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# The earth and beyond: developing primary teachers' understanding of basic astronomical events

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RESEARCH REPORT

# The earth and beyond: developing primary teachers' understanding of basic astronomical events

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The demands on the primary school teacher in delivering the National Curriculum in England and Wales at Key Stage 2 (KS 2) for children aged 7–11 years are considerable. Public debate concerning teacher subject knowledge and understanding, particularly in science, has raised the issue of the need for increased specialism in the primary school. A core element of this debate has focused on how to develop teacher subject knowledge for the effective delivery of the Programme of Study (POS) at KS 2 for practising teachers. This has resulted in the increased provision of in-service courses in higher education and has also impacted significantly on course content in initial teacher training. This paper relates to the 'The Earth and Beyond' POS exploring factors which contribute to developing teachers' understanding of basic astronomical events. Results indicate that providing teachers with the necessary skills and confidence to teach this aspect of science effectively is much more complex than simply explicating science content knowledge. The findings suggest that what is needed is the explicit recognition of key features in supporting learning. These are identified and the implications for teacher education are discussed.



## Introduction

Change to the National Curriculum (NC) in science in England and Wales (DFE 1996) has reduced significantly the content demands for the primary curriculum concerning basic astronomy. The conceptual demands for the 'Earth and Beyond' Programme of Study (POS) for Key Stage 2 (KS2 – for children aged 7–11 years), however, remain ambiguous, centred around the notion of periodic change. This explicitly requires a causal explanation of night and day with respect to the earth's spin and implicitly suggests that seasonal change should be explained through the orbit of the earth around the sun.

There is considerable historic tradition in the primary curriculum focused on developing children's awareness of periodic change. The marking of the passage of time on a daily basis, the celebration of festivals, the effect of seasonal change on life cycles and the repeatability of such changes are not elements that have suddenly emerged as a result of the implementation of the NC. What has changed significantly is the need to underpin an understanding of such changes with a coherent explanatory model of the solar system congruent with the currently accepted scientific view.

This presents considerable challenge and demand on the teaching profession at KS2. It is unlikely that existing primary teachers will have encountered basic astronomical concepts in their own education and, prior to the NC implementation, would not have been required to include such a curriculum in their own teaching. This is supported by the findings of Mant and Summers (1993) in a case study in which they found a considerable difference between teachers' understanding and the scientific model of explanation for night and day, the phases of the moon and the seasons. The findings concur with research in other conceptual areas including forces (Kruger *et al.* 1990 a,b,c, Summers 1992), energy (Kruger 1990, Solomon 1992) and materials (Kruger and Summers 1989), which have demonstrated that there is considerable mismatch between primary teachers' understandings of some science concepts and the conceptual demands of teaching science in the NC.

The research has fuelled recent debate concerning the issue of how best to develop teacher subject knowledge and understanding in both initial teacher training (ITT) and in-service (INSET) course provision for the effective delivery of the content of the NC at KS2. Such research appears to be predicated on a constructivist approach to learning (Driver and Easley 1978) focusing on finding teachers' existing ideas and the discrepancy of those ideas with scientific models of explanation. On occasions the findings have resulted in the development of teaching materials (PSTS 1991–1993) to support learning through constructing meaning leading towards scientifically accepted ideas. There is less research evidence which provides insight into the processes of teacher learning in what Mant and Summers (1993) acknowledge is an inherently difficult conceptual area.

The implication for the debate concerning developing teacher subject knowledge and understanding of complex ideas implicitly suggests that supporting professional learning is unlikely to be simply a case of knowledge transfer. Indeed, this is supported by the findings of Barba and Rubba (1992) who studied the differences between experienced teachers and novice teachers in their approach to teaching and learning of basic astronomical events. Their study highlights the complex interactive nature of the various types of knowledge drawn upon by experienced teachers in promoting effective learning. This raises the question as to what it is that teachers need to know in order to operate effective pedagogy.

Shulman (1987) has indicated that good teachers need to possess a detailed and subtle understanding of not only the content of the subject matter they are to teach, but also an in-depth knowledge of how best to represent the subject in the classroom setting (*pedagogic content knowledge*). The implications are that teachers require insight into the mechanisms of learning which pupils adopt in making sense of abstract ideas which do not resonate with their experience and view of the world from the observations they encounter. There is research evidence (Vosniadou 1991) which provides insight into how pupils develop an understanding of familiar astronomical events including gravitational fields and ideas of the earth in space. This work suggests that there is a chronological progression of thinking from early naive flat earth notions towards more abstract sophisticated scientific observations of explained events. Such an evolution of thinking is supported in cross-cultural studies (Mali and Howe 1979, Klein 1982) and is indeed to an extent seen to parallel the historical development of ideas in science in this area (McCloskey 1983, Baxter 1989). That this transition in conceptual understanding requires a radical shift in thinking is highlighted by Sharp (1996) in a study of year 6 11-year-old pupils' astronomical beliefs. A clear pattern emerges that the ideas are themselves inherently difficult to make sense of and although mechanisms within the construction of meaning have been identified and categorized

(Vosnaidou 1991), there is less evidence of the effectiveness of teaching and its subsequent impact on learning.

The research paradigm needs to move from identifying the problems learners encounter and the constructs they use to interpret meaning, towards identifying key features of the learning process itself and determining their effectiveness in developing teacher subject knowledge and understanding which is coherent with scientific models of explanation of basic astronomical events.

