University of Southampton

Children's ideas in astronomy: a quasi-experimental study of knowledge acquisition and concept learning in the upper primary years of schooling

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Abstract

The research presented here, a quasi-experimental study of knowledge acquisition and concept learning in the upper primary years of schooling, systematically identifies, categorizes and describes children's ideas and mental models in the 'traditional' content areas of astronomy (the Earth, the Sun, the Moon, Earth-Sun-Moon System phenomena and the Solar System and wider Universe) and measures and maps the changes in those ideas and mental models as a result of exposure to a ten week period of formal astronomy teaching in one English primary school setting. In total, 62 children in two vertically grouped Year 5/6 classes were involved (9 to 11 years of age). Within the context of the quasi-experimental design employed, one class was designated the experimental group (n=31), the other the control group (n=31). Initially, only the children in the experimental group were taught astronomy and by their own class teacher, a highly experienced practitioner with a positive attitude and orientation towards science. Within the limitations of the work undertaken, research findings indicate that among children in the experimental group, and in most of the content areas investigated at least, progression was evident in many different forms and levels of scientific conceptualization were high suggesting that an acceptable scientific knowledge and understanding of sometimes complex and abstract astronomical information is attainable in the upper primary years of schooling and can be retained over time. Research findings also draw attention to the individuality, commonality, non-linearity and dynamic nature of astronomy learning as a whole and a new, if tentative, perspective on astronomy learning involving chaos theory is presented. The place of astronomy education provision in primary schools is reconsidered and concerns are expressed over the need for extreme care at a time when classroom practices and expectations are increasingly driven by curriculum guidelines and science curricula which remain to be fully informed.

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Chapter 1

Research Outline

1.1 Introduction

In 1929, Piaget wrote that to teach young children astronomy too soon would be 'completely useless' as they could not possibly understand it, their explanations giving rise to the 'quaintest distortions'. More than 70 years on, things have changed. Many children today have unprecedented access and exposure to quite sophisticated astronomical information, fact and fiction, via a wide range of sources, including popular media, and astronomy now appears in the primary science curricula and curriculum guidelines of many countries around the world. Evidenced by its appearance alone, the overwhelming educational significance of teaching astronomy in the primary school, including the intellectually and spiritually uplifting experiences it provides and the contribution it makes towards the development of scientific literacy and the public understanding of science, is recognized and acknowledged. As a direct result, children in those countries where astronomy education is widely available are being provided with the opportunities they need to help them come to terms with some of the major scientific events that shape and form significant parts of their everyday lives. Astronomy is, after all, the 'stuff' of headline news and, as is believed here, the 'stuff' of science that really 'turns kids on'!

Until recently, however, and despite the considerable efforts in children's ideas research emanating from the 'constructivist' or 'alternative frameworks' movement which grew in acceptance and gained general momentum in the mid- to late-1970s, children's ideas in astronomy were not particularly well documented. Even today, and despite increased attention, the detailed nature of these ideas and how they change with regard to the teaching and learning of astronomy in formal classroom settings remains to be fully explored. This work, a quasi-experimental study of children's ideas as they learn astronomy in the upper primary age phase (9-11 years), begins to address this situation, provides a sense of balance

with other more established areas of children's ideas research, and makes a significant and original contribution to what is currently an ever growing field. In this chapter, an overview of the work undertaken is presented. This includes details of the location and participants involved, the research questions raised, the type of research undertaken, the overall research design and the theoretical and analytical framework. All aspects will be revisited and expanded upon in subsequent chapters.

1.2 Location and participants

The 'fieldwork' for this research was undertaken in Big Town County Primary School, one of eight primary schools located within the east Devon town of Exmouth in the south-west of England. At the time of the study, Big Town CPS was an average sized Local Education Authority (LEA) maintained primary which drew its children from a mixed catchment identified by owner-occupier homes and both rented and local authority housing (Howard 1997). The human participants were 62 upper primary children and their teachers. The 62 children constituted two of Big Town CPS's three vertically grouped and combined Year 5/6 classes. Each of the two classes contained 17 boys and 14 girls (n=31). Vertical grouping is a strategy adopted by some schools in the UK where, for various reasons, usually associated with the mismatch between the number of children on the school register and acceptable class sizes, children who would normally be in different years are taught together. The 31 children in each of the two classes were between 9 and 11 years of age when the 'fieldwork' began and following Key Stage 2 Programmes of Study of a National Curriculum of subjects, including science with an existing astronomy component, operating in all maintained schools throughout England and Wales (DfE/WO 1995). As a quasi-experimental study, one class was designated the experimental group, the other class the control group. The experimental group, the group of principal interest, was taught astronomy by Jack who was also the deputy head teacher of the school. The control group was taught materials as part of Big Town CPS's own internal organization and management of the science curriculum (they were taught astronomy later). All 'fieldwork' phases of the research were undertaken throughout the 1996/1997 academic year.

The names of the school and the human participants have been changed to protect their identities and to respect the given promise of anonymity and the confidentiality. All procedures were carried out in accordance with the University of Plymouth's policy on

ethical principles for research involving human participants and other associated codes of conduct (e.g. Burgess 1989; Homan 1990; Cohen et al. 2000).

1.3 Research questions

Children's ideas research in science education, of which this is an example, essentially seeks to explore how children conceptualize the objects, events and phenomena of science usually by means of eliciting their knowledge and understanding of them. The area under consideration here, children's ideas in astronomy and how they change as a result of teaching, knowledge acquisition and concept learning, stems from the author's own interest in astronomy following the Apollo Moon landings of the late 1960s and early 1970s, the components of his own science degree undertaken in the early 1980s, and his time spent teaching primary children astronomy as part of a National Curriculum for science in the early 1990s. The work presented here also represents the culmination of his research activity in higher education and as a member of academic staff to date. While children's ideas research in science education is a particularly well established field (Driver et al. 1984, 1994a; Osborne and Freyberg 1985; Carmichael et al. 1990; Pfundt and Duit 1994; Johnsey et al. 2002), and many successful projects of international significance have emerged, notably the recent and pre-experimental as well as developmental Science Process and Concept Exploration (SPACE 1990-1998) Project conducted jointly at the University of Liverpool and King's College, London, with its strong primary focus (e.g. Osborne et al. 1994), many questions about children's ideas remain unanswered, particularly those associated with the processes of knowledge acquisition and concept learning. The research presented here was given direction and focus by considering four questions, all of which are inter-related:

- can knowledge acquisition and concept learning in children's ideas in astronomy be adequately described and measured?
- can the routes and pathways involved in knowledge acquisition and concept learning in children's ideas in astronomy be identified and mapped?
- can actual learning outcomes as a result of an experimental treatment contribute anything towards the nature and status of children's ideas in astronomy and learning theory?
- can actual learning outcomes as a result of an experimental treatment contribute anything towards the teaching of astronomy and curriculum design?

Raising questions such as these provides an appropriate means of conducting experimental research in education without the formal need to test hypotheses (Charles 1998). Once questions are raised, of course, it is only natural to attempt to find answers to them. The initial questions themselves draw attention to the empirical, reflective and creative nature of research activity as described by Bassey (1995). The research here is empirical with data collection centre stage. The research here is reflective in the sense that empirical findings will form the starting point for critical review and argument about educational issues such as curriculum development associated with a National Curriculum for science. The research here is creative in that new systems of describing and measuring children's ideas are presented which may yet need to be subjected to the rigours of evaluation by further empirical research. The questions also draw attention to the pure, applied and psychological as well educational dimensions of the research.

1.4 Research summary

Educational research has become so diverse that beyond the most basic of descriptions it no longer has any single identifiable meaning. The boundaries between the different types of research, the different methods and methodologies employed, and the research paradigms with their associated ideologies and political theories into which they fall have become blurred and, at times, indistinguishable. These views of educational research as a whole, recognised as long ago as the late 1960s (e.g. Travers 1969), are also true of science education research itself (e.g. Robottom and Hart 1993). As a direct consequence, attempting to ascribe meaning to, categorize and contextualize any educational research undertaken can be a difficult and, at times, hazardous activity which, nevertheless, must be attempted to a degree if only to navigate successfully through the mine-field of confusing terminology.

1.4.1 Educational research and the normative research paradigm

It is possible to begin to describe the research presented here by starting with a generic definition. The definition of educational research as the process of arriving at dependable and verifiable answers to questions and solutions to problems through the planned, systematic and critical collection, analysis and interpretation of data in order to inform educational judgements and improve educational action provided by Stenhouse (1975) and Mouly (1978)

is particularly useful. The research presented here attempts to explore, in just such a manner, children's ideas and how these ideas change as they learn about the 'traditional' content elements of astronomy in one English primary school setting. It attempts to do these things within the context of an educational experiment and, by virtue of its design, and where possible, by a process of scientific enquiry. The 'traditional' content elements of astronomy are taken to include the Earth, the Sun, the Moon, events and phenomena associated with the Earth-Sun-Moon System (day and night, seasonal change, phases of the Moon), and the Solar System and wider Universe.

In earlier days of educational research, experiments and scientific method, as the process of scientific enquiry was more formally known, dominated over almost everything else and the terms experimentation and scientific method became to be used almost synonymously. This was typified in the research text produced by Best (1959) who identified five characteristics of acceptable practice in educational research at that time:

- Research gathers new knowledge or data from primary or first hand sources. It is not research when one merely restates or reorganizes what is already known or what has been written. Research places emphasis upon the discovery of general principles. It goes beyond the specific groups and situations investigated, and by careful sampling procedures, infers qualities of the entire population from those observed in the smaller group.
- Research is expert, systematic and accurate investigation. The researcher knows what is already known about the problem. He [sic] proceeds from this point, carefully planning his procedures. Data are gathered, recorded, and analyzed with as complete accuracy as possible. He uses such valid data gathering instruments as he can find or devise, and employs mechanical means to improve on the accuracy of human observation, recording and computation of data.
- Research is logical and objective, applying every possible test to verify the data collected and the procedures employed. The researcher constantly strives to eliminate personal feeling and preference. He resists the temptation to seek only the data that support his hypothesis. There is no attempt to persuade or to prove. The emphasis is on testing, rather than on proving, the hypothesis. The researcher elevates clear thinking and logic. He suppresses feeling and emotion in his analysis.

- Research endeavours to organize data in quantitative terms, if possible, and to express them as numerical measures. Research is patient and unhurried. The researcher is willing to exert painstaking effort, suspending judgement to permit the data and logic to lead to sound conclusions. He realizes that significant findings do not come as a result of hurried and careless procedures. Research requires courage. The researcher is willing to follow his procedures to conclusions that may be unpopular and bring about disappointment.
- Research is carefully recorded and reported. Every term is carefully defined, all procedures are described in detail, all limiting factors are recognized, all references are carefully documented, and all results are objectively recorded. All conclusions and generalizations are cautiously arrived at, with due consideration for all of the limitations of methodology, data collected, and errors of human interpretation.

Campbell and Stanley (1963) wrote about and defended their view that research of an experimental and scientific nature was indeed the 'only means for settling disputes regarding educational practice ... the only way of varifying educational improvements ... and the only way of establishing a cumulative tradition in which improvements can be introduced without the faddish discard of old wisdom in favour of inferior novelties'. Experimentation and scientific method were not only considered appropriate for the science laboratory but for the classroom too (Kerlinger 1969). While it might be argued that in certain circumstances Campbell and Stanley's claims remain valid even today, with educational research as diverse as it currently is, experimentation and scientific method have a more restricted and specialized application. Of course, there is no unique way of conducting educational experiments and no unique form of scientific enquiry and the extended steps often regarded as essential in the nature of scientific practice (e.g. objectivity, selecting or recognizing a problem, defining the problem in clear and specific terms, developing and testing a hypothesis or answering questions, manipulating and controlling variables, creating sophisticated instruments and developing techniques, collecting, organizing, presenting and quantitatively analyzing data, and forming generalizations and applications) are at best idealized accounts of how scientists and educational researchers work (Good 1963).

