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Does the man in the moon ever sleep? An analysis of student answers about simple astronomical events: a case study

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In this article the answers provided by 98, 12-year-old students to questions included in an end-of-year science examination are analysed. Almost all of the students are able to explain day and night, but the reason why the Moon always presents the same face to the Earth is less well understood. Estimations of the time in Earth days from sunrise to sunrise on the Moon vary. Most students can explain the apparent movement of stars across the night-sky, but their direction is less certain. Implications of the findings for teaching and learning are addressed.

Introduction

A large body of research suggests that both children (Klein 1982, Jones *et al*. 1987, Baxter 1989, Osborne *et al*. 1994, Vosniadou and Brewer 1994, Sharp 1996) and adults (Cohen 1982, Targan, 1987, Jones 1991, Mant and Summers 1993, 1995, Parker and Heywood 1998) have difficulty explaining simple astronomical events. Evidence suggests that understanding improves with age, but some 'alternative conceptions', may persist into adulthood (Baxter, 1989). The term 'alternative conception' is taken here to refer to mental constructs that differ from the scientifically accepted explanation of a concept (Kuiper 1994). Students may continue to hold alternative conceptions after instruction and even those with a correct understanding may revert back to intuitive ideas after a period of time (Kikas 1998).

A number of suggestions have been put forward to explain why students encounter difficulty explaining astronomical events. A common problem is one of reconciling everyday experiences, such as observing the rising and setting sun, with abstract models which attempt to explain why this occurs (Vosniadou 1991). Another widespread difficulty is that of interpreting two-dimensional diagrams which attempt to represent three-dimensional space (Parker and Heywood 1998). Misleading diagrams can encourage alternative views (Ojala 1997). Books where text and diagrams do not correspond can also be a source of confusion (Vosniadou 1991). Ambiguous terminology may also cause difficulties (Parker and Heywood 1998).

This study contributes to the research by identifying the prevalence and nature of alternative conceptions about selected astronomical concepts after pupils

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have been exposed to a period of instruction. The research is achieved through the analysis of answers provided by 98, 12-year-olds in an end-of-year science examination which included questions on selected astronomical events. The topics tested were explanations for day and night, why we always see the same face of the Moon, an estimation in Earth days of the period from sunrise to sunrise at a lunar space station on the Moon and the cause and direction of the apparent movement of the stars across the night sky. Analysis of the findings, together with discussions with the pupils and teachers involved, were used to identify ways in which the subject matter could be delivered more effectively in the classroom.

Day and night

Explanations for day and night, provided by 100, 9- to 16-year-old students at five schools in the UK, have been investigated by Baxter (1989). The students' understandings were largely assumed to be based on personal constructs because astronomy was not taught at the schools, although the topic might have been mentioned in geography. The findings revealed that understanding increased with age, although some alternative ideas still persisted at age 16. Common alternative ideas were that day and night were caused either by the Sun orbiting the Earth, or the Earth encircling the sun. Another common notion, still prevalent at 16, was that day and night were caused by the Moon covering the Sun. Other blocking mechanisms such as clouds were largely dismissed by the age of 12.

The alternative views detected by Baxter (1989) were noted in several other studies of children (Klein 1982, Jones *et al.* 1987, Sadler 1987, Osborne *et al.* 1994, Vosniadou and Brewer 1994, Sharp 1996, Kikas 1998). In interviews with 60, 5- to 11-year-olds in the USA, Vosniadou and Brewer (1994) found that 63% of the children could provide a coherent explanation for day and night. A study in the United Kingdom by Sharp (1996), which post-dated the introduction of astronomy into the National Curriculum in England and Wales, found that 60% of the 42, 10- and 11-year-olds interviewed in three schools could explain day and night. The most common alternative notion, held by 17% of the students, was that day and night were caused by the moon, or clouds obscuring the Sun. The study by Kikas (1998) in Estonia, was undertaken after 20, 10- and 11-year-olds had been exposed to a period of teaching. Two months after the instruction, 65% of those interviewed were able to provide a correct explanation for day and night. A further 20% of the students falsely believed that day and night were caused by the Sun revolving around the Earth. Four years later when all the students were interviewed again the percentage providing the correct explanation had fallen to 20%. Kikas (1998) attributed this result to didactic teaching methods that provided few opportunities for students to apply their knowledge to problem solving exercises. Another reason offered was that students had been unable to integrate their everyday experience of day and night with what they had been taught in the classroom.