The principal concern for teacher education centres on course provision for both students in initial teacher training and existing teachers on in-service courses. Attempts at producing teaching materials based on research findings (PSTS 1991–1993) which have focused on teachers' existing ideas and their incompatibility with scientific explanations have resulted in the recommendation that teacher education courses should be underpinned by constructivist approaches to learning. Whilst an important element in this includes determining teachers' existing conceptual understanding and attempting to help them develop the current scientific view, we argue that this in itself is insufficient. The pedagogic challenge confronting teacher education concerns determining the effectiveness of teaching approaches in learning. Teachers require insight and knowledge of the learning process and need to be aware of key features instrumental in promoting learning.

Our research attempts to provide insight into factors influencing the processes of knowledge acquisition when teachers are learning about difficult abstract ideas encountered while developing causal explanations of observed familiar astronomical events. It subscribes to the view that primary teachers need to be in control of their own learning and develop an understanding of how they might learn effectively (metacognition). This could be regarded as integral to a constructivist approach to learning in that it 'promotes sciences as constructed rather than given or absolute knowledge' (Summers 1992). An important element of this concerns learners auditing their own learning in order to identify movement in their understanding. Research methodology employed during this study sought to incorporate such auditing into learning interaction.



## Methodology

The research involved three groups (a total of 89 students) learning about basic astronomical events related to the Programme of Study for the Earth and Beyond at KS2 in the NC. Concepts included causal explanations for night and day, the seasons and phases of the moon. Two of the groups were on primary ITT courses. One group were in their first year of a four-year Bachelor of Education (BEd) honours degree course, and a second group comprising postgraduate students were studying on a one-year course leading to the Post Graduate Certificate of Education (PGCE). The third group were primary teachers on an in-service course designed to enhance teacher subject knowledge and understanding in order to support the effective delivery of the NC Programme of Study for Science in primary schools. The background knowledge and experience of course members varied, with the PGCE students having a range of first degree expertise and none of BEd studying science as their main subject. The primary teachers, many of whom were science co-ordinators, had not encountered basic astronomical concepts in their own educational background but had experienced teaching some aspects of the Earth and Beyond Programme of Study to primary pupils.

Each group was asked to produce annotated diagrams indicating a causal explanation about the concepts of night and day, the seasons and phases of the moon prior to their teaching and learning. The rationale for this was to provide a starting point to which the learner could refer in auditing their own learning during the session. Following teaching inputs and learning experience during the session, they subsequently recorded, through annotated diagrams and written statements, their explanations of the causes of night and day, the seasons and the phases of the moon. Individuals within each group were then asked to indicate whether their learning had evolved with respect to their initial ideas and to identify and record those factors which had contributed significantly to developing their understanding. The responses were collected and teachers' initial ideas were analysed and categorized. Further interpretation of the data involved reviewing post-teaching accounts which were scrutinized for whether there was evidence of understanding having moved towards causal explanations of day and night, the seasons and phases of the moon which were consistent with a scientific view.

The rationale underpinning this approach is predicated on the need for teachers to recognize those elements influencing their learning such that they might draw parallels with children's learning and address identified key features of learning that are problematic in promoting understanding. Our findings indicate that teachers' constructs have much in common with those identified by children in this area (Baxter 1989, Vosniadou 1991, Sharp 1996). A fundamental research question concerns developing insight into the processes of how conceptual acquisition can be made accessible. Self-audit is significant in this process in that the learner is best positioned to articulate his/her understanding and to recognize how his/her thinking has progressed in the teaching–learning interaction.



## Results

### *Day and night*

Analysis of students' annotated drawings of how day and night occurs is given in table 1. Responses which were unclear in terms of the explanation offered were placed in the indeterminate category; the remainder were categorized as scientific if they illustrated the earth spinning on its axis once every 24 hours with the part of the earth receiving sunlight being in daytime and that receiving no sunlight being in night-time (figure 1.6). There were a variety of other explanations which represented what we called *alternative views*; these represented an alternative mechanism that would explain the phenomenon of day and night and provided insight into

**Table 1. Student and teacher explanations for day and night.**

| | *Learner group* | | |
|---|---|---|---|
| *Factor* | *BEd Year 1 students* | *PGCE students* | *10-day course teachers* |
| Sample size | 31 | 41 | 17 |
| Scientific view | 10 (32.3%) | 23 (56.1%) | 15 (88.2%) |
| Alternative view | 19 (61.3%) | 13 (31.7%) | — |
| Indeterminate view | 2 (6.5%) | 4 (9.8%) | 2 (11.8%) |
| No response | — | 1 (2.4%) | — |