In reality, and despite those who continue to adhere to the formalities of experimentation and scientific method (Kerlinger 1991), practical, ethical and design considerations in classroom-based educational research usually exclude rigorous or true experiments from ever being

undertaken. Quasi-experimental studies, from the typology of educational experiments provided by Campbell and Stanley (1963), provide something of a 'trade-off', or better, a compromise (Kerlinger 1969), between the rigours of true experimentation and the more multifaceted research approaches considered to hold most promise in educational research as a whole (Bynner 1980). As noted by Campbell and Stanley themselves, many empirical studies in social settings are most suited to quasi-experimental rather than true experimental study and this is the case here. Denscombe (1998) adopted a similar view referring to quasi-experimental studies as 'field experiments'. According to Denscombe, 'field experiments' succeed in capturing the essence of the notion of true experiments without the artificial 'laboratory' conditions imposed or the need for 'men in white coats'. Such 'field experiments' might be loosely described as of relatively long duration, located in social settings such as classrooms and undertaken by means of systematic 'fieldwork' recorded by collecting systematic 'field notes'. Bogdan and Biklen (1998) and Cohen et al. (2000) have recently suggested that all forms of systematic research, whether they be experimental or not, are in fact 'scientific' in nature, systematicity reflecting the most fundamental principle of scientific enquiry.

Educational experiments are usually located and considered within the normative rather than the interpretive or critical research paradigm as described by Cohen et al. (2000). The process of scientific enquiry, despite the position of Bogdan and Biklen (1998) and Cohen et al. (2000), is usually considered normative too. It is easy to see why. Research paradigms are best described as the networks of coherent ideas about the nature of the world inhabited by researchers which, in turn, influence the functions of researchers themselves. As such, research paradigms condition patterns of thinking and underpin research actions. Research paradigms provide communities of researchers with a sense of shared purpose in terms of what is important, legitimate and reasonable and an ability to communicate with each other on similar grounds. Within the normative research paradigm, as it is frequently presented, acquiring knowledge about educational matters is seen as a process of gathering information that is independent of the researcher, knowledge is viewed as objective, generalizable and predictable, and the use of appropriate, quantitative methods based on statistical techniques is thought to minimize or eliminate researcher bias and allow for undertaking research which is value-free. Normative paradigm research is also, rather unfortunately, often regarded as 'superior' by some of its practitioners who reject the idea of other paradigms being a valid basis for educational research (Bassey 1995). The similarities between these generalizations

of the normative research paradigm and the early work of Best (1959) are obvious. Such generalizations about the normative research paradigm and the research conducted therein are, to say the least, unhelpful for they are presented at their most extreme and critics have wasted little time on deconstructing their validity in favour of their own chosen ideology and educational politics on the basis of this presentation. Most frequently, for example, attacks centre on the usefulness of normative paradigm research to improve teaching and other aspects of classroom practice which, it is claimed, seems to have had little effect. The cause of the failure is often reduced to a misplaced assumption on the part of normative paradigm practitioners that teaching is linear and that teachers as 'cause' can produce measurable learning or 'effect' in children and that by identifying the most profitable aspects of human behaviour bringing about 'effect' they can be directly transferred from one classroom and one teacher to another. As many authors have pointed out, while generalizations formed in this way may lead to certain theories of classroom-based human behaviour and the testable predictions which follow, the complexities of human behaviour cannot be mechanistically reduced to such simple terms. Walford (1991), building on the earlier work of Medawar (1963), for example, pointed out that '[normative paradigm] research [in education] is frequently not carefully planned in advance and conducted according to set procedures, but often centres around compromises, shortcuts, hunches and serendipitous occurrences'. Walford went further and suggested that the 'step-by-step model of the [normative paradigm] research process [in education] is a fraud and ... the standard way in which [normative paradigm] research methods are taught and real research is often written up for publication perpetuates what is in fact a myth of objectivity'. While Walford's first point is certainly a valid one and certainly applicable within educational research as a whole, his attack on the normative research process as fraudulent is perhaps unjustified. While there is no doubt that such research has been undertaken in the past, these attacks reflect a somewhat naïve and distorted view of the normative research paradigm and the scope or potential scope of the work undertaken within it. A less extreme and more balanced view of the normative and other research paradigms and normative and other paradigm research, including the designs most frequently associated with them and the approaches, methods, methodologies and means of analysis most frequently employed, is taken here. This eclectic perspective is important. As Peshkin (1993) has indicated, 'no research paradigm has a monopoly on quality ... none can deliver promised outcomes with certainty ... and none have the grounds for saying "this is it" about their designs, procedures and anticipated outcomes'. Davies et al. (1985) suggested that it would be 'wilfully damaging not to juxtapose methods and their

datafruits within [different paradigm] perspectives'. Bell (1993) pointed out clearly that no form of educational research 'automatically rejects' any other and that once selected that does not mean that the researcher may not move from one to another for this depends on 'the nature of the enquiry and the type of information required'. Bell also noted that 'understanding the advantages and disadvantages of each [form] is likely to help select the most appropriate methodology for the task at hand'. Miles and Huberman (1994) proposed that any approach [from within any paradigm] that will produce 'clear, verifiable, credible meanings' from research is acceptable. As will be demonstrated in the following sections, while the work presented here is undoubtedly experimental and scientific, variations and departures from how experimentation and scientific enquiry are normally perceived and the research paradigm into which they normally fall do exist. At times, the boundaries between research categories at all of the different levels described, however they are defined, remain blurred. This is considered a strength rather than a weakness of the research as a whole.

1.4.2 Design

According to Kerlinger (1969), research design is the 'blueprint of the research architect' and its purpose is to guide. Kerlinger added that 'if the design is poorly conceived structurally, the ultimate product will be faulty'. The overall aim of this research, and the questions posed, lend themselves readily to experimentation and a quasi-experimental design was employed (Campbell and Stanley 1963). Quasi-experimental designs, also referred to as 'compromise designs' (Kerlinger 1969) and 'field experiments' (Denscombe 1998), are particularly useful in educational settings where a reasonable degree of control or comparability is required in order to determine the cause-effect relationships of an experimental treatment involving at least two participating groups, in this case to describe and measure learning, the dependent 'variable', as a result of an extended period of astronomy teaching, the independent 'variable', and to minimize threats associated with internal and external validity. At the same time, and unlike their true experimental counterparts, quasi-experimental designs recognize that the random selection of schools and classrooms is not always possible in some cases and that the experimental and control groups involved are not always formed as a result of randomization or matching. Quasi-experimental designs offer significant and immediately obvious interpretational advantages over summative, developmental, *ex post facto* and pre-experimental designs which usually lack any degree of control (Cohen et al. 2000) and which, to date, have been more typical of

children's ideas research as a whole. Reinforcing and extending the views expressed earlier, Mouly (1970) pointed out that the notion of establishing causation is always troublesome even during laboratory experimentation where it is of fundamental importance. This is particularly the case in education, for example, when attempting to reduce an inherently complex classroom teaching and learning environment to the operation of a single variable and attempting to find a partial answer to a question out of the context of reality. Mouly noted that the 'unwanted transfer of the law of the single variable' from the sciences, where it may or may not be appropriately adopted, is again largely responsible for the relative unproductivity of educational experimentation. In educational settings, Mouly suggested that researchers should not be interested in the effects of single variables examined in isolation but more in the joint effects and interactions of relevant factors operating simultaneously and that cause-effect relationships in educational settings are better regarded, therefore, as 'multiple causations' and that 'experimentation must inevitably operate in the complex multivariate interactions which characterize phenomena', such as learning about astronomy, as they actually exist. The broad nature of scientific enquiry remains unaffected. Similarly, Gall et al. (1996) reminded all educational researchers that while all experimental designs are relatively powerful in terms of what they set out to achieve, they are, of course, by no means perfect. As they wisely pointed out, no single experimental approach provides an irrefutable demonstration of cause and effect or results in unequivocal transferability, generalizability or representativeness and therefore the replication of experimental approaches, especially those that seek to investigate different cause-effect relationships, are desirable. Carefully designed and executed experiments can, nevertheless, provide a much needed evidence-base for future comparative research.

In their original paper, Campbell and Stanley offered sixteen different experimental designs of which ten are quasi-experimental. A modified version of their non-equivalent, quasi-experimental design (Design 10) is used here (Fig. 1.1). The term non-equivalent acknowledges the lack of randomization or matching between the experimental and control groups (as shown by the dashed line in Fig. 1.1). While neither randomized nor matched, the experimental and control groups in this study were found to be identical in both gender and ethnic make up and statistically inseperable when tested in terms of age, socio-economic background, intellectual maturity, science interest and curiosity, and informal science experiences (see Chapter 5). With the complexities of the human participants and classroom settings involved, no control could be established over home, religious, emotional or

behavioural backgrounds, motivation, study habits, general interests, peer interactions, absenteeism, and so on. As a result, the term non-equivalent to describe the experimental and control groups is retained. Extraneous variables such as those identified, can threaten the validity of cause-effect relationships particularly where any influence may be confounded with that of the dependent 'variable' under question.

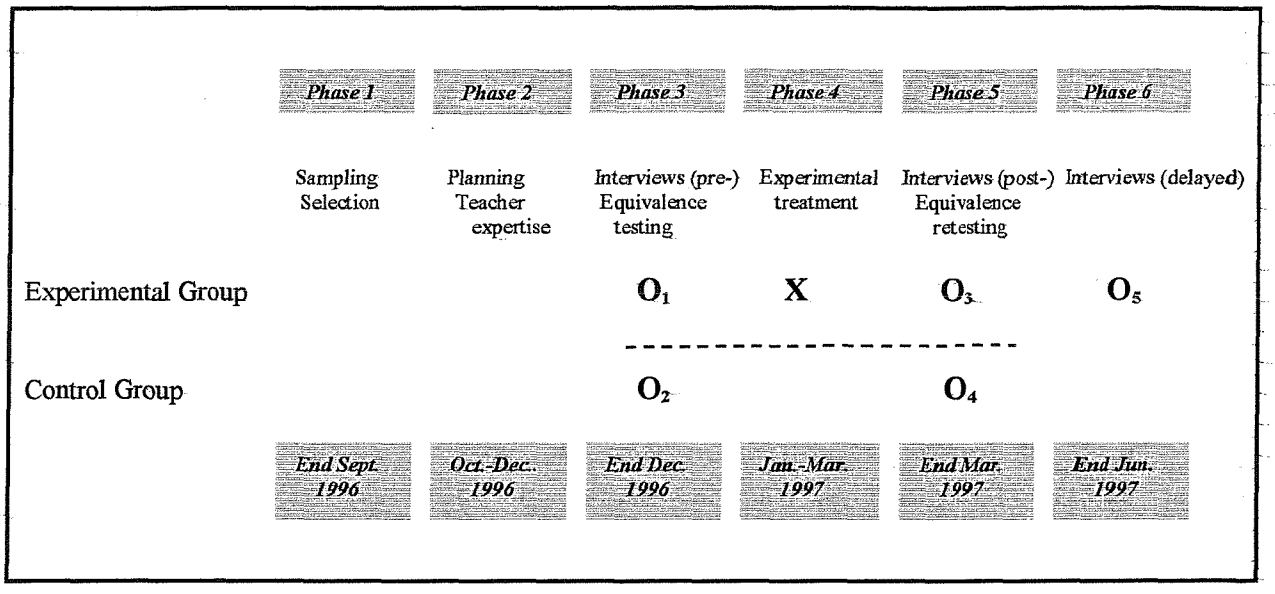

Fig. 1.1 Modified quasi-experimental design (after Campbell and Stanley 1963)

Within the overall structure of the design, six phases of research are identified:

- Phase 1 Sampling and selection of school, class teacher and children;
- Phase 2 Planning for research and teaching, establishing the curricular expertise of Jack, the class teacher, provision of in-service training where necessary;
- Phase 3 Elicitation of children's ideas in the experimental and control groups before astronomy teaching (denoted by O_1 and O_2 in Fig. 1.1), equivalence testing, implications for teaching considered;
- Phase 4 The experimental treatment (denoted by X), in this case 10 weeks of astronomy teaching to the experimental group only;
- Phase 5 Elicitation of children's ideas in the experimental and control groups after astronomy teaching (denoted by O_3 and O_4 in Fig. 1.1), equivalence retesting;

- Phase 6 Elicitation of children's ideas three months after astronomy teaching (denoted by O_5 in Fig. 1.1), experimental group only.