Studies of trainee and practising teachers' explanations for day and night have much in common with those of children (Jones 1991, Mant and Summers 1993, 1995, Parker and Heywood 1998). Jones (1991), in a study of 63 trainee teachers in Australia, found that only 36% could provide a reasonable written account of day and night. The most common alternative explanation for the concept was that the sun orbited the Earth once in 24 hours. A study by Matt and Summers (1995) in the United Kingdom of 66 primary school teachers and 54 post-graduates on a teacher training course revealed that 66% agreed with the written statement, which suggested that day and night were caused by the Earth spinning on its axis once in 24 hours. In a study by Parker and Heywood (1998) also in the United Kingdom, 32% of the 31 undergraduates surveyed and 56% of the 41 post-graduates on teacher-training courses together with 88% of the 17 practising teachers interviewed were able to provide a correct explanation for day and night. A third of these were able to clarify that the spin occurred around the Earth's axis. The most common alternative conceptions were that day and night were caused by the Moon blocking the Sun, or it was the result of the Earth orbiting the Sun.

Dark side of the moon and the period in earth days from sunrise to sunrise on the moon

Many studies have addressed explanations for the phases of the Moon (Cohen 1982, Klein 1982, Jones 1987, Targan 1987, Baxter 1989, Jones 1991, Vosniadou 1991, Mant and Summers 1993, 1995, Osborne *et al.* 1994, Sharp 1996, Parker and Heywood 1998), but few have specifically included questions on the so-called 'dark side of the moon'. Few investigations have also asked students to estimate the time from sunrise to sunrise at a space station on the Moon (a period equal to a lunar month – see further on for an explanation of this). Parker and Heywood (1998) found that although most trainee and practising teachers were aware of 'the dark side of the Moon', few could explain the concept even after they were provided with information on the rate of spin and length of orbit of the Moon. Sharp (1996) found that, although 38% of the 10- and 11-year-olds interviewed were aware of the phases of the Moon, only 17% were able to suggest the correct length of the lunar month.

Star movements

A few investigations into the understanding of astronomical events have included questions on star movements. Sharp (1996) found that only 14% of the 10- and 11-year-olds he interviewed were aware that the stars moved across the sky. Mant and Summers (1993), in interviews with 20 practising teachers in the UK, found that half of them knew that the stars moved across the sky at night, but many were uncertain the direction this took. Some 68% of those interviewed were, however, aware that the Moon moved across the sky although half had no idea of its path.

From a review of the research, it was predicted that, despite instruction, some students would offer alternative notions about astronomical events. It was hypothesized that students would have less difficulty explaining day and night than why the moon always presents the same 'face'. It was suspected that although many students would be able to explain day and night after instruction, the degree of accuracy of their answers would vary. It was hypothesized that questions about star movements might prove difficult for students to answer. It was suspected that a question, which asked students to calculate the length of time from sunrise to sunrise at a space station on the moon, would also cause difficulty. Discussions with students participating in the research, together with the teachers responsible for the course, was expected to provide insights into alternative views. Further clues to the problems would be assessed from an analysis of textbook diagrams portraying astronomical events.

Methodology

The responses to nine questions about astronomical events included within an end-of-year science test were analysed. The responses were provided by 98, 12-year-old girls attending a secondary school in the United Kingdom. To attend the school the students had to have successfully passed an entrance examination i.e. it was selective in intake.

The students had been taught in one of four science classes by four different teachers. The teachers had followed a common scheme of work. The topics taught over the year had included: an explanation for day and night and the seasons, the phases of the Moon, the locations and orbits of the planets, and a basic understanding of the constellations and the night sky. The children had used globes, tennis balls and torches in a darkened room to stimulate explanations for day and night, the phases of the moon and the seasons. The concepts taught were supported by videotapes and worksheets. Students were also taken on a visit to the London Planetarium.

The aim of the end-of-year test was to assess the students' knowledge and understanding of what they had been taught in science during the year. The length of the test was one and a half-hours and included sections on biology, chemistry and aspects of physics including astronomy. The students would probably have spent about 10 minutes answering the questions analysed in this article. The questions included in the astronomy section were those chosen to reflect the core concepts taught during the year. The test items were devised by the science teachers who had taught the students and were loosely based on standard assessment test questions (SATs) which children in UK schools sit at the end of 'key stage three' (11–14 years). The questions had been trialled in the sense that they had been used in previous examinations and discovered to discriminate successfully between higher and lower attaining candidates. The test was marked by the four science teachers who had taught the topics using an mark scheme which they had discussed and agreed upon before the examination. The test scripts were then passed to the researcher (JD) for analysis.