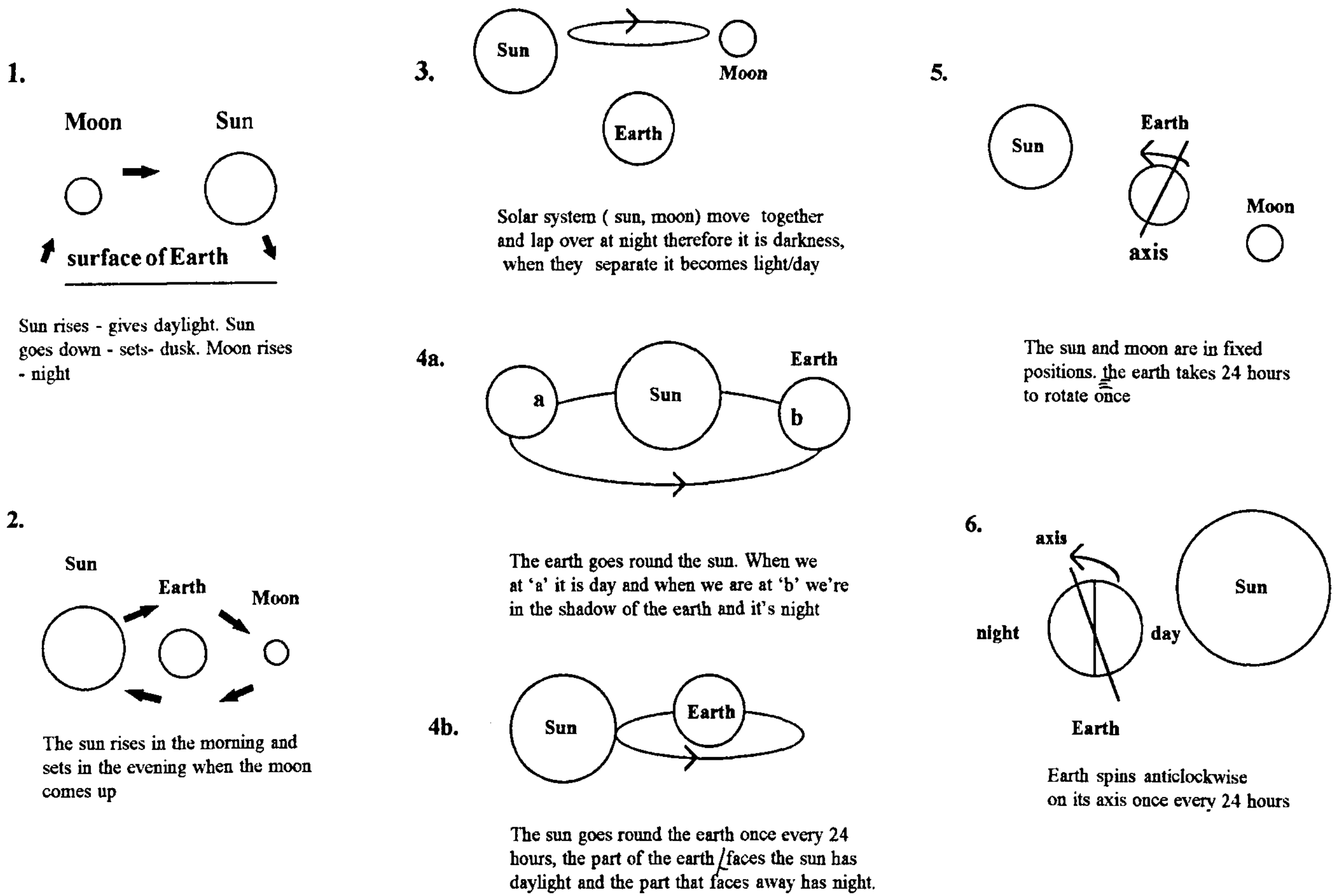


**Figure 1. Explanations for day and night.**

**Table 2. Frequency of alternative ideas on day and night in BEd and PGCE groups expressed as a percentage of sample size.**

| *Alternative view* | 1 | 2 | 3 | 4a | 4b | 5 | 6 |
|---|---|---|---|---|---|---|---|
| BEd | 2 | 2 | 4 | 4 | 2 | 5 | 10 |
| ($n = 31$) | 6.5% | 6.5% | 12.9% | 12.9% | 6.5% | 16.2% | 32.3% |
| PGCE | 2 | — | — | 7 | — | 4 | 23 |
| ($n = 41$) | 4.9% | | | 17.1% | | 9.8% | 56.1% |

how the learners were reasoning with respect to this concept. The results showed that most of the teachers possessed a scientific view of day and night; however, surprisingly this was not the case with the PGCE students (56.1%) and it occurred to a lesser extent with the BEd (32.3%) students.

Alternative views of day and night, together with examples of students' written explanations, are illustrated in figure 1. These have some resonance with the mental models of children described by Vosnaidou (1991) but contain some differences. In this study all students held notions of the earth as a spherical body in space. Figures 1.1–1.3 were essentially earth-centred explanations with the moon and sun revolving around the earth in order to create day and night. Figure 1.1 shows the moon and sun rising and setting as viewed from the earth's surface, a common model also described by Vosnaidou. Figure 1.2 shows the moon and sun orbiting a centrally located earth as an explanation for why we see the sun and moon rising and setting. Figure 1.3 also has the sun and moon orbiting the earth but reasons that at night the sun is overlapped by the moon and as they separate daytime occurs. Notions of the sun being obscured from view during the night-time are also common in learners and other studies have shown that explanations involving clouds, hills or moving further into space are frequently employed by children. Figure 1.4a and 1.4b demonstrate notions of orbit of the sun and earth which result in day/night as one face of the earth becomes illuminated by the sun whilst the other face experiences night-time. Figure 1.5 shows the earth spinning on its axis with the sun and moon in fixed positions; as the earth turns towards the sun it becomes daytime and as it turns away from the sun and towards the moon it becomes night-time. This was also a mental model recognized in Vosnaidou's study. Table 2 shows the frequency of alternative ideas for the PGCE and BEd groups respectively.

Through analysis of annotated drawings and writing it was possible to gain some insight into the type of knowledge the subjects were applying in their explanations. More than three-quarters of learners indicated that they had knowledge of the earth spinning, but only 32.6% mentioned the earth's axis. Although many students had knowledge of the earth's orbit, 11 students viewed this as a 24-hour orbit of the sun by the earth and two students indicated that the sun orbited the earth. Thus relatively high numbers of subjects were using knowledge of the earth's spin with few indicating knowledge of the earth's axis and, although an explanation of day and night does not necessarily demand knowledge of orbit, approximately 20% of the sample exhibited such notions.