Phase 6 represents the modification over Campbell and Stanley's original design and this was intended to establish the retention and stability of children's ideas over time. Phases 1 to 6 lasted about 12 months. As indicated in the overall design, data were collected from a variety of different sources, employing a variety of different techniques, at a variety of different times and for a variety of different reasons. Each data collection episode is discussed in subsequent chapters (see Chapters 4 and 5). For the central focus of this work, children's ideas in the 'traditional' content areas of astronomy considered were obtained using a multiple-method survey instrument administered in the form of largely structured one-to-one interviews (Good 1963; Cannell and Kahn 1968; Powney and Watts 1987; White and Gunstone 1992; Cohen et al. 2000). Interviews were conducted in accordance with general interview procedures for science elicitation outlined by Osborne and Freyberg (1985). While considerable efforts were made to establish and address any shortcomings in Jack's curricular expertise in astronomy and to plan together the astronomy teaching which only Jack would deliver, no guarantees could be given that the work undertaken would not be disadvantaged from time to time by the day to day events which might significantly interrupt the teaching and learning process. While recognizing that a certain degree of experimenter bias and loss of experimental treatment fidelity (Gall et al. 1996) are almost inevitable in this situation, every effort was taken to minimize their effects where possible.

1.4.3 Theoretical and analytical framework

This research is framed within a broadly constructivist view of learning science in the primary classroom, one which places emphasis on the active and dynamic construction of scientific knowledge by learners themselves, individually or in more social settings, rather than on the passive absorption of information transmitted by others, and that any prior knowledge brought into new teaching and learning situations can strongly influence the effectiveness of any further learning that might take place. With its focus almost entirely on children's ideas about astronomical objects, events and phenomena, and how these ideas change as a result of knowledge acquisition and concept learning, this work is located firmly, though not exclusively, within the cognitive domain. This section continues with reference to some of these key terms.

(a) Constructivism and science education

The view that scientific knowledge cannot be transmitted directly from one individual to another but must be constructed through acts of personal and social cognition by learners themselves lies at the very core of almost all children's ideas research and continues to underpin contemporary perspectives on science education today (Glynn et al. 1991; Driver et al. 1994b; Hollins and Whitby 2001). The personal and social dimensions of knowledge acquisition essentially emerged out of the works of Jean Piaget (Piaget 1964, 1969; Gilbert and Swift 1985; Bliss 1993, 1995; Fosnot 1993; Marin and Benarroch 1994; von Glaserfeld 1995) and Lev Vygotsky (Vygotsky 1962, 1978; Wertsch 1985; Solomon 1987; Howe 1996; Hodson and Hodson 1998) and the competing and, at times, complementary perspectives they brought to the relationship between learning and development (Durkin 1995; Wood 1998; Marin et al. 2000). The exact origin of the constructivist or 'alternative frameworks' movement (Gilbert and Watts 1983; Johnson and Gott 1996) in science education is itself, however, attributed to neither. According to most authors, that accolade goes to Driver and Easley (1978). Reacting principally against Piaget's developmental stage model of cognitive growth which was interpreted as implying deterministic limitations to children's learning capabilities, and an empiricist's view of science, both of which were dominant forces in science education at that time (Osborne 1996), Driver and Easley provided the language, the re-description and the re-interpretation of children's ideas in science from which constructivism emerged (Solomon 1994a). While Driver and Easley were not the first to draw attention to the limitations of the application of Piaget's 'ages and stages' theory in science education (Flavell 1963; Pella and Stauss 1967; Bass and Montague 1972; Lovell 1974; Lawson and Renner 1975; Sayre and Ball 1975; Shayer et al. 1976; Brown and Desforges 1977), their seminal paper, which reviewed available nomothetic and ideographic approaches to studying children's ideas, recognised the significance and implications of children's idiosyncratic or autonomous interpretations of the physical world as 'alternative frameworks', already identified as 'critical barriers' to science learning (Hawkins 1978), and considered a shift from 'global' to 'domain-specific' theories of learning wherein 'achievement in science depends to a greater extent upon specific abilities and prior experience than general levels of cognitive functioning'. Driver and Easley's paper also initiated a deeper interest in and subsequent proliferation of children's ideas research itself. It should be noted, of course, that, in addition to Piaget and Vygotsky, the evolution of constructivism in science education was also influenced strongly by other 'global' theories of

cognitive development and learning such as those proposed by Kelly (1955), Bruner et al. (1966), Ausubel (1968), Ausubel et al. (1978) and Gagné (1985). Indeed, before the full emergence of constructivism in science education, the work of Ausubel in particular had received considerable attention (West and Fensham 1974; Novak 1977a, b) and the application of Ausubel's work had also found a strong place in primary science (McClelland 1985). Prior to 'alternative frameworks', children's ideas were also referred to as quaint distortions (Piaget 1929), sophisticated errors (Kuethe 1963), preconceptions (Ausubel 1968) and misconceptions (Novak 1977a). From the significant body of early research undertaken within the constructivist or 'alternative frameworks' movement, Tasker (1981) and Driver and Bell (1986) made the following generalizations:

- children form their own ideas about the world in which they live long before any formal teaching takes place in school;
- children's ideas frequently differ from the science taught at school and the ideas of scientists themselves;
- children's ideas can be strongly held and resistant to change even in the most supportive, caring and stimulating of learning environments;
- children's ideas can and do change but often in unanticipated ways, the perceptions of what is intended by the teacher or the science curriculum often at odds with that of the child;
- children are responsible for their own learning in that they should be sufficiently motivated to direct their attention to the learning tasks at hand and remain in a state of metacognitive awareness throughout;
- children often share similar ideas as a result of shared experiences, the use of language, and interpersonal relationships.

Largely because of constructivism, the passive role of children in science learning, which assumed children to be merely empty vessels waiting to be filled, was no longer considered acceptable (Driver 1981). Children's ideas had to be taken seriously. The implications for school science, that is the science contained within a school science curriculum, and a teacher's interpretation and presentation of it, soon became obvious (Gilbert et al. 1982, 1985).

Despite all the obvious successes and strengths of constructivism in science education, it also has its weaknesses. As indicated earlier, the greater awareness of the learner and his or her 'alternative frameworks' in learning situations quickly gave rise to important questions about curriculum development and the nature of science pedagogy and constructivism in science education spread rapidly into these areas (Strauss 1981; Tasker 1981; Driver 1991; Driver and Erickson 1983; Gilbert and Watts 1983; Driver and Oldham 1986; Watts and Bentley 1987, 1991; Cheung and Taylor 1991). As compelling as it might be, the shift from a view of learning to a view of curriculum development and teaching has no immediate or obvious justification. According to Matthews (1994), for example, a view of learning gives no indication of what, how much and to whom science should be taught and that a science curriculum requires additional considerations including at the very least social, cultural and personal needs. Similarly, and according to Millar (1989), a constructivist view of learning does not logically entail a constructivist view of teaching. Indeed, Millar correctly pointed out that as a consequence of a constructivist view of learning, science could in reality be taught by any means considered most likely to engage the active involvement of the learner whatever they might be. Solomon (1994a) and Osborne (1996) have identified what they regard as perhaps the source of all of constructivism's weaknesses by calling into question its failure to fully outline its own epistemological and ontological commitments and its failure to recognize its own limitations. As a result, and in addition to curriculum and pedagogy, the distinctions between school science and real science and the internal or mental processes associated with learning and the external conditions in which learning takes place, as well as other matters, have become blurred and confused. Nowhere is this blurring and confusion more vividly portrayed than in what Hodson (1998) has referred to as 'the paradox of constructivism'. According to the review of work presented by Hodson, in its depiction of the 'individualized' nature of children learning science, constructivism has left itself wide open to misinterpretation, misrepresentation and the charge of neglecting or trivializing science itself. In his example, Hodson suggested that at the heart of all of this lies a concern that, in some instances, children who are engaged in science activities at school and constructing their own knowledge and understanding of the world around them are also considered to be constructing scientific knowledge and understanding of the world around them and that anything is allowed to count as science provided the children are working co-operatively in a friendly learning environment. Thus, by engaging in practical investigations and enquiries all children are considered scientists. Interestingly, Hodson's example can be identified with the much criticized child-centred, discovery-led and process-driven science

pedagogy which dominated primary science education in the UK until the late 1980s (Osborne and Simon 1996). But, as Hodson asserted, not all investigations and enquiries are scientific and not all forms of knowledge and understanding arising from them are equally valid from a scientific point of view and to accept anything less is to do children a gross disservice. Hodson's example illustrates a relativist view of science, one in which the concept of constructivism refers to an entire family of theories that share the assertion that human knowledge and experience entail the active participation of the individual and that all we can know is, in fact, a product of our own creation (Mahoney 1988). While relativism certainly has a place in the philosophy of science and the sociology of scientific knowledge (Nussbaum 1989; Selley 1989; O'Loughlin 1992; Fosnot 1996; Hawkins 1994; Slezak 1994) such relativist views are alien to science and most scientists (Chalmers 1978; Dunbar 1995). That said, even science education's most hardened constructivists have made statements which, while making perfect sense within the context of the works in which they appear, are easily misconstrued. Frequent reference to children as 'architects of their own knowledge' (Driver 1989), for example, are far from helpful for all of the reasons described. Children learning with reference to 'the architecture of cognition', a similarly expressed but profoundly different metaphor in meaning introduced by Anderson (1983) to describe the constraints of learning imposed by the mind, may have been more appropriate.

In response to these concerns and criticisms in relation to constructivism in science education, Driver et al. (1994b) mounted what might be considered a relatively robust defence. According to Driver et al., the view of learning science as acts of personal and social construction does not imply relativism but realism. This acknowledges the more scientifically acceptable view that scientific knowledge is constrained by how the world is and that its knowledge claims are considered to reflect or work towards that reality. Any science curriculum and pedagogical approach ultimately based upon a constructivist learning perspective should at the very least provide children with practical and other experiences and access to the subject matter of science that induce cognitive conflict. If, as Driver et al. suggested, children are to adopt scientific ways of working and knowing, then intervention and negotiation of meaning with a teacher is essential if the cultural tools and conventions of the scientific community are to be made available. As Driver et al. pointed out, however, 'the challenge is one of how to achieve such a process of enculturation successfully in the round of normal classroom life' particularly when 'the science view that the teacher is presenting is in conflict with the learners' prior knowledge schemes'.