It was recognized that any interpretation of the results would need to take account of the fact that the test was performed under examination conditions, whereas with more time and less pressure students might have come up with more accurate responses. The test situation may, however, have encouraged students to take the task more seriously than they otherwise might have done.

Responses to factual or one-word questions were tallied into the most commonly occurring replies. Answers to questions where explanations were required were grouped into one of six categories; correct scientific explanation, partially correct explanation, alternative explanation, simple description, all embracing statement, unclassified. For example, an explanation of day and night which suggested that: 'the Earth Spins on its axis once every twenty-four hours' was classified as a correct scientific explanation. An answer to this question, which stated that: 'the Earth moved once a day' was identified as a partially correct explanation. The correct and partially correct categories corresponded to the 'scientific model' identified by Vosniadou and Brewer (1994). Answers such as: 'the Sun goes behind clouds' or 'the Earth moves around the Sun' were classified as 'alternative explanations' a category corresponding to the 'intuitive' and the 'synthetic' models identified by Vosniadou and Brewer (1994). The category 'simple description' was used for responses where students had failed to discriminate between the terms 'explain' and 'describe' and instead had written answers such as 'the sun lights up half the Earth at a time'. The 'all embracing statement' was exemplified by the answer: 'the Earth rotates in its axis and also orbits the sun', a response which incorporated the correct answer but did not discriminate this from the other information. 'Unclassified' was applied to confusing answers such as: 'the Earth rotates around the Earth' where students had mistakenly repeated the same term.

After the students had received their marks, but before the end of the term, informal discussions were held with them to discuss their responses. The resources used to support the scheme of work were examined. Discussions were held with the teachers to ascertain how the course had been taught and also to seek possible explanations for the answers that the students had provided.

Results

Day and night

Nearly all pupils (91%) were able to explain correctly that day and night are caused by the Earth rotating once in 24 hours. Moreover, three-quarters of these were also able to clarify that the spin occurred around the Earth's axis (figure 1). Only one student offered an alternative explanation in suggesting that day and night occurred because the Earth orbited the Sun. The remaining students provided descriptions rather than explanations, as illustrated by comments such as: 'day occurs when half the Earth is facing the sun'. Alternatively students gave all embracing statements such as: 'the Earth spins on its axis and also orbits the Sun'.

The result supports previous research that suggests that both children and adults find day and night one of the easier astronomical concepts to explain. One reason for this is probably because only two bodies, namely the Earth and the Sun, are involved. Direct experience of day and night undoubtedly also helps students to conceptualize this event. Some students were, however, imprecise as to whether the Earth spins, rotates or orbits once a day, a confusion also reported by Parker and Heywood (1998).

The dark side of the Moon

Almost half of the students (46%) were able to suggest correctly that we always see the same face of the Moon because it rotates on its axis in the same time that it takes to orbit the Earth (figure 2). A further (4%), in interpreting the question to

91% correct explanation – 'the Earth rotates on its axis once in 24 hours'
1% alternative explanation – 'Earth moves round the Sun'
5% simple description
1% all embracing description
1% unclassified
1% no response

$N = 98$

Figure 1. Categories and percentage of students responding to the question 'why does Britain have day and night?'.

46% correct explanation – 'the Moon rotates on its axis in the same time that it takes to revolve around the Earth'
4% partially correct explanation – 'gravitational forces have caused the Earth to slow the Moon's rotation'
33% alternative explanations
14% 'the Moon does not rotate'
11% 'the Moon and Earth spin in unison'
5% 'the Earth rotates on its axis at the same time as the Moon orbits the Earth'
3% other notions of spin

8% simple description

1% all embracing statement

8% unclassified

$N = 98$

Figure 2. Categories and percentage of students responding to the question 'why do we always see the same face of the Moon?'.

mean 'how has this come about', suggested that the Earth's gravitational field has been responsible for slowing the Moon's rotation down. This response was regarded as a partially correct because it is believed that early in the Moon's history when the Moon was more plastic, gravitational forces exerted by the Earth were responsible for reducing its rotational speed. Both bodies still exert a gravitational force over each other although because the Earth has a larger mass its effects are stronger than those of the Moon.

The most common alternative explanations were that the Moon did not rotate (14%), or that the Moon and Earth were spinning in unison (11%). Discussion with students after the test suggested that some had felt that the diagrams they had seen of this concept had failed to convey to them that the moon rotated. Other ideas offered by a minority of students were that the Moon and Earth rotated in opposite directions, or that the rotation of the moon was twice that of the Earth. A few (5%) thought that the Earth rotated on its axis at the same speed as the Moon orbited the Earth. A further 9% of answers were either simple descriptions such as: 'the Sun shines on one side of the Moon', or all embracing statements.