The type of language used by learners in their annotations and writing was rooted in everyday descriptive terms. Only 14 learners out of the total sample of 89 employed the word '*spin*' in their descriptions, with fewer still (4) using the term

| Initial view | Post -learning view |
|---|---|
| a) Scientific view drawn | a) *'I knew that the Earth rotated on its axis but I wasn't sure of the direction. By doing the investigation it helped clarify and explain day and night clearly in my head.'* |
| b) Earth orbits sun once every 24 hours | b) *'I thought that the earth moved around the sun once a day rather than the earth revolving itself and the earth revolving round the sun once a year'.* |
| c) Moon blocks out the sun to give night time. | c) *'I was really confident on the reasons for day and night so no explanations were needed, although we did a quick demonstration'.* |
| d) Earth orbits sun once every 24 hours | d) *'I knew that the earth moved around the sun once a day and the sun shone on the earth. I have discovered that whilst half of the earth is in daytime the other half is in night because 1) the earth is on a tilt therefore the sun can only get to half of it and 2) as the earth goes round one half becomes day and one half becomes night'.* |

**Figure 2. Student reflections on learning about day and night.**

'*orbit*'. Words such as *rotate, revolve, turn, move around, goes around, circulates turns, turns completely* seemed to be used interchangeably to describe orbit and spin. This often led to difficulty in communicating ideas and interpreting more complex situations during group work.

Following learning experiences in this area, students were asked to review their learning by reflecting on their initial ideas and indicating how these had been extended or modified in the light of experience. This enabled us to identify what they saw as significant features of their own learning. On analysis of outcomes several important points emerged. Students who had possessed a scientific view at the outset reported no change in their thinking or had simply gained more knowledge, usually about the direction of the earth's spin, time zones and shadow lengths at various points on the globe (figure 2a). Many commented that modelling ideas and demonstration had enabled them to visualize what was happening much more effectively.

Some students holding clearly alternative views had undergone substantial reorganization in their thinking (figure 2b), whilst others had merely confirmed their existing ideas or developed them further through incorporating new information, demonstrating how difficult it is to shift entrenched concepts (figures 2c and d). Practical exploration and demonstration combined with group discussion had been significant factors in students' learning. Many talked of *clarifying* the picture in their head or the importance of being able to *visualize* what was happening.

### *Seasons*

The scientific view of seasons (figure 3.3) entails considerably more challenge for the learner: it demands differentiation of the earth's orbit and spin with respect to the sun's position as well as knowledge of the earth's axis in relation to the sun. Analysis revealed that few students held the scientific notion of the seasons (table 3). Indeed, some learners found themselves unable to attempt any explanations at all and resorted to descriptions of seasonal change in terms of temperature and day length.

Indeterminate responses often showed knowledge of some aspects of orbit and spin but were unclear as to how these resulted in seasonal change. Two broad

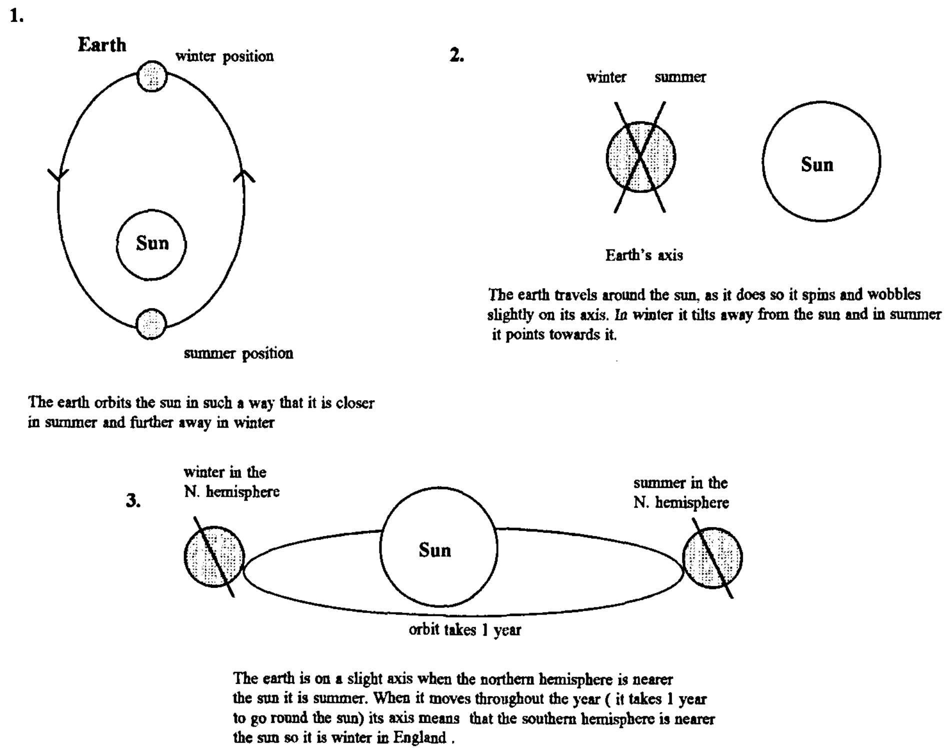


**Figure 3. Explanations for the seasons.**

**Table 3. Student and teacher explanations for the seasons.**

| | *Learner group* | | |
|---|---|---|---|
| *Factor* | *BEd Year 1 students* | *PGCE students* | *10-day course teachers* |
| Sample size | 31 | 41 | 17 |
| Scientific view | 3 (9.7%) | 4 (9.8%) | 4 (23.5%) |
| Alternative view | 23 (74.2%) | 24 (58.5%) | 5 (29.4) |
| Indeterminate view | 2 (6.4%) | 6 (14.6%) | 1 (5.9%) |
| No response | 3 (9.7%) | 7 (17.1%) | 7 (41.2%) |