Learning characterized as a process of knowledge acquisition, conceptual change and the associated generation of new meaning or sense-making, however, may be overly simplistic. Driver et al. (1994b), for example, suggested that children need not be expected to abandon their 'alternative frameworks' or common-sense ideas as a result of science teaching. Instead, they should have these ideas available to them for communication within appropriate scientific contexts. Evidence that children of all ages do, in fact, retain a variety of 'alternative frameworks' for 'context-specific' reasoning or 'situated cognition' is widely available (Solomon 1983; Engel-Clough and Driver 1986; Kuiper and Mondlane 1994; Millar and Kragh 1994). Linder (1993) also argued from both cognitive and phenomenographic perspectives that individuals could construct a repertoire of conceptions of objects, events and phenomena ('domains of knowledge'), the one eventually chosen and used depending on the context, social, scientific or otherwise, for which it is required ('mode of perception'). Linder has proposed that the term 'conceptual appreciation' might be more appropriate than learning by conceptual change. While the focus of this section has been on cognitive factors associated with learning science, the complex social and affective dimensions involved are also important and should not be overlooked (Claxton 1989, 1990; Head 1989; Solomon 1989, 1993).

(b) Learning

According to Driscoll (2000), learning is a life-long activity which occurs intentionally in formal teaching settings and other learning environments and informally or incidentally through other experiences, encompasses a multitude of competencies from a knowledge of simple facts to the great skills required for complex and difficult procedures, and sometimes requires great effort or proceeds with relative ease. According to Driscoll, most authors share a common view of learning which can be defined as 'a persistent change in human performance or performance potential' which is not simply ascribed to growth or maturation. Fortunately, the results of learning are often observable in the outcomes of human performance. Taxonomies of learning outcomes are well known. Bloom's taxonomy of learning outcomes in the cognitive domain, for example, consists of six related levels including knowledge, comprehension, application, analysis, synthesis and evaluation (Bloom et al. 1956). Each level represents progression in terms of complexity. The higher the taxonomic level, the more complex the learning involved. Gagné's taxonomy of learning outcomes, on the other hand, is broader and considers cognitive, affective and psychomotor

domains of learning including verbal information, intellectual skills, cognitive strategies, attitudes and motor skills (Gagné 1985). While Driscoll's definition of learning is valuable in helping to identify learning in terms of human performance, and this will be of great value throughout this work as children's ideas in astronomy are considered before and after teaching, it does not help in understanding why learning is often limited, selective and incomplete, significant features of learning science described earlier. For this, a more focused definition of learning is required, learning defined as the internal, mental processes which allow for and bring about the acquisition of knowledge itself (Jahnke and Nowaczyk 1998). In order to fully understand the processes involved in knowledge acquisition and concept learning it is necessary to view science education and cognitive psychology together, the link in this case being information processing theory.

By the end of the 1970s, most cognitive psychologists were in general agreement that information processing theory, using the functioning of a computer as a suitable metaphor, was the most appropriate way to study human cognition (Broadbent 1958; Lachman et al. 1979; Gardner 1985). Information processing theory has since given rise to a diverse range of computational models of cognition, most of which are associated with semantic or declarative networks, and most of which share the same basic characteristics. Central to all computational models of cognition is the multi-store notion of memory first proposed by Atkinson and Shiffrin (1968) and Shiffrin and Atkinson (1969) and now generally accepted by most cognitive psychologists (Fodor 1983; Parkin 1993; Squire et al. 1993; Baddeley 1997). Within information processing theory, individuals are viewed as autonomous, intentional beings who interact with the external world, the mind through which they interact is a general-purpose, symbol-processing system (symbols being patterns stored in long-term memory which designate or point to entities outside themselves), symbols are acted upon by various processes that manipulate and transform them into other symbols that ultimately relate to things in the external world (much of this processing takes place in short-term or working memory), the mind is a limited capacity processor having both structural and resource limitations, and the symbol system depends on neurological substrate but is not wholly constrained by it (Eysenck and Keane 1995).

While making links between science education and cognitive psychology is an attractive and exciting prospect it should also proceed tentatively and with care. Researchers in each field study knowledge acquisition and learning in different ways and at different levels of

abstraction (Brown 1995; Gredler 2001). The explanatory power afforded to science education by information processing theory, however, is too good to ignore and this has not entirely gone unnoticed.

(c) Knowledge and understanding

The origin and acquisition of knowledge in humans has been a matter of intense philosophical debate for centuries. In valuable summaries provided by Broudy (1977) and Anderson (1989), three basic categories have been identified: nativism, empiricism and rationalism. While the subtleties are many, nativism considers all individuals to be born with the knowledge they need and that anything else is acquired by some innate or inherited characteristic, empiricism considers all individuals to acquire knowledge out of experience, and rationalism considers all individuals to acquire knowledge by engaging in reasoning. As both Broudy and Anderson pointed out, most philosophers were inclined to argue that all knowledge was of one kind or another. If a less extreme position is taken, however, the categorization provided does at least allow for the origin of an existing piece of knowledge, rather than knowledge as a whole, to be evaluated. Today, of course, individuals are considered to be born with a mind which facilitates cognition rather than with a mind full of knowledge *per se* (Brown 1986). The complex interplay between each of the philosophical and current positions presented is still of interest to many cognitive psychologists as they strive to unravel and determine the 'nature' and 'nurture' effects on the development of cognitive ability (Plomin 1988).

As mentioned earlier, children's ideas research of which this is an example, essentially seeks to explore how children conceptualize the objects, events and phenomena of science usually by means of eliciting their knowledge and understanding of them. The knowledge obtained in most research studies of this type is typically declarative or 'knowing that' knowledge (Ryle 1949). This type of knowledge is most closely associated with the semantic and episodic components of long-term memory. According to Tulving (1972, 1985), semantic memory refers to the memory for words, propositions, general knowledge and concepts and is characterized by an individual's ability to represent mentally conditions of the world that are not perceptually present. Episodic memory refers to the memory for images and episodes that occupy a particular spatial and temporal context. Both semantic and episodic memories are similar in that their contents can be 'brought to mind' or recollected. The organized body

of declarative knowledge pertaining to a domain like science or sub-domain like astronomy that is stored in long-term memory is referred to as the cognitive structure of that domain or sub-domain (Pines 1985). Procedural knowledge or 'knowing how' knowledge (Ryle 1949) is most closely associated with the procedural component of long-term memory and refers to the memory for skills (Tulving 1972, 1985). Understanding, on the other hand, involves thinking, reasoning, problem-solving and other higher-order cognitive functions (McCown et al. 1996). According to Ogborn (1993), being able to do what another does or to say what they have been told is not enough to say that there is understanding. For that, a level of 'knowing why' is needed in addition to 'knowing that'. For Ogborn, sharing a common understanding is to locate a common level of 'why', that is to say, providing 'explanations of explanations'.

(d) Knowledge representation in memory: the schema construct

One current conception of the organization and representation of declarative knowledge in memory is based on the schema construct (Bartlett 1932; Rumelhart and Ortony 1977; Rumelhart 1980). A schema of an object, an event or a phenomenon is a knowledge package that represents all the information elements associated by an individual with that object, event or phenomenon. Schema or schemata (plural) are, therefore, the declarative and procedural representations of experience. Information elements can themselves be schema ensuring that cognitive structures comprise many complex semantic or declarative networks. Semantic networks are important forms of computational models within information processing theory (Collins and Quillian 1969, 1970; Craik and Lockhart 1972; Newell and Simon 1972; Smith et al. 1974; Collins and Loftus 1975). Theories of knowledge acquisition and concept learning based on schema constructs and semantic networks assume that schema are not static and that their content, the arrangement of that content and the relations within that content change when presented with new information. Either new elements are added or existing schema elements are modified. Considerable evidence exists that knowledge can only be acquired meaningfully (as opposed to by rote or by conditioning) if its elements can be related non-arbitrarily to already established schema in a learner's existing cognitive structure (Ausubel et al.1978).

(e) Concepts, concept formation and concept learning

Because a schema is regarded as an organizing structure for knowledge, schema can take on many different forms when representing different types of knowledge. For the purposes of this work, it is convenient to consider declarative knowledge to be organized and represented in memory in terms of concepts or conceptual schema (Bruner et al. 1956). Conceptual schema are, therefore, embedded within semantic networks (Miller and Johnson-Laird 1976). Of course, concepts themselves provide the organizing elements and guiding principles for most science lessons as well as for scientific enquiry and fieldwork (Nussbaum 1989) and children's ideas research has tended to focus attention on knowledge acquisition and learning as simply concept learning, a process usually taken to involve conceptual challenge and change (e.g. Driver 1989). Existing literature on concepts and concept formation is vast. In science education, concepts and concept formation have been comprehensively reviewed by Gilbert and Watts (1983) and in cognitive psychology by Smith and Medin (1981), Pozzani 1990, Komatsu (1992), Mechelen et al. (1992) and Estes (1994). Summarizing, concepts are the ideas individuals think with. Expressed more technically, concepts are the internal, mental representations of the abstract properties of objects, events and phenomena. The objects, events and phenomena that embody a concept are said to form a conceptual category. Concepts provide cognitive economy that is essential to communication. Without concepts, for example, every object, event and phenomenon would have to be identified by its own name. Concepts also provide for variety and clarity of thought. Without concepts, for example, it would not be possible to consider objects, events and phenomena in terms of their similarities and differences. In classical theories of concept formation, concepts have attributes. Attributes define what it is to be a member of a concept and concept learning takes place by association (similarity, contiguity and contrast). Attribute views of concept formation are useful for object concepts (e.g. the Earth, the Sun, the Moon) but many concepts involve more than simple attribute lists. Concepts also contain causal and other background knowledge that might be represented by schema or schemata. More recently, this has given rise to explanation-based views of concepts and concept formation. Explanation-based views of concepts and concept formation are useful when dealing with the complexities of relational concepts (e.g. day and night, seasonal change, phases of the Moon). Within explanation-based views of concepts, concepts can have attributes but they also have relations between them forming explanatory connections. The meaning that an individual gives to a particular word, or the complex semantic network that an individual possesses

which makes him or her knowledgeable about or understand something, for example, depends significantly on relations (Pines 1985). More importantly, explanation-based views of concepts and concept formation suggest that concepts need not be permanently stored but may be dynamically constructed in short-term or working memory in response to perceived requirements and that context-dependency effects may play a part in that construction (recall Linder's 'domains of knowledge' presented earlier).

