the interview. Some subjects kept referring to shadow, or blocking of light and then they corrected themselves. The corresponding shapes that they drew, especially for the gibbous phase were that of the eclipse. Another reason could be that subjects were compelled to draw the inner boundary of the moon's phase as a concave curve probably because of difficulties in representing a 3 dimensional curve in 2 dimensions, which they could not correct till the end. Subjects with a physics background were drawing a curved line to indicate a great circle on a sphere. So they never drew exactly half moon with a semicircle and a straight line. (Drawing it so might have led them to the idea that the curvature of the inner boundary is reversed for the gibbous shape.) This might be due to their limited drawing skills. These kinds of diagrams may have influenced their thinking, by reinforcing the eclipse mechanism.

One more alternative explanation was found in the case of those subjects who could not approximate sun-rays to be parallel. They had a difficulty both in visualizing and also in deducing the fact that half of the sphere is illuminated at any time. These subjects had the following representations (usually both together):

1. Extended source representation:The Sun is very big so more than half the moon is illuminated.
2. Inverted light cone mechanism:Subjects thought that the closer the sun, the the larger the area of the moon that was lit; as though an inverted cone of light emanated from the sun (with the base of the cone at the sun.)

Another significant finding was that drawings and/ or gestures were important tools in solving the problem. Graduates of architecture took significantly less time to complete the solution of the problem once they realized the correct mechanism.

Once the subjects had arrived at the correct mechanism causing the moon's phases, they were probed about the exact shapes of the different phases. Three major strategies were found to be used by the subjects to derive the mechanism as well as the exact shape of the different phases. While there was a mixture of strategies at times, subjects predominantly followed one of the strategies, depending on the skills they could draw upon. Let us discuss these strategies.

1. **Visualization:**The problem can be solved entirely using visualization. Subjects who were comfortable with visualization, visualized the situation given in the hint and drew the sequence of phases accordingly. They did not explicitly derive the shapes, but it came as a product of visualizing the mechanism. Four (three from architecture background and one from Physics background) out of eight subjects used this strategy. The following features were used to identify this strategy:

- Subjects who depended on visualization needed less number of hints.
- Subjects took long pauses for visualization.
- Gestures were used predominantly along with diagrams.

It appeared that this strategy needed a lot of mental effort, especially when subjects needed to simulate motion or to visualize the situation from another point of view. Hence this strategy was found to be time consuming. But according to subjects' reports, it was fairly convincing. Of the four subjects, two could solve the problem fully with the help of hints.

2. **Geometrical Reasoning:**Once the mechanism is clear, the exact shapes of the phases can be derived by geometrical reasoning. Three subjects (all with physics background) could not completely solve the problem by visualization. They were encouraged to reason geometrically with the help of hints. These subjects attempted to use visualization for some of the steps, for example to arrive at the shape of the boundary between the lit and the dark parts of the moon. Whenever they were unable to visualize, the interviewer suggested that they try to make a drawing. However, partially due to their limited visualization and drawing skills, all three were unable completely solve the problem. Even when they were able to correctly deduce each step, they were unable to synthesize the steps. For example, although they realized that the boundary was a great circle, they were unable to derive the shape of phases.
3. **Diagram based reasoning:**This strategy needed the least number of steps, least time and produced accurate results. Only one subject used this strategy. This can be considered as the most elegant strategy amongst the three. But this needs a correct and precise diagram and the skill of projecting a three dimensional object onto a plane when seen from different points of view. This technique exploits the inherent power of pictures and it appears that drawings here are not merely means of representation or visualization nor are they used only to reduce working memory load. They may mean something more, and the subject's responses suggested that elements of the diagram can be manipulated analogous to the symbols manipulated by purely deductive logic.

The results of the study point to the difficulty of clearly explaining the moon's phases. Solving the problem by means of visualizing or deductive strategies by themselves or in combination may be too difficult for individuals, especially for school students. Diagram-based reasoning however offers promise as a strategy that can be learnt and adapted by students following suitable instruction. Such instruction will need to include a component on the representation of three dimensional objects and curves in two dimensions and a component on how diagrams can be manipulated to yield inferences.

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