groups of alternative views were discernible (figures 3.1 and 3.2). The first represented the predominant view involving reasoning based on the relative physical proximity of the earth to the sun in summer and winter. This notion we called the '*distance model*' and students expressed a variety of possible mechanisms for it including elliptical orbits, circular orbits in which the earth was situated off centre, spiral orbits and models which entailed the earth moving backwards and forwards in space. The second model was what we termed the '*wobbly earth*' model with the earth's axis appearing to oscillate, pointing towards the sun in summer and away from the sun in winter. It is worth reflecting that most students using the wobbly earth model stated that the reason for seasons was again located in a distance view

| Initial ideas | Post -learning reflections |
|---|---|
| a) Scientific view | a) *'My previous knowledge was quite good. I learned that the effect of the elliptical orbit of the Earth round the sun on night/day length or seasonal sunlight is nil'.* |
| b) Limited explanation : *'the position of the sun determines the seasons'.* | b) *'Earth moves around the sun....the axis stays the same ! The position the Sun is in relation to the Earth determines the seasons'.* |
| c) Distance view based on elliptical orbit | c) *'The tilt causes the seasons, I realised that the difference in distance is irrelevant'.* |
| d) Wobbly Earth view | d) *'The complete opposite happens - i.e. the axis does not change its tilt but stays the same'.* |
| e) No response given | e) *' I didn't know how we get seasons. I didn't know that the Earth's axis was on a slant. I did know that the Earth went round the sun but until now I didn't know that was how we got seasons'.* |

**Figure 4. Student reflections on learning about seasons.**

with the Northern Hemisphere being physically nearer the sun in summer as the axis was pointed towards the sun. Of the 11 learners expressing a scientific view, five stated that the tilt of the earth in relation to the sun would affect the amount of light or warmth received and only one learner made specific reference to the way in which the direction of the sun's rays falling on the earth would effect light intensity and no student attempted to describe why day length would change.

Again, descriptive language was rooted in everyday usage with words such as *goes round, moves about, turns,* etc. being employed interchangeably in describing orbit and spin. Other terms employed to describe the tilt of the earth's axis were: *angled, sloped, tilted, not straight, angle of rotation, on a slant.* There was also distinct problem in interpreting diagrams of what was happening. Despite being given a diagram of the seasons to follow, many students did not recognize the importance of keeping the axis on the earth at a constant angle to the elliptical plane and proceeded to rotate the angle in attempting to develop explanations.

Figure 4 shows some examples of students' reflections on their own learning. As with learning in the area of day and night, it was possible to identify certain categories of how thinking had been effected by learning experiences. First, those students who had a scientific view of how seasons occur at the outset had usually extended their insights and often commented on how they were better able to visualize what was happening (figure 4a). Second, there was a category of learners who had possessed little knowledge in this area at the outset and they were beginning to develop the concept of orbit and spin, and the effect of the earth's axis in relation to the sun in determining seasonal change (figure 4b). Another discernible category involved learners who had a reasonable grasp of orbit and spin but who had developed a distance view of seasons. Such learners often reported developing insight into the role of the earth's axis as a sudden occurrence (figure 4c and d) and there were those who had attempted to assimilate new knowledge into their existing frameworks (figure 4e). Again, for most students key features of their learning were discussion of their own and scientific ideas with peers and tutors, practical exploration using models and demonstrations and recognizing the problems inherent in interpreting diagrams.

*Phases of the moon*

Learners' knowledge and understanding about the phases of the moon was explored with PGCE and teacher groups. In common with other studies (Cohen 1982, Targan 1987) we found this to be a challenging area for most learners. Table 4 shows that few learners held a scientific view of the occurrence of the phases of the moon, indeed, several were unable to offer any explanations at all and the majority expressed alternative views. In order to understand how the phases occur the learner needs to have a sophisticated knowledge and understanding of the relative movements of the earth, sun and moon as well as knowledge of how light travels and is reflected from spherical surfaces.

Both students and teachers demonstrated a strong awareness of the moon's appearance during its monthly cycle and many were able to supply names for the various stages and indicate its orbit around the earth. Of the alternative views expressed, 26 out of a total of 27 attributed the phases to the casting of a shadow onto the moon by the earth, or less frequently by other planets. Only five students indicated explicitly that the moon reflected sunlight.

Reflections on learning revealed some key issues. The realization that it was the *relative positions* of the sun, earth and moon that resulted in visible phases was a difficult concept for most learners and there was an acute need to visualize what was happening through the use of models:

> I know of the phases and had seen the 2D diagram before but my understanding was really helped by putting myself in the role of the earth.

One question which arose frequently in this area concerned the notion that it is possible to see only one side of the moon from the earth. Most learners had come across the idea of the so-called dark side of the moon before and were keen to develop explanations for it. They were supplied with explanatory diagrams showing the moon's orbit and spin in relation to other bodies, together with information that the rate of spin and orbit of the moon are the same. Using this information they proceeded to explore the notion. The following transcript is taken from a recording of a group attempting to model the relative positions of the bodies. One learner (F) has decided that the time it takes the moon to spin on its axis is irrelevant data and is currently rotating the moon on its axis at right angles to the earth as it orbits:

> F: As long as one pole faces the earth you'll always have a dark side ... the angle has to be at right angles to the earth.
>
> M: So that's never going to get any light from the sun?