(f) Mental models

Because schemata are active in influencing and determining how individuals conceptualize, interpret and ascribe meaning to objects, events and phenomena, they have also been conceived as mental models (Johnson-Laird 1980, 1983), though the exact relationship between schemata and mental models remains unclear (Brewer 1987). Mental models are schemata that not only represent an individual's knowledge about specific subject matter but include perceptions of task demands and task performances. Thus, mental models are schemata that guide and govern performance as individuals undertake certain tasks or attempt to solve problems. In this respect they are broadly similar to explanation-based views of concepts and quite possibly derived from them. The main role of a mental model is to allow its builder to explain and make predictions about the physical or other system represented by it. According to Gentner and Stevens (1983), mental models are often incomplete, an individual's abilities to 'run' their models are often severely limited, mental models are unstable in that information and details are forgotten or discarded, mental models do not have firm boundaries, mental models are parsimonious in that individuals would rather choose operations that require more energy in exchange for less mental complexity, and mental models are 'unscientific' in that they contain beliefs. Mental models have found their way into science education (Norman 1983; Duit and Glynn 1996; Greca and Moreira 2000). Vosniadou (1991a, b), for example, adopted the construct of the mental model to characterize the kinds of representations children form when they are asked questions or solve problems in astronomy. Vosniadou assumed that mental models of astronomical objects, events and phenomena are generated from and constrained by underlying conceptual structures and that understanding the mental models an individual uses to answer questions and solve problems can provide important information about the content, organization and relations of an individual's knowledge-base. Like explanation-based views of concepts, mental models may be constructed on the spot or stored as separate structures in long-term memory and retrieved

when needed. According to Vosniadou, there are three kinds of mental model: intuitive, scientific and synthetic. Intuitive models deviate as little as possible from the world as it is experienced directly. They show no influence from the scientific models presented by adults at school or elsewhere. Scientific models are the models held by individuals that agree with current scientific views or at least the views presented at school. Synthetic models show a combination of intuitive and scientific views. Sharp et al. (1997) preferred the term transitional to synthetic, the latter implying something artificial or manufactured which may not actually be the case. Boulter et al. (1998) adopted a slightly different perspective referring to children's ideas as 'expressed models' acknowledging that they may be derived from scientific or culturally accepted 'consensus models' and some prior-constructed mental model. Broadly speaking, intuitive and synthetic or transitional models reflect the alternative interpretational frameworks described by Driver and Easley (1978). The mental model and, in particular, Vosniadou's view of the mental model is adopted and extended throughout this work by virtue of its appropriate and all encompassing nature. By eliciting children's ideas at regular intervals throughout the experiment (see Fig.1.1), it is considered possible to identify and describe the differences which occur within each individual's knowledge-base over time and to capture something of the process of knowledge acquisition and learning in terms of conceptual change. According to Bliss (1995), mental models are also important in science education for they possess both epistemological and ontological significance.

(g) Models of knowledge acquisition and concept learning in science education

Information processing theory is not without its problems (Lachman et al. 1979; Gardner 1985; Levy 1987; Eyesenck and Keane 1995). Humans are, of course, living organisms capable of independent thought and not machines which rely on programming and circuitry. The human brain is a complex organ which, while currently thought to operate in a modular way (Fodor 1983), does not contain box-like storage areas within which discrete processing takes place. Within the field of cognitive psychology, information processing theory has developed as a result of laboratory-based, highly controlled experiments, usually with individuals and in areas of linguistics and general problem-solving, all as far removed from science education and classrooms as it is possible to get. Many cognitive psychologists consider schema to be unprincipled and lack the predictive power they would prefer. Many early and influential converts to information processing theory have since turned away and begun to look towards all factors associated with learning in its widest sense (e.g. Bruner

1986, 1990). Despite these difficulties, successful models of knowledge acquisition and concept learning in science education have been proposed (Shavelson 1974; Hewson 1981; West and Pines 1985; Pines and West 1986; Duschl and Erduran 1996). Perhaps the best known model of knowledge acquisition and concept learning in science education, and broadly typical of most models of cognition derived from information processing theory, is the generative learning model proposed by Osborne and Wittrock (1983). This is represented as shown (Fig.1.2).

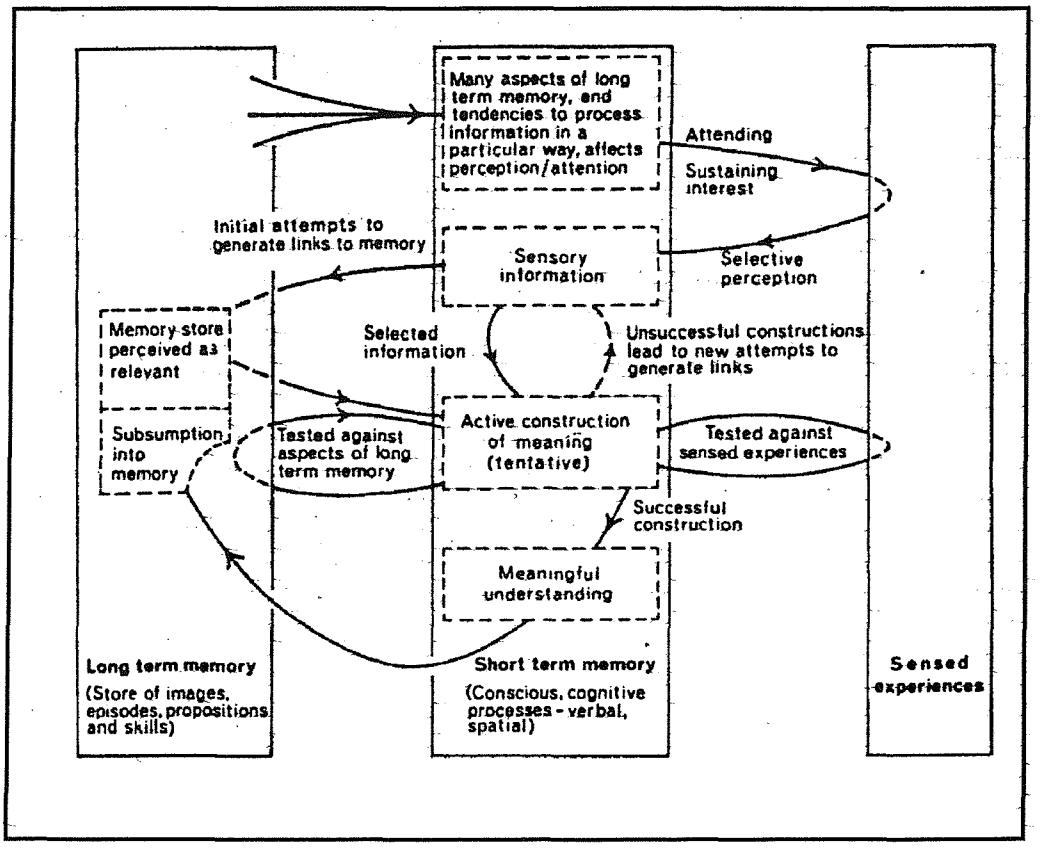

Fig. 1.2 The generative learning model (Osborne and Wittrock 1983)

Osborne and Wittrock's generative learning model is important for it deals with explanation-based views of concepts and concept formation and mental models. According to Osborne and Wittrock, all learning begins with a stimulus, the information that is detected by human senses from what is being taught say. This sensory information is transferred via the peripheral nervous system to the central nervous system and the brain for attention. So much sensory information is often presented at any one time that only a small amount of it receives

attention and is perceived. To comprehend what is being taught, an explanation or mental model is generated from relevant information stored in long-term memory against which the perceived information is tested. This takes place in short-term or working memory. Adjustments to the explanation or mental model are made and this new information accommodated only when there is dissatisfaction with the existing model and when a new model is both intelligible and plausible (after Posner et al. 1982). Osborne and Wittrock's generative learning model helps to explain the generalizations derived from the constructivist or 'alternative frameworks' movement presented by Tasker (1981) and Driver and Bell (1986). Children bring their own ideas about the world in which they live to the classroom long before any formal science teaching takes place at school. As a result, the content, arrangement and relations of conceptual schema may give rise to 'alternative' interpretational frameworks and ideas and meanings which differ from the science taught. Unless the new information presented to them is intelligible and plausible, children are unlikely to consider new ideas in favour of those which already make sense. Poorly developed or incomplete conceptual schema may give rise to unanticipated changes as knowledge acquisition and learning take place. Children's ideas tend to be context-specific for that is how the content and arrangement of conceptual schema and the relations within and between them are constructed and subsequently activated during retrieval and this essentially results in situated cognition.

The addition of new elements to and the changing of existing schema, as knowledge acquisition and concept learning takes place, has been described in different ways. Assimilation and accommodation are perhaps the most familiar. In brief, assimilation involves the 'taking in', filtering and modification of sensory information while accommodation involves the modification of internal schemes to 'fit' reality (Piaget and Inhelder 1969). Others have extended assimilation and accommodation to include progressive differentiation and integrative reconciliation (Ausubel 1968; Ausbel et al. 1978). Rumelhart and Norman (1978) describe three modes of knowledge acquisition and learning: accretion, tuning and restructuring. Accretion is described as the 'normal kind of fact learning'. Such learning is presumed to occur through appropriate exposure to the new information to be acquired which is then transformed into some appropriate memory representation and matched with and added to an individual's existing data-base of knowledge according to the principles contained within existing schemata (e.g. there are nine planets in the Solar System). In other words, the content changes but little else. Tuning is

more significant and involves more than simply changing content. According to Rumelhart and Norman, upon having developed an interpretational framework of schema or schemata with which to consider new information, these are presumed to 'undergo continual tuning or minor modification to bring them more in congruence with the functional demands placed upon them' in the learning situation. Schema or schemata change (content, arrangement, relations), albeit in a relatively minor way, when new information does not fit currently available schemata or when the organization of existing schemata is not satisfactory (e.g. there are nine planets in the Solar System each of which exhibit certain differences as well as similarities). Restructuring is even more significant and difficult. According to Rumelhart and Norman, the interpretational framework of schema or schemata developed to consider new information are presumed to undergo considerable reorganization imposing a new organization on that information already stored. Schema or schemata change in a radical way (content, arrangement, relations) which allows for new meaning, improved accuracy and generalizability, different accessibility to that information and for changes in the interpretation and therefore the acquisition of further information (e.g. the Solar System is heliocentric and not geocentric which is how it appears). Carey (1985, 1986) and Vosniadou and Brewer (1987) refer to accretion, tuning and restructuring as weak and radical knowledge restructuring. According to Vosniadou and Brewer, who located their work within the context of the development of astronomy schemata in children, for example, weak restructuring involves the enrichment of, or adding to, existing knowledge and the 'accumulation of new facts and the formation of new relations between existing concepts' (effectively accretion and tuning). Radical restructuring involves the abandoning of old knowledge for the appearance of new knowledge and a 'change in core concepts, a change in structure, and a change in the phenomena to be explained'. As indicated earlier, existing schema or schemata, representing an individual's prior declarative knowledge-base, constitute the most influential factor affecting the rate, accuracy and effectiveness of knowledge acquisition and meaningful concept learning. This is an established feature of cognitive psychology as well as science education (Bransford 1979; Pazzani 1991; Ahn et al. 1992; Pinker 1997). More advanced models of learning science involving dynamical systems theory and chaos and neural or connectionist networks will be introduced and discussed later (see Chapter 7).

(h) Interpreting children's ideas

According to Claxton (1993), to assume that children's ideas about the objects, events and phenomena of science directly reflect the nature and structure of their prior knowledge and their 'alternative frameworks' is to be 'guilty of a gross oversimplification of their psychology'. As Claxton pointed out, being a subject in an 'experiment', however informal, is a novel social and cognitive experience that demands the selection or construction of knowledge and of knowledge-manipulation and expression procedures. As a result, what children reveal is not what they know or how they think but what they choose to present to researchers within the perceived requirements of the research context. Claxton suggested that in such novel situations, children are prepared to oblige researchers with any number of responses no matter how fabricated if only to appear helpful. The stability or reality of the underlying knowledge structures are thus called in to question. Children's ideas research, Claxton asserted, suffers from the simple assumption made by its practitioners that similar responses from different children overcome this matter. It could easily be the case that children tend to 'manufacture' responses in the same kind of way 'in the heat of the moment'. Design and a combination of principle data collection techniques help to overcome this. Von Glaserfeld (1989) and Johnson and Gott (1996) also question the reliability and validity of evidence in relation to children's ideas but from a different perspective. According to Johnson and Gott, for example, 'finding out' what a child thinks rests on an interpretation of a child's responses to a researcher's question. This is a fundamental point in children's ideas research and one which is frequently overlooked or neglected. Johnson and Gott pointed out clearly that each person makes his or her own sense of the world and can only use what they already know, drawing on their own cognitive structure, to do this. This they referred to as an individual's 'frame of reference'. It follows, then, that during an interview say, there are two 'frames of reference' to consider, that of the interviewer and that of the interviewee. This results in an in-built uncertainty in any communication between them. Throughout an interview, there will exist what Johnson and Gott called a 'translation interface' which is traversed twice for every question posed. For the researcher, there are the researcher's questions and the researcher's interpretation of the response. For the child, there is the child's interpretation of the question and the child's response. Each traverse presents an opportunity for misinterpretation associated with meaning. To overcome this, Johnson and Gott proposed 'neutral ground'. They defined 'neutral ground' as more limited than either the researcher's or the child's 'frame of reference', even if the child understands what the

researcher is asking in the meaning intended by the researcher, and the researcher understands the child's response in the meaning intended by the child, for no one is completely able to construct another's constructs, a point made by Kelly (1955) some 40 years earlier. Interpretation on 'neutral ground', therefore, is simply the best that can be aspired to. Even if evidence obtained from responses during interview is considered reliable and valid, it may still be far removed from the 'frame of reference' which provided it.