The findings are consistent with research by Parker and Heywood (1998) who found that adults had difficulty understanding that we always see the same face of the Moon because it rotates on its axis in the same time that it takes to revolve around the Earth. There are several possible reasons why students have difficulty understanding this concept. One problem is that to understand what is happening requires an appreciation of the relative movements of three, rather than two bodies, namely the Earth, Sun and the Moon. Another reason is that a non-rotating Moon may be encouraged by the fact that from Earth we do not see the so-called 'dark side of the Moon'. A further possibility, as Parker and Heywood (1998) have noted, is that students may fail to understand that rotation can occur slowly. Furthermore, unlike day and night, students have no personal experience to relate to and therefore may well believe that all bodies rotate once in 24 hours. A further source of confusion could be that some diagrams of the phases of the Moon fail to show that the moon rotates on its axis.

Period in Earth days from sunrise to sunrise on the Moon.

Less than half (39%) of the students were able to appreciate that the slow rotation of the Moon would mean that the time period between sunrise to the following sunrise at a lunar space station in Earth days would be about a month (figure 3). Of these, 6% suggested 27.3 days, 30%, 28 days and 3%, 29 days. The time taken for the Moon to rotate on its axis is 27.3 days. This is also the time taken for the Moon to orbit of the Earth with respect to fixed stars on the celestial sphere and is called a sidereal month. However, the time taken for the Moon to complete all its phases, that is from one New Moon to the next, is 29.5 days and is known as a 'lunation', or a 'lunar month'. This is also called the synodic month and refers to the Moon's orbit around the Earth with respect to the sun. It is longer than the sidereal month because not only is the Moon orbiting the Earth, but both bodies are also orbiting the Sun. During the month the Earth moves forward in its own orbit around the Sun and consequently in order for the Moon to realign with the Sun it must travel another two Earth days beyond its sidereal period to complete all its phases. Many key-stage three-science textbooks do not distinguish between a sidereal and a synodic month, others suggest the period is about 28 days. Given this all three responses were deemed acceptable, although 27 days was the least permissible answer.

10 hours	1%	
12 hours	5%	
1 day	17%	
2 days	1%	
4 days	1%	
7 days	1%	
12 days	1%	
14 days	3%	
16 days	1%	
24 days	3%	
26 days	1%	
27.3 days	6%	range of acceptable responses for Key Stage three children
28 days	30%	
29.5 days	3%	
30 days	4%	
31 days	1%	
37 days	1%	
365 days	1%	
no response	19%	

$N = 98$

Figure 3. Categories and percentage of students responding to the question 'how long in Earth days would it be from sunrise to sunrise on a space station on the Moon'.

The most common alternative suggestion provided by 17% of the students, was 'one day'. Other students provided estimates ranging from 12 hours to 365 days. Many of these students later in interview confessed these were largely guesses. A further 19% of students were unable to provide an answer to this question.

Students found this question difficult, probably because they had to apply their knowledge rather than simply state the number of days in a lunar month. Moreover, as one student in interview commented: 'I do not associate ''sun rise'' with the Moon, only with the planets'. The most common alternative suggestion of one day might be explained by the fact that the question followed that about the same face of the moon where several students had incorrectly suggested that the Earth and Moon were spinning in unison. Students may also have been thinking of the textbook diagram of the phases of the moon which shows half of the moon lit up from the sun at any given time. This might have given the false impression that the moon, like the Earth, spins once in 24 hours.

Movement of stars across the night sky

A majority of students (78%) were able to explain correctly that the apparent movement of the bright star Regulus across the night sky near the Equator in February was caused by the rotation of the Earth (figure 4). A further 14% of the students provided an incomplete explanation in suggesting that the Earth 'moved'. A few students (7%) offered an alternative view in proposing that the Earth moved around the sun.

Nearly three-quarters of the students (73%) correctly suggested that Regulus moved from east to west across the sky at night at the Equator (figure 5). A further 22% of the students incorrectly suggested that the movement was from west to east. A few (4%) of the students proposed the direction was north to south.

These results support previous research which suggests that although most students are familiar with the idea that a spinning Earth is responsible for the apparent migration of the sun across the sky during the day, they are unaware that this movement also explains the passage of stars across the night sky. Such a finding is unsurprising given that what happens at night is less likely to be observed than during the day. The tendency for almost a quarter of the students to incorrectly suggest a west to east, rather than east to west movement, may have been because they were confusing the Earth's direction of spins from west to east, with the apparent movement of the stars from east to west.