**Table 4. Student and teacher explanations for phases of the moon.**

| *Learner group* | *PGCE students* | *10-Day course teachers* |
|---|---|---|
| Sample size | 41 | 17 |
| Scientific view | 4 (9.8%) | 3 (17.7%) |
| Alternative view | 23 (56.1%) | 4 (23.5%) |
| Intermediate view | 9 (21.9%) | 5 (29.4%) |
| No response | 5 (12.2%) | 5 (29.4%) |

F: No, it depends on where on earth you see it from.
M:No the point at which it's facing us will never get any sunshine, that's why its dark.
G: It does turn towards the sun... that's the point where you get a lunar eclipse and the dark side comes round and we don't see it.
F: You have to see that this will never face that... it orbits the same as it spins... It's *going within two different dimensions within* itself.
M: So we get our phases from the orbit not the spin.

The group go on to conclude that the spin of the moon is irrelevant; as long as it spins with its axis at right angles to the earth, there will always be a dark side. The above extract raises several important issues. First, there is the difficulty of holding notions of both orbit and spin simultaneously. This is an area where communicating thinking from one person to another can be problematic. We are all viewing the movements of the bodies from slightly different positions and, clearly, communication and interpretation can vary from person to person. Second, learners experienced difficulty in interpreting information expressed in 2D diagrams and written form into a 3D working model. With respect to the question as to why we see only one side of the moon from the earth, it was apparent that despite being told the relevant information about rate of spin of the moon on its axis being the same as the time taken to orbit the earth once, this slow rate of spin was difficult to interpret in practice.



## Discussion

That the concepts involved in developing a causal explanation of basic astronomical events consistent with that of a scientific interpretation are difficult is supported by research evidence of children's ideas (Baxter 1989, Vosniadou 1991, Sharp 1996). There is less evidence of primary teachers' subject knowledge of astronomy although Summers and Mant (1995) concur with the findings of this research in confirming that the concepts involved are both difficult to interpret and often partially, if at all, understood.

The prominence of alternative views as exemplified in these other studies is supported by our research findings. For example, initial ideas on day and night for those without experience of teaching the concept, approximately one-fifth of the sample, were explained through an earth-centred perspective. The seasons caused even more problems, particularly with respect to the tilt of the earth's axis, and the phases of the moon highlighted further difficulty with regard to the manipulation of the relative positions in space of the three bodies.

A central question concerns the process of conceptual acquisition and the extent to which key features in the learning process can be identified to help teachers in constructing and interpreting meaning. Subjecting teachers to creative versions of the same story is unlikely to resolve the problem. Repetitive exposure to scientific explanation is no guarantee of the emergence of understanding. Although complex, the mechanisms involved in the development of understanding require identification and attempts at this in research to date are inconclusive. Where information has been explored, the outcomes are unconvincing and offer limited scope in determining a pragmatic way forward.

In their study of children's mental models of the earth, Vosniadou and Brewer (1992) found that perceptions were influenced by everyday experience and culturally received information. Understanding this often conflicting evidence for the individual requires a synthesis of each in order to make sense of a scientific explanation that does not resonate with an individual's experience of the world. Thus, it is quite possible to juxtapose between the two models or conceptual frameworks in constructing a reinterpretation of events. A falling object will fit with a conceptual model of a flat earth. Culturally received information that the earth is a sphere does not alter the physical reality of the object 'falling down'; it does, however, require a reinterpretation of this phenomenon in terms of the force of gravity being earth centred rather than 'downward'. Reinterpretation could therefore be considered the core issue in supporting teachers' learning.

The extent to which reinterpretation can be achieved is dependent on a wide range of complex factors which transcend simply the provision of scientific explanations. What is needed is a mechanistic causal explanation which is coherent to the learner. For example, our research did not cover teachers' mental models of the earth since it was assumed the earth as a sphere was an accepted culturally received model. However, explanations for day and night (figure 1) revealed some interesting insights into alternative perspectives held by teachers which had some parallels with children's ideas (Baxter 1989, Sharp 1996). This is not entirely surprising since the observed event of day and night can be coherently accounted for using a range of mechanisms which produce alternative categories to the accepted scientific explanation.

It is clear, according to students' reflections, that there was evidence of learning involving, for some learners, the radical reorganization of thinking from initial ideas. For others there was recognition that there was an integration of new information into their existing alternative view and for some the learning involved an extension and evolved interpretation of an existing scientific model. Baxter's (1989) work with children aged nine to 16 years showed a longer term progression of ideas from early naive ideas through notions of astral bodies moving up, down or across, and later embracing the notion of orbital motion.

The geocentric position often predominates and a heliocentric explanation requires an abstraction which, prior to the Copernican revolution, confounded science for centuries (Kuhn 1957). It is entirely understandable that in making sense of what at first appears to the scientifically initiated a straightforward mechanism of explanation through the earth's spinning on its own axis, is often considered through alternative perspectives. A close examination of the categories deployed by learners reveals coherent ideas which initially explain observed events. The extent to which this influences a learner's readiness to accommodate an equally coherent alternative perspective seems to be significant in that periodic change with respect to day and night as explained through the mechanism of spin was relatively well received. Teachers who had experience in teaching this aspect of the curriculum appeared comfortable with the idea and those who had alternative conceptions found such an explanation accessible, apparently incorporating this model of explanation without difficulty. There are implications concerning the transfer of ideas in promoting alternative interpretation and the event to which culturally received wisdom is incorporated is influenced by a number of factors including the effectiveness of the constructs developed to bridge scientifically accepted ideas with the individual's underlying conceptual structures and the coherence of the idea itself.

In the case of day and night this could derive from the fact that such a mechanism requires the consideration of only one concept, that of spin, and that movement relative with respect to position in space is not a complicating factor. Other observed events do, however, require conceptualizing the earth as a sphere in conjunction with its spin and also its orbit. An understanding of the sun's apparent movement across the sky demands a synthesis of shape and magnitude (a giant sphere) with movement (spin). Further consideration of periodic change in daylight hours throughout the year in the temperate zones of England and Wales is conceptually much more complex and involves incorporating three ideas simultaneously, namely spin, orbit and tilt, in developing an understanding of a scientific explanation.