(i) Primary science and the National Curriculum

Unfortunately, even today, primary science means different things to different people. Considerable debate revolving around whether or not primary science should be driven by content, in which scientific knowledge is portrayed implicitly and explicitly as arrived at by objective methods capable of yielding absolute truths, or driven by process, in which scientific knowledge is portrayed implicitly and explicitly as arrived at subjectively and involving engagement with practical activity, still exists even today (Harlen 2000). Such a polarization of views reflects a very real distinction between the child-centred/discovery-led and teacher-centred/didactic pedagogies described by Harlen (1983a). Considering content and process as alternative ways of presenting science to children has not, however, served science education well (Cheung and Taylor 1991). In terms of the nature, teaching and learning of science, both extremes have something to offer and it might be suggested that finding an appropriate balance between the two is required. For this reason alone, it is important to make a clear statement of what primary science is here. Primary science is regarded as an intellectual, practical, creative and social endeavour which seeks to help children to better understand and make sense of the world in which they live by involving them in thinking and working in particular ways in the pursuit of reliable scientific knowledge (Sharp et al. 2002). In line with most current thinking (e.g. Swatton 1990; DfEE 1998a; Hollins and Whitby 2001), it is accepted that while practical work undoubtedly contributes towards securing children's interest, curiosity and progress in science, children's scientific knowledge and understanding cannot always be developed through practical work alone. While the counter-intuitive and non-spontaneous nature of many scientific ideas can lead to science being difficult to learn, intrinsically as well as extrinsically (Millar 1991), any view that science can be taught and learned by process alone, which until very recently dominated primary science, is entirely fallacious (Millar and Driver 1987; Millar 1994; Donnelly 1994). If teaching science at school is intended to lead children towards the

conventional ideas of science itself, then, as has been stated before, the teacher's intervention is essential (Driver et al. 1994b).

At the time this work was undertaken, primary schools throughout England and Wales were continuing to adjust to the changes associated with a period of unprecedented and sweeping educational reform including the introduction of a National Curriculum of subjects and the constant rounds of subject revision which have taken place subsequently. Between 1989 and 1995, for example, the National Curriculum for primary science, that is, the National Curriculum for Science at Key Stages 1 and 2, was revised on two separate occasions, each revision proceeding by means of outlining new proposals and a period of public consultation. The *third version* of the National Curriculum for primary science was the version in place at the time of this work (DfE/WO 1995). The revision process outlined continued after the 'fieldwork' for this research had been undertaken and there seems little reason to assume that further revisions will not continue long into the future. This research will not only be considered within the context of the National Curriculum for primary science, it will be used to inform the National Curriculum for primary science itself (see Chapters 3 and 7).

1.5 Originality of research

The work presented here is considered original in several respects. While children's ideas research is not new and children's ideas in certain aspects of astronomy have already been reported from several countries around the world, quasi-experimental studies of knowledge acquisition and concept learning are rare and, in recent years at least, have never been undertaken within the UK. Astronomy coverage is also extensive, with all aspects of children's ideas in the 'traditional' content areas of astronomy considered systematically resulting in new insights into the conceptual routes and pathways as knowledge acquisition and concept learning take place as well as new insights into science learning theory. The learning outcomes as a whole also provide an evidence-base with which to reconsider effective astronomy teaching and curriculum design.

1.6 Summary

Children's ideas research in science education essentially seeks to explore how children conceptualize the objects, events and phenomena of science usually by means of eliciting

their knowledge and understanding of them. The research presented here attempts to explore, in just such a manner, children's ideas in astronomy and how these ideas change as a result of knowledge acquisition and concept learning in one English primary school setting. It attempts to do these things within the context of an educational experiment. The 'fieldwork' for this research was undertaken in Big Town County Primary School in Exmouth. The human participants involved were 62 upper primary children and their teachers. The 62 children constituted two of Big Town CPS's three vertically grouped and combined upper primary Year 5/6 classes. The 31 children in each class were between 9 and 11 years of age when the 'fieldwork' began. As a quasi-experimental study, one class was designated the experimental group and exposed to the experimental treatment, a 10 week period of formal astronomy teaching. The other class, the control group, was taught materials. The research presented here is framed within a broadly constructivist view of learning science in the primary classroom, one which places emphasis on the active and dynamic construction of scientific knowledge within learners themselves rather than on the passive absorption of information transmitted by others, and that any prior knowledge brought into new teaching and learning situations can strongly influence the effectiveness of any further learning that might take place. In order to characterize the kinds of representations children form when they are asked questions or solve problems, the construct of the mental model has been adopted. Mental models are generated from and constrained by underlying conceptual structures or conceptual schemata, changes in which, as a result of knowledge acquisition and learning, can be identified and described over time. Primary science is regarded here as an intellectual, practical, creative and social endeavour which seeks to help children to better understand the world in which they live by involving them in thinking and working in particular ways in the pursuit of reliable knowledge. The chapter which follows contextualizes the work presented here further by locating it firmly within a review of appropriate children's ideas research literature.

Chapter 2

Review of Literature

2.1 Introduction

Reviews of available literature serve a number of different functions. They deepen the author's and the reader's knowledge and understanding of a field of research, they provide an insight into methodological issues and the analysis and interpretation of data, and they expand upon the context and background of a study to provide a platform on which to build and justify new lines of enquiry by establishing points of departure from existing studies. This chapter provides a relevant and critical review of available literature concerning mainly primary children's ideas in astronomy. The review of literature is extended later to include teachers' curricular expertise and equivalence testing as part of the quasi-experimental design and the school context (see Chapter 5).

2.2 Children's ideas in astronomy

As mentioned in Chapter 1, children's ideas in astronomy were, until recently, poorly documented relative to other areas of science and even today, despite increased attention, the detailed nature of these ideas and how they change as a result of teaching and learning in formal classroom settings remains to be fully investigated. According to Vosniadou and Brewer (1992) and Osborne et al. (1994), exploring children's ideas in astronomy is particularly useful in children's ideas research as a whole, for astronomy is a relatively rich knowledge area composed of a number of concepts with complex causal relations and therefore an area where there is potential for developing or validating domain-specific theories of knowledge acquisition and concept learning. In addition, children's everyday experiences provide them with enough information to develop an early and somewhat intuitive knowledge and understanding of many of the relatively familiar objects, events and phenomena that are part of astronomy. In the following sections, the available research

literature is reviewed in terms of the 'traditional' content areas of interest here. Excluding the early works of Piaget (1929, 1930), of the 30 or so evidence-based, research articles written about primary children's ideas in astronomy over the past 25 years and available at the time of this study, about one-third concentrate almost exclusively on children's ideas about the Earth as a cosmic body. Of those remaining, almost all consider children's ideas about the Earth as a cosmic body as a matter of importance. Of the same 30 or so research articles available, about one-third are derived from studies conducted within England since the introduction of a National Science Curriculum in 1989. Not unexpectedly, from what is currently known about children's ideas research and children learning science in general, even the most cursory review of available literature from around the world reveals that children's ideas in astronomy are found to be in a variable state of development across the primary age phase (5 to 11 years) as indeed they are beyond it. This includes students in the secondary phase of schooling and in higher education (Kuethe 1963; Sadler 1987; Targan 1987; Noce et al. 1988; Finegold and Pundak 1991) as well as teachers (Cohen 1982; Noce et al. 1988; Jones 1991; Ojala 1992, 1997; Schoon 1992; Barba and Rubba 1993; Mant and Summers 1993; Summers and Mant 1995; Spiliotopoulou and Ioannidis 1996; Parker and Haywood 1998) and members of the general public (Lightman et al. 1987; Acker and Pecker 1988; Durant et al. 1989). In addition to children's ideas research, astronomy has also been used as the stimulus for detailed psychological studies of memory, recall and emotion associated with the Space Shuttle Challenger disaster (Monaco and Gaier 1987; Bohannon 1988), exploring views at the interface between science and religion (Brickhouse et al. 2000), public decision making associated with matters of scientific interest (Bingle and Gaskell 1994) and helping bilingual students to develop their knowledge of science and the English language (Fouzder and Marwick 1999).

2.2.1 Early work

Some of the earliest accounts of children's ideas in astronomy are found in Piaget's *Conceptions of the World* (1929) and *Physical Causality* (1930). Both of these works outline Piaget's clinical research method (unstructured one-to-one interviews), the means by which he gathered data, and provide an insight into his interpretation of children's notions of reality and causality. By reality, Piaget referred directly to his interest in concept development and the origins of personal thought in the child and to what extent concept development and personal thought were influenced by the child's ability to distinguish an external 'real' world,

as it might be perceived by adults, from an 'internal' world associated with play and imagination. By causality, Piaget referred to the significance of the explanations provided by children and the nature of the cause-effect relationships they appear to accept. Throughout, Piaget presented in detail transcripts of responses to various lines of questioning within which different 'stages' or levels of concept development and thought were identified. These 'stages' or levels were described by him in terms of:

- feelings of participation or magic, where the child is involved in or with the actions of nature;
- animism, in which consciousness is attributed to inanimate objects or events;
- anthropomorphism, in which consciousness and human attributes are attributed to inanimate objects or events;
- artificialism, in which the child considers objects or events as the product of human or God-like creation;
- teleology, in which creative activity is attributed to the objects or events themselves, phenomena having a predetermined purpose reflected in the outcome of their occurring;
- a kind of naturalism, in which everyday occurring elements interact to produce an observed object or event;
- finalism, the idea of finality without the origins or consequences of an event or process being noticed;
- force, that things work in a way similar to human muscular action;
- physical or mechanical explanations which approximate to correct scientific solutions.