78% correct explanation – 'the rotation of the Earth gives the impression that the Regulus migrates across the sky'
14% incomplete explanation – 'the Earth moves'
7% alternative explanation – 'the Earth moves round Sun'
1% no response

$N = 98$

Figure 4. Categories and percentage of students responding to the question 'why does Regulus, a bright star seen near the Equator in February, move across the sky during the night?'.

73% correct response – 'it moves from east to west'
27% alternative responses
22% 'it moves from west to east'
4% 'it moves from north to south'
1% 'it moves from west to north'

$N = 98$

Figure 5. Categories and percentage of students responding to the question ' In which direction did Regulus move across the night sky?'.

Conclusions and implications for teaching

For student learning to be effective, teachers need accurate, detailed knowledge of their subject and an understanding of how best to represent the concepts in the classroom (Vosniadou 1991, Parker and Heywood 1998, Sharp 1996). Findings from this study suggest that using unambiguous terminology, recognizing that diagrams are simplifications of reality, linking direct observations with classroom theory, using hardware models, and devising questions which encourage lateral thinking, could all promote student understanding.

Accurate use of terminology by teachers and the students they teach would reduce the misunderstandings over terms such as 'orbit', 'spin' and 'turn'. Encouraging students to use these terms in written descriptions of explanations of day and night would re-enforce learning. Discouraging students from believing that rotation must always be rapid may help students understand why the Moon always presents the same face to the Earth. Comparing the Earth's rotation with for example that of Venus, which has a sidereal period of 243 days, and Jupiter, which spins once in 9 hours and 50 minutes, will enable students to appreciate that different bodies rotate at different speeds.

Students also need to be aware that some astronomical terms can be misleading. For example the term 'new Moon' to an observer on Earth really means 'no Moon' because it cannot be seen from here. Similarly the term 'first quarter' describes the fact that the Moon has completed a quarter of its orbit, but half of the Moon is visible from the Earth. Furthermore, the term 'crescent', derived from the Latin 'to grow', should only be applied to a waxing and not a waning Moon.

Diagrams as well as ambiguous terminology can create confusions. Students need be aware that diagrams are simplifications of reality and that some may also encourage misconceptions. One approach, for example when studying the phases of the moon, might be to ask students in what ways the standard secondary textbook illustration of this concept is misleading. Many texts depict the moon orbiting the Earth in an anti-clockwise direction (figure 6). Four, or more usually eight Moons, are shown in their phase positions each half illuminated by the Sun's rays beaming in from the left or the right. The appearance of the moon from Earth is shown in a further four, or eight Moons positioned either in a ring outside those showing the Moon's phase positions, or presented separately. The Earth is shown either from a polar or equatorial perspective, with or without day and night.

The diagram is misleading because the Moon's orbit is shown aligned with the ecliptic, whereas if this was true there would be a solar eclipse every new moon and a lunar eclipse every full Moon. In reality the Moon's orbit is inclined to the