An account of seasonal periodic change demands the conceptualization of position and movement in space holding the axis tilt of the earth relative to its orbital plane around the sun. This compounds the issue significantly and teachers' initial ideas confirmed that an understanding of the scientific model of seasonal change was considerably more difficult to comprehend and articulate. That is not to say that there is no possibility of developing existing ideas which are in conflict with scientific explanations. The post-teaching evidence indicates that movement in learning did occur. A central question concerns the processes which underpin learning in such circumstances and those elements that contribute positively to accessing conceptual areas.

According to Sharp (1996), conceptual change of this order requires a radical shift in thinking from an intuitive egocentric view towards a scientific, remote objective interpretation. It is implied that facilitating the construction of meaning in problems of this nature is dependent on identifying 'hierarchical enabling concepts' in supporting learning. Hierarchical enabling concepts are a similar notion to bridging analogies investigated by Brown (1994) in which he explored facilitating conceptual bridges through presenting *bridges* using analogies which progressively build on existing experience towards more abstract notions.

Such axiomatic reasoning is an attempt to make the abstract more tangible by relating the concept broadly to already established, or at least believable ideas. The extent to which this process is transferable to increasingly abstract and difficult ideas as encountered in developing an understanding of basic astronomical events is questionable. Our findings point towards the importance of identifying a structured framework which outlines *key features* in promoting understanding and making these explicit to teachers during their own learning. The significance of this is outlined by Shulman (1987) as involving much more than the explication of subject knowledge. It is concerned with identifying the processes and conceptual frameworks which underpin qualitative constructs for causal explanations and is referred to as *pedagogic content knowledge*.

Key features of the learning process as identified by the students themselves included not only the need to be confronted with the key scientific ideas, but also the importance of being made explicitly aware of those factors which promote access to such ideas and elements which are restrictive in the development of understanding. Our findings indicate that these features include the following:

*Spatial awareness*: First, there is the generic problem of spatial awareness in relating to position in space of the observer and the observed objects. There is a need to visualize and clarify what is happening. As the following student comments illustrate:

...the physical demonstration of standing around the moon and seeing for myself the shape of the visible light was a revelation!

I was unaware that (a) the moon made only one spin during its orbit of the earth and (b) that you only saw one side of the moon. Even with this information I couldn't accept it until I saw it in the class demonstration.

Practical modelling was paramount in learners clarifying and articulating ideas and an integral part of this process involved listening to and observing other groups' explanations. It seems that this process facilitates access to the scientific model in that the learner is able to consider a range of solutions and the degree of coherence with the currently accepted explanation. Experiencing incongruence in this sense can support learning.

*Two- and three-dimensional reasoning*: This causes particular problems in the interpretation of seasons and the phases of the moon. Learners often found difficulty in visualizing three-dimensional models with respect to relative position in space. This difficulty in visualization concerns three-dimensional position in space and two-dimensional representation of three-dimensional objects.

Problems of intepretation are likely to be encountered in making sense of two-dimensional representation and in translating three-dimensional position in space into two-dimensional diagrams. Culturally received science from textbooks illustrates the point, since in Western art, most representation is orientated from left to right side elevation which is a particularly distorting view of the frame, freezing the movement of spin and orbit. Some texts present a different perspective (e.g. Barrass 1991) and this can be useful provided that the learner has experience to bring to the interpretation.



*Spin and orbit*:

'I got mixed up in the earth turning itself and the earth moving round the sun in one year.'

Annotated diagrams and written reflections indicated that many learners were not differentiating between the notion of spin and orbit. Even where they did, most found difficulty in applying the notions to other situations (e.g. in explaining why only one face of the moon is seen from earth). There was a high degree of uncertainty as to what constituted orbit and how this differed from spin.

Spin and orbit cannot be adequately represented in two-dimensional format without most learners constructing the three-dimensional model of representation. Oscillating from one to the other can prove a useful strategy in consolidating ideas. This needs cautionary treatment since it is easy to confuse. The problem is not necessarily resolved through breaking the whole into parts, no matter how carefully structured. Two-dimensional representation of spin alone is difficult although achievable. Orbit presents a more challenging recreation. The fundamental difficulty lies in the need to simultaneously consider each in relation to the other in developing a coherent understanding of the seasons. The recognition of this problem is conspicuous by its absence in research literature and this could well be a result of an assumed culturally accepted explanation to which 'everyone in the know' subscribes and makes sense of. Clearly this is not the case. As Vosniadou (1991) indicates, a distance model of the seasons is actively promoted in some texts with such phrases as 'when the earth tilts towards the sun it is summer and when it is further away from the sun we have winter'. No such reasoning could account for a change in daylight length. What is needed is a pedagogic structure that facilitates a visualization of the mechanism which accounts for all the observed phenomena and experiences associated with seasonal change, and this includes the changing duration of daylight.

*The earth's tilt*:

> 'I don't think that I ever thought that the earth is on a tilt even if I have been told.'