In 'the origins of the Sun and Moon' (1929), three 'stages' or levels are presented. In the first 'stage' (average age 6 to 8 years), accounts involved a human or God-like process (e.g. the Sun, the Moon and stars were lit by a match struck by God; the Sun, the Moon and the stars were born or made in the heavens; the Moon becomes whole because it grows in size like humans do). In the second 'stage' (average age 8 to 9 years), accounts involved half artificial and half natural processes (e.g. the Sun, the Moon and stars are made from clouds but the clouds are made of smoke which comes from chimneys; the Sun and stars are made of fire which comes from burning coal sent into the air or volcanoes which humans make; the Moon changes shape by cutting itself up). In the third 'stage' (average age 9 to 11 years), accounts involved only natural processes (e.g. the Sun and the Moon come from clouds, the clouds

being made of compressed air or steam; stars come from the Sun; the Moon changes shape as clouds cover it up). In 'meteorology and the origin of water' (1929), perhaps an odd place to find information about the day and night cycle, four 'stages' or levels are presented (but with no age boundaries). In the first 'stage', accounts explained the occurrence of night in terms of its use or by some human or God-like request (e.g. darkness comes so that humans might go to sleep; the need for sleep brings on darkness; it gets dark so that children know when they ought to go to bed). In the second 'stage', accounts often retained some earlier characteristics but a 'how' factor was introduced (e.g. darkness helps humans to sleep better; night is when the white air goes away and a great black cloud fills the sky). In the third 'stage', accounts continued to retain some earlier characteristics but differed in that night was no longer considered in terms of a substance but in terms of the absence of light (e.g. night is a black cloud that hides the white sky; the sky is hidden by clouds). In the fourth 'stage', accounts described night in terms of the Sun's disappearance (e.g. night begins when the Sun sets). Piaget noted that even in the fourth 'stage', children still knew little about movements associated with the Earth-Sun-Moon System. To illustrate his point, Piaget provided a 'flat Earth' account of the day and night cycle from children aged 9 and 10 who, on having been taught that America is on the other side of the globe to where they lived, had concluded that:

> " ... America is like a lower story (sic) compared with Europe and that to reach America the Sun had to cross the sea by a tunnel which pierced what formed the floor of Europe and the roof of America." (1929: 296)

Piaget later went on to suggest that:

> "The extraordinary custom followed by some pedagogues of teaching the system of Copernicus to children of this age [beyond 8 or 9] has given rise to the quaintest distortions." (1930: 85)

In 'movement of the clouds and heavenly bodies' (1930), five 'stages' or levels are presented. In the first 'stage' (average age 5 years), accounts considered the apparent movements of the Sun and Moon in terms of magic and animism (e.g. the Moon walks when humans walk and consciously follows them around). In the second 'stage' (average age 6 years), accounts often retained earlier characteristics but the apparent movements of the Sun and the Moon were considered in terms of a partly moral action or artificialism and the orders humans, God or their 'makers' gave them to obey (e.g. the Sun is compelled to move by humans which it does in order that it might keep humans warm or to provide the sunshine required for pleasant

walks). In the third 'stage' (average age 7 years), accounts often retained some earlier characteristics but the apparent movements of the Sun and the Moon were considered in terms of a partly physical action and the transfer of artificialism to agents of movement like the wind, rain or clouds (e.g. the Sun moves in advance of clouds either by imitation or as it flees before them out of fear or force). In the fourth 'stage' (average age 8 years), still retaining some earlier characteristics, accounts considered the apparent movements of the Sun and the Moon only in terms of a natural or physical action involving the 'reflux' of air, fire or heat which they make themselves (e.g. by advancing, rolling or by rotating, the Sun and the Moon produce air, fire or heat which flows in after them and pushes them along). In the fifth 'stage' (average age 9-and-a-half years), accounts no longer retain earlier characteristics and the apparent movements of the Sun and the Moon were described in purely physical or mechanical terms (e.g. the Sun is a fiery cloud which moves independently of other objects in the sky).

Despite a general reconsideration of Piaget's work (e.g. Marin and Banneroch 1994), his original empirical descriptions remain a valuable and often under used source of information.

2.2.2 The Earth, Sun and Moon

As mentioned earlier, of all the evidence-based, research articles which concern themselves with children's ideas in astronomy, about one-third concentrate almost exclusively on children's ideas about the Earth as a cosmic body. It would seem appropriate, therefore to devote a reasonable space to this topic here. Findings generally typify other areas of children's ideas in astronomy as a whole. By comparison, relatively few research articles deal with children's ideas about the Sun and the Moon as cosmic bodies in the detail that might be expected given their immediate relevance and significance to children's everyday and other experiences.

(a) The Earth

In the first 'recent' and detailed study of its type, Nussbaum and Novak (1976) described children's ideas about Earth shape, gravity and cosmic space, or Earth concept, within the context of a much larger project aimed at designing and evaluating individual audio-tutorial science units to enhance and to improve concept learning in the elementary age phase.

Audio-tutorial instruction, they argued, would provide an excellent research tool since all of the children exposed to it would receive the same input with the teacher variable removed. Participants included 52 second-grade American children from two classes attending a school with mixed socio-economic catchment in Ithaca, New York. Nussbaum and Novak randomly split the children into two groups (n=26 each group), one of which would later receive six 15-20 minute audio-tutorial lessons. The children's ideas were obtained from structured interviews patterned on Piaget's clinical research method and conducted on a one-to-one basis. Interviews lasted between 20 and 40 minutes and were audio-taped. All interviews opened with direct questioning about the shape of the Earth itself (e.g. What shape is the Earth?). This was followed by a series of short tasks and problem-solving activities using various diagrams, pictures and props. These required a prediction and explanation for various free-fall situations occurring at different points on the Earth's surface (e.g. rocks dropped from the hands of stick figures, water pouring out of bottles, rocks dropped into tunnels through Earth). From the information collected, Nussbaum and Novak identified five qualitatively different Earth concept notions in both the instructed and uninstructed groups. These are described as follows.

- Notion 1 (instructed 3; uninstructed 3). Despite answering that the Earth is 'round', children think that the Earth they live on is essentially 'flat'. Roundness may be attributed to the curves in roads around trees in parks, the appearance of mountains and hills, the Earth being another planet in the sky (a two-Earth or dual Earth variety), or the shape of the sky over the Earth itself (a hollow Earth variety). Such ideas were said to arise from a variety of sources and in different ways (use and misinterpretation of globes in class, an association between globes and the Sun and the Moon in the sky, and TV and radio programmes).
- Notion 2 (instructed 7; uninstructed 7). Children think that the Earth they live on is 'round like a ball' but consider it limited in space, bound by a cosmic 'bottom', ground or ocean towards which objects released from the southern hemisphere will fall, and a cosmic 'top' or sky towards which objects will travel from the northern hemisphere if thrown. Proofs such as travelling around the Earth or seeing it from space may be offered.
- Notion 3 (instructed 3; uninstructed 6). Children think that the Earth they live on is 'round like a ball' and that it exists in unlimited space. Objects released can still fall from

the Earth but they do so towards the sky or into space. The Earth is not used as a reference frame for up-down directions and down is absolute.

- Notion 4 (instructed 7; uninstructed 6). Children think that the Earth they live on is 'round like a ball' and that it exists in unlimited space. Objects released fall towards the Earth's surface but not towards its centre. The Earth is now viewed as a reference frame for up-down directions. Gravity may be mentioned in accounts.
- Notion 5 (instructed 6; uninstructed 4). Children think that the Earth they live on is 'round like a ball'and that it exists in unlimited space. Objects released fall towards the Earth's surface and towards its centre. Children with this notion display all three aspects of Earth concept and are able to overcome immediate perceptual distractions and respond consistently in a way which is compatible with scientific viewpoints.

While details of the research are interesting from a preliminary experimental point of view, the main thrust of their paper was to describe the notions or models observed and not to comment on the mode of instruction which was at an early and developmental stage. This would be returned to later (Nussbaum and Sharoni-Dagan 1983). Nussbaum and Novak concluded from their findings that learning about the Earth as a cosmic body appeared to take place in a series of identifiable steps rather than as a single 'conceptual leap'. They also concluded that while it was tempting to suggest that the notions might represent 'natural sequential steps', the routes through the steps were unknown and might vary. More importantly, they identified the steps as examples of progressive differentiation and the findings more consistent with the theory of learning proposed by Ausubel (1968) than Piaget (1964, 1969). Nussbaum and Novak proposed that it might be possible to direct children's concept learning by specific instruction aimed at stimulating a cognitive structure to accommodate and assimilate Earth concept provided that the instruction allowed children to anchor new information on previously existing ideas. Overall findings in terms of scientific conceptualization are summarized as follows:

- Earth shape (Notions 3, 4 and 5), instructed and uninstructed groups 16 (62%);
- Earth's gravitational attraction (Notions 4 and 5 correct gravity to surface), instructed group 13 (50%), uninstructed group 10 (38%).

From the earlier and preliminary experimental study of Nussbaum and Novak (1976),

Nussbaum (1979) himself went on to explore the cross-age development of ideas about Earth concept with 240 particularly high attaining children from an Israeli public school in Jerusalem. 48 individuals from each of the fourth to eighth grades were randomly selected to participate. Information was also collected on home background (father's education), socio-economic background (father's occupation), and intelligence (MILTA IQ test). Each child completed a 20-30 minute multiple-choice questionnaire based on the open-ended interview technique used previously. The use of diagrams, pictures and props was retained and children were still required to explain their answers. Each child was classified into a specific Earth concept notion category on the basis of their pattern of responses. It was noted that Earth concept was taught formally in geography in the fifth grade. General outcomes indicated that the 'spectrum' of Earth concept notions held by Israeli children were similar to those found earlier. This validated the previous findings. Some refinement of the five original notions was made though five were ultimately retained. Notions 1 and 2 were combined as essentially reflecting 'flat' Earth views and the hollow Earth variety of Notion 1 was recognized as moving sufficiently towards scientific correctness with respect to shape to become Notion 2. Nussbaum noted that children from all grades exhibited all notions but the frequency profile changed largely with age. Overall findings in terms of scientific conceptualization are summarized as follows:

- Earth shape (Notions 3, 4 and 5), fourth grade 18 (37%), fifth grade 36 (75%), sixth grade 32 (67%), seventh grade 46 (96%), eighth grade 43 (90%);
- Earth's gravitational attraction (Notions 4 and 5 correct gravity to surface), fourth grade 8 (17%), fifth grade 27 (56%), sixth grade 19 (40%), seventh grade 37 (77%), eighth grade 32 (67%).

Nussbaum noted the fifth grade results being higher than those results in grades around it due to the location and timing of instruction and the seventh grade results being higher than those results in grades around it to qualitatively higher home and socio-economic background and IQ scores (no inferential statistical analyses were presented). Nussbaum proposed, perhaps radically at that time, that, in order to learn about the Earth as a cosmic body effectively, children should be made aware of their own ideas prior to instruction and that those ideas be challenged and placed into a state of cognitive disequilibrium that would hopefully be followed by cognitive accommodations through notion changes.

Perhaps motivated or inspired by the works of Nussbaum and Novak (1976) and Nussbaum (1979), Mali and Howe (1979) reported a study of cognitive and conceptual development in 252 children aged 8, 10 and 12 from two regions of Nepal: the relatively urban Kathmandu Valley including the capital city (n=40, 52 and 35 by grade) and the rural Pokhara Valley region at the foot of the Himalayas (n=44, 47 and 34 by grade). Significantly, it was noted at the time that for geographical and historical reasons most of the people of Nepal had limited or no contact with Western scientific views, their daily lives being largely agricultural or centred around the home or field and with no access to TV or radio or even formal schooling. For many, the traditional belief was that 'the Earth is a large flat mass supported on four corners by an enormous elephant'. Increasingly, however, school textbooks included material which challenged this belief. Individual interviews were administered as described by Nussbaum and Novak. Mali and Howe also oversaw individual Piagetian tasks related to conservation, seriation and classification conducted by trained workers and information was also collected on years of schooling, the number of languages spoken, the occupation of parents, information sources at home, and domestic chores and games played. Findings were broadly similar to those in the Nussbaum and Novak study in terms of the range of Earth concept notions described, but the Nepali children appeared to hold on to the lower notions, particularly Notion 1 which they subdivided into three smaller categories, for longer than the children studied in America or Israel (e.g. 36 or 88% of 8-year-olds, 18 or 35% of 10-year-olds and 6 or 17% of the 12-year-olds in the Kathmandu sample; 39 or 89% of the 8-year-olds, 23 or 49% of the 10-year-olds and 13 or 38% of the 12-year-olds in the Pokhara sample). The frequency of higher notions were observed to increase with age and taken to support a hypothesis that Earth concept develops through a series of progressively more advanced notions towards scientific conceptualization. At all ages, but more so at 12, children from Kathmandu held higher notions than their Pokhara contemporaries. Overall findings in terms of scientific conceptualization are summarized as follows:

- Earth shape (Notions 3, 4 and 5), Kathmandu 8 years 2 (5%), 10 years 16 (31%), 12 years 22 (61%) and Pokhara 8 years 1 (2%), 10 years 12 (26%), 12 years 15 (44%);
- Earth's gravitational attraction (Notions 4 and 5 correct gravity to surface), Kathmandu 8 years 1 (2%), 10 years 7 (13%), 12 years 17 (47%) and Pokhara 8 years 1 (2%), 10 years 2 (4%), 12 years 10 (29%).