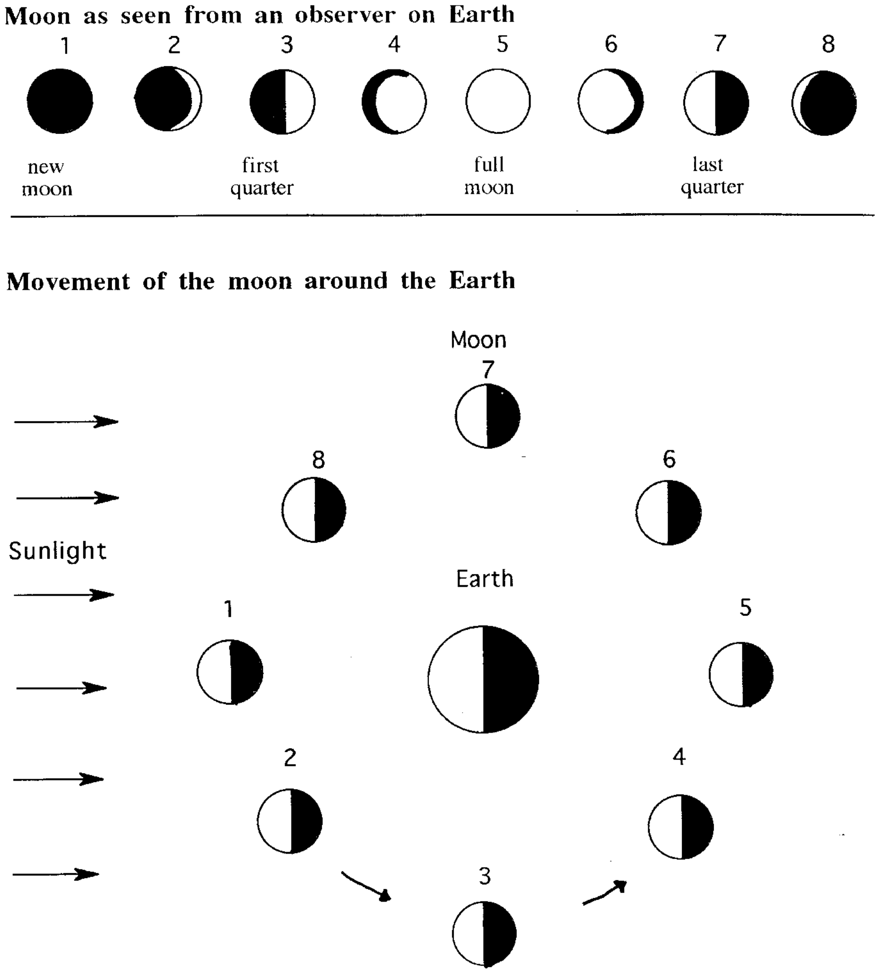

Figure 6. Typical Key Stage 3 textbook illustrations of the phases of the Moon.

ecliptic by on average 5 degrees, and as a result eclipses only occur when the Sun, Earth and Moon are aligned. Another source of confusion is that the Moon is shown to be about half the size of the Earth whereas in reality its diameter is only 0.27 times that of our planet. Furthermore, eight or four Moons are depicted orbiting the Earth whereas in reality there is only one.

The diagram is also a simplification of reality in that it portrays the Moon's orbit as circular rather than an ellipse. The eccentricity of its orbit explains why the moon appears larger at perigee than apogee. The Moon is also shown spinning on a vertical axis whereas in reality it is inclined at about 6 degrees. This is one reason why over a period of time we are able to see 59 rather than 50% of the Moon's surface.

Everyday experience as well as misleading illustrations can lead to false perceptions of astronomical events (Vosniadou 1991). Yet if links can be made between personal experience and classroom theory there is less likelihood of students reverting back to intuitive ideas after instruction (Kikas 1998). Students will find learning more meaningful if they are able to observe for themselves what they have learnt in the classroom. For example, observing the face of the Moon during the month will help to confirm that it always presents the same perspective to the Earth. Suggesting that students check to see if, the Moon does appear to rise later in the night as the month progresses, or that the Moon is higher in the sky in the winter than in summer will all help to re-enforce learning. Students need also to be aware that what can be seen is dependent on latitude and the time of year. For example, stars seen at midnight tonight will be in the sky at noon in six months time, although they will not be seen because the Sun is so bright.

Classroom models can help to demonstrate and explain the direct observations made outside. Parker and Heywood (1998) found that students find models useful in helping to explain concepts. These do not, however, have to be sophisticated or expensive to be effective. As this study showed, students found using their hands to demonstrate astronomical movements as they verbally articulated explanations was helpful.

Questions which require students to apply their knowledge rather than to reproduce rote learning is, as Kikas (1998) suggests, another way of ensuring learning is meaningful. One way of encouraging students to think rather than just memorize is to devise questions which challenge generalizations, such as: 'does the Sun always set in the west and rise in the east?' Another approach is to pose questions such as: 'what would happen if the Moon did not rotate'. Another idea is to show pictures of Moons in impossible positions such as a full moon high in the sky near sunset in the west, or a crescent with horns, which point downwards, and ask students why these cannot be real. Students could also be encouraged to look for paintings where artists have depicted impossible moons. Photographs are also useful when devising questions about star movements. For example, students could be asked to explain pictures of lines across the night sky encircling the Poles, and others showing straight lines at the Equator.

This study supports previous research in suggesting that there is a need to reflect more deeply about the ways in which we teach concepts in astronomy. Explanations for day and night and the phases of the Moon have been well researched, but there is considerable potential for further investigations into other aspects of astronomy. For example, do students think that the craters of the Moon are filled with water? Do they realize that the Moon has no atmosphere and therefore no weather or sound. A better understanding of students' alternative ideas will enable misconceptions to be corrected and lead to improved student learning.

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