For example, it may seem less than obvious that both spin and orbit need to be considered together in understanding change in daylight length throughout the year. To understand this it is necessary to 'visualize' the tilt of the earth's axis at different points in the earth's orbit around the sun. This is best exemplified at four strategic points, the summer and winter solstice and the autumn and spring equinoxes. A key teaching point in modelling a three-dimensional demonstration concerns keeping the tilt of the earth's axis constant to the orbital plane throughout the entire orbit, something which many learners find difficulty in doing. The key which unlocks the puzzle concerns the duration of spin in shadow and light. Thus in winter at the northern hemisphere when the tilt of the axis is pointing away from the sun, the duration of turn in the shade is greater than the duration of turn in the light. This equates with short daylight length in winter. The reverse is true in summer. Of course in the southern hemisphere the same orbital position results in a greater duration of turn in the light. The effect is exaggerated the further from the equator. Although modelling of this nature is no guarantee that the concepts will necessarily be interpretated satisfactorily for all learners, our research supports the view that learners find this pedagogic content knowledge invaluable in moving towards a more thorough intepretation.



*Light shining on a sphere*: A further aspect requires consideration and that concerns the nature of light and shadow formation. There needs to be explicit recognition of how light shining on the spherical globe model creates a vertical shadow line which does not follow the tilt line of the axis. If this is not explicitly highlighted in the teaching then understanding is more likely to remain a best partial. We could find no explicit reference to this fundamental prerequisite for understanding in current literature. It does raise the issue of conceptual hierarchy referred to by Vosniadou (1991) in that it could prove productive in developing understanding to consider whether learners should have a basic experience of light and shadow prior to embarking on this area of study.

*Language and communication*: A further element which we have identified in this essential aspect of developing teacher expertise is that of language. There is a considerable language issue in developing knowledge and understanding in this domain. Our research revealed that teachers on the courses had difficulty in describing movement in space and often confused the word spin with orbit, using the terms interchangeably. Orbit and spin were generally referred to as 'goes round'. In fact, initial ideas did not use the word spin systematically and few mentioned orbit in any consequential way. Nowhere is this problem more acute than in developing an understanding of the phases of the moon. The words spin and orbit with respect to the cyclical movements of the moon hold particular difficulties. Before we explore this it is important to consider the wider conceptual demands placed on the learner in making sense of the observed phases of the moon. In order to understand this, the learner needs to position him/herself as an observer looking at the sun–moon system. What learners need to be made aware of is that what you see is dependent upon the position of the observer (in this case from earth), the position of the reflective object (the moon) and the position of the light source (the sun). In order to understand the nature of the shape of the moon the learner needs to have experienced how shadows are formed when light is incident on a sphere from different positions and angles. For example, there is only one set of circumstances when a half-moon can be observed. Any doubt as to the difficulty of interpretation of this observed effect is confirmed when attempting to discern whether the moon will look the same in Australia!

*Applying knowledge*: A final point emerging from our work concerns the application of knowledge. A central tenet of constructivist approaches to learning is not only finding out a learner's existing ideas but also determining whether a concept is understood through encouraging the learner to apply his/her learning in different contexts. The moon offers a considerable challenge in this respect. A causal explanation as to why you see only one face of the moon from earth even though the moon is spinning on its own axis presents considerable challenge for most learners. It could be summarized in the following way:

> The reason you see only one face of the moon from earth is because the moon's phase of spin is the same as its phase of orbit.

This challenge requires addressing the language issue discussed, the interpretation of spin and orbit and the ensuing difficulties encountered in three-dimensional movement and position in space. An understanding of this requires a review of the interpretation of the word spin because in this example the spin rate is very slow compared with most people's personal experience of spinning objects. Spin is often associated with rapid rotation; a spin which takes approximately 28 days to complete is therefore difficult to envisage. Our research revealed, not surprisingly, that students and teachers experience considerable difficulty in accessing an interpretation of this. The above statement is a 'correct scientific content knowledge' description as to a causal explanation of what is observed. The inadequacy of such an explanation exemplifies our very point and is the essence of our arguement, that it is not the knowing of the explanation but the understanding of the factors contributing to the development of understanding that is the key issue for the primary teacher.

## Conclusions

A fundamental principle of teacher education should be concerned with identifying and making explicit the underlying conceptual frameworks which the learner is likely to have difficulty with in becoming encultured into the scientific interpretation of events. It is our contention that this objective is most effectively achieved in the teacher auditing his/her own learning when engaging with the concepts themselves.

This is fundamentally different from simply addressing the issue of knowledge acquisition for teachers with alternative conceptual frameworks. What would be an unrealistic expectation for both initial teacher education and in-service provision would be for teachers to identify the underlying principles which form the foundation for the development of knowledge and understanding in such a complex area. Without insight into the learning process involved, subtle nuances that impact markedly on the capacity for learners to make the necessary links are lost.

It is our view that in order to further inform the debate, the focus of the research paradigm needs to move towards identifying and informing the essence of pedagogical subject knowledge – knowledge of how learners learn, in addition to subject knowledge and understanding of scientific causal explanations for basic astronomical events. It is not simply a case of understanding the conceptual domain of the earth's spin causing day and night or the orbit causing the seasons. It is also necessary to recognize the nuances of structuring learning to make the conceptual frameworks accessible. We believe that understanding the structure of learning requires recognition of that structure through the individual learning experience. The implication for teacher education concerns making teachers explicitly aware of this in their own learning.

A significant point here seems to be a lack of explicit reference to this in available literature. This could derive from the fact that most information on basic astronomy prior to the NC was written by astronomers rather than educators and there was perhaps an assumption that the intended audience would have already mastered such basic fundamentals.

In essence the concern for the researcher is not necessarily arguing the merits of the chronology of concept explanation in science, but recognizing that only through exploring such phenomena with the learner in the learning interaction can judgements be made as to their effectiveness. For teacher education, this would seem to be a central tenet of course input. That is, making the teacher aware of the pedagogic content knowledge which transcends mere subject knowledge, a challenge that is far and away more complex than the public rhetoric of developing teacher subject knowledge and understanding in science.



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