Performances on each Piagetian task were significantly correlated with Earth concept notions ($p<0.01$). It was noted, however, that while some children scored highly on say conservation and held higher Earth concept notions, the reverse was not always the case. Mali and Howe suggested that this confirmed findings elsewhere that attainability or development of concrete operations as determined by Piagetian tasks does not pre-determine the extent to which non-spontaneous concepts such as Earth shape and gravity can develop. In fact, Mali and Howe established that the extent to which non-spontaneous concepts such as Earth shape and gravity can develop were, in their study, more dependent on other factors including grade, years of schooling and access to information sources at home ($p<0.01$). Mali and Howe's work drew attention to the problems associated with unravelling the effects of development through maturation, the influence of teaching on knowledge acquisition and concept learning and level of understanding and meaning, and the validity of and reliance upon 'established' Piagetian tasks.

In almost the final paper of its type, Sneider and Pulos (1983) undertook a further study of Earth concept, this time with 159 third to eighth grade children (mean age 9 years 0 months to 14 years 2 months) from public schools in the San Francisco Bay area of California (n=30, 16, 21, 23, 26 and 28 by grade). The purpose of this study was to assess the developmental model proposed by Nussbaum (1979) in terms of data from a new sample of subjects with no special instruction in these concepts other than through 'usual' textbook approaches and to explore the role of individual differences in attainment of spherical Earth and gravity concepts - the first time the two variables had been treated independently. To achieve this they adopted a slightly modified version of the research instrument developed by Nussbaum and Novak (1976) and they modified Nussbaum's (1979) classification scheme to form separate Earth shape and gravity scales. Actual responses obtained for shape and gravity were then matched against the criteria set out for each. Classified in this way, individual shape and gravity responses for each child were finally placed on a combined shape and gravity matrix for analysis. In addition, and using a series of recognized psychological tasks, Sneider and Pulos collected information on each child's spatial reference system, field dependency and verbal ability. These were thought useful to comment on the abilities of individuals to use an internalized frame of reference and to avoid task and observational distractions, to understand class lessons, and to express themselves appropriately during interview. From their findings, and by considering Earth shape and gravity separately,

Sneider and Pulos were able to validate and to refine the Earth notion classification of Nussbaum (1979) even further. The development of both were not only strongly associated ($p<0.001$), prediction analysis indicated that shape preceded gravity development ($p<0.001$). A strong association was found between the distribution of notions and age or grade ($p<0.001$). The only parameters with significant predictive value were spatial reference and verbal ability ($p<0.01$ and $p<0.001$ respectively). Overall findings in terms of scientific conceptualization are summarized as follows:

- Earth shape (Notions 3, 4 and 5), third grade 12 (40%), fourth grade 9 (56%), fifth grade 16 (77%), sixth grade 17 (75%), seventh grade 21 (81%), eighth grade (19 (68%);
- Earth's gravitational attraction (Notions 4 and 5 correct gravity to surface), third grade 0 (0%), fourth grade 0 (0%), fifth grade 1 (5%), sixth grade 7 (31%), seventh grade 20 (77%), eighth grade 14 (50%).

Sneider and Pulos concluded that mature Earth and gravity notions are acquired through a series of distinct levels culminating in scientific conceptualization for most children in their sample by seventh or eighth grade. Individual differences in verbal ability were correlated with performance on Earth concept interviews at all notion levels and suggested that care would be required for the vocabulary and language used during science lessons. Sneider and Pulos used 'alternative frameworks' in preference to misconceptions and introduced the term 'physico-cultural concept' to describe a view of the physical world held in common by a cultural group.

Following a review of Earth concept interest from 1976 to 1983 by Nussbaum (1985), with some minor additional work from Japan (Matsumori 1986; Tonishi and Shimizu 1986), children's ideas about the Earth as a cosmic body were investigated by other authors, some using different methods and methodologies and a different theoretical and analytical framework. The first of these by Vosniadou and Brewer (1992) was an important developmental study with 60 first, third and fifth graders (mean ages 6 years 9 months, 9 years 9 months and 11 years 0 months) from middle-class backgrounds attending an elementary school in Urbana, Illinois ($n=20$ in each of the three grades). In fact, Vosniadou and Brewer's work presented data published in an earlier and wider ranging cross-cultural study which included children from Greece (Vosniadou and Brewer 1989, 1990). Vosniadou

and Brewer pointed out that however provocative the existing research on children's ideas regarding Earth concept may be, the exact nature of the notions uncovered remained uncertain. Vosniadou and Brewer set out to test three hypotheses: that children start the knowledge acquisition process by assuming, intuitively, that the Earth is 'flat', for that is how it appears; that children will have difficulty understanding the Earth as a sphere on exposure to this culturally accepted information; and that children's notions are sufficiently well defined to be used in a consistent manner. In order to do this, Vosniadou and Brewer made use of a 48-item questionnaire (15 items devoted to Earth shape and gravity) containing factual and generative questions, as well as opportunities to obtain drawings, in the context of individual interviews. Their work represented a major departure from the task-driven methods used by previous researchers particularly with respect to obtaining ideas about gravity. Vosniadou and Brewer also adopted the construct of the mental model to characterize children's representations of the Earth. In total, six mental models were identified: the rectangular Earth, the disk Earth, the dual Earth, the hollow sphere, the flattened sphere, and the sphere. Of the five alternative models, the rectangular and disk Earths were referred to by Vosniadou and Brewer as the most intuitive, the others constituting what they referred to as synthetic. A developmental progression of models was apparent. Most first graders held mixed or dual Earth models with elements of 'flatness' in which unsupported objects would fall, most third graders held a wider range of models and most fifth graders held the spherical model. Overall, only 23 children (38%) considered the Earth to be spherical in shape. Though widely used and quoted by Vosniadou and Brewer, this figure is perhaps misleading. By grade, the picture is more positive. Findings in terms of scientific conceptualization are summarized as follows:

- Earth shape, first grade 3 (15%); third grade 8 (40%); fifth grade 12 (60%).

Vosniadou and Brewer acknowledged that their findings agreed with the results of earlier studies which they suggested showed that elementary school children have difficulty understanding the shape of the Earth. They argued, from their data, that children form an initial, intuitive mental model of the Earth which is indeed 'flat'. Perhaps prematurely, given the nature of their study, Vosniadou and Brewer also argued that the process of changing from a 'flat' Earth model to an Earth conceptualized as spherical was 'slow' and 'gradual' and that this gave rise to synthetic models of the Earth. The youngest children were least consistent in their use of any one model, their responses at interview giving rise to a range of

ideas which were difficult to categorize. In order to form a spherical mental model of the Earth, Vosniadou and Brewer suggested that processes of knowledge acquisition and concept learning were constrained by certain epistemological and ontological presuppositions and beliefs which must be reinterpreted within different explanatory networks before progress could be made. Their view of learning about the Earth as 'slow' and 'gradual' and from intuitive through synthetic to scientific models also appeared in later works involving Vosniadou and Brewer where it was extended to include children's ideas about the day and night cycle (Vosniadou and Brewer 1994; Samarapungavan et al. 1996; Diakidoy et al. 1997).

The processes of knowledge acquisition and concept learning as 'slow' and 'gradual' and from intuitive through synthetic to scientific models seeming to emerge from many studies involving the Earth as a cosmic body is not a position widely accepted by all. With the exception of Nussbaum and Novak (1976), most of the investigations making such claims were largely developmental in nature and few of the authors involved described any of the children involved as having been exposed to instruction specifically targeting the Earth as a cosmic body other than what they might have encountered incidentally or through existing curriculum provision at school - the details of which for science were sketchy to say the least. Other studies of ideas involving primary aged children up to 11 years of age from Israel, America, Australia and England, and deaf children from Norway, exposed to more explicit cultural transmission and formal instruction, for example, uncovered similar models to those presented earlier but the profile of models obtained differed substantially particularly with respect to shape (Nussbaum and Sharoni-Dagan 1983; Sneider and Ohady 1998; Osborne et al. 1994; Arnold et al. 1995; Butterworth et al. 1997; Sharp 1995, 1996, 1999; Roald and Mikalsen 2000). Among these studies, particularly those involving Australian and English children, between 70 and 95% were found to exhibit scientific conceptualization by age 8 (though only about 50 to 55% or so with respect to gravity). The studies by Butterworth et al. (1997) and Sharp (1999) are of interest in terms of the methodological perspectives adopted.

In their cross-cultural study of the Earth as a cosmic body with 60 Australian and 72 English children between the ages of 4 and 8 selected from a University pre-school playgroup, a suburban pre-school and elementary school groups in Brisbane and from an admissions class and elementary schools in Newhaven, Butterworth et al. (1997) used a forced-choice procedure involving counterbalanced alternative answers drawn from the Earth-items questionnaire of Vosniadou and Brewer (1992). Butterworth et al. reported that nearly all of

the Australian children aged 4-5 and 6-7 years (40 from 42 or 95%) and most of the English children of similar age (38 from 54 or 79%) considered the Earth spherical. By age 8, this cultural difference had disappeared. While Vosniadou and Brewer (1992) indicated from their work that an intuitive 'flat' Earth stage always preceded scientific conceptualization, Butterworth et al. found little or no evidence that this was in fact the case. Instead, they suggested that even with children as young as 4 years of age, particularly those raised within an 'Australian immigrant culture', direct cultural transmission played a significant part in Earth shape development. Globes, atlases and relatives living in the northern hemisphere were often mentioned in children's justification of Earth shape and answers seemed to genuinely reflect understanding rather than the simple repetition of overheard and ill-understood facts. Notably, Butterworth et al. suggested that it might also be important to distinguish between different aspects of the knowledge about the Earth being acquired (e.g. geographical, spatial, gravitational, cosmological) and the bearing this has on concept learning.

Somewhat similarly, and in a study by Sharp (1999) involving 25 Year 2 children from an east Devon primary school with mixed socio-economic catchment in the south-west of England (average age 7 years 5 months), it was suggested that bias towards children's ideas about the Earth as a cosmic body in terms of its shape and gravitational attraction alone may have resulted in an underestimation of children's other abilities and learning potential in this field. In particular, Sharp suggested that a more 'realistic' model of the Earth, perhaps focusing on shape, the representation of land masses and other surface features in drawings, and the very nature of the Earth as a planet, should be given at least equal if not more consideration. Sharp's suggestion was motivated by children's abilities to accurately draw and describe the Earth as it might appear in space found in his own earlier studies (Sharp 1995, 1996) and geographical research which demonstrated very young children's apparent readiness to learn new map skills and macro-spatial concepts (Spencer et al. 1989; Matthews 1992; Catling 1996; Blaut 1997; Liben and Downs 1997), their ability to produce technically competent freehand sketch maps of the world (Wiegand 1995, 1997) and to learn using globes (Sharp 1998). Using a multiple-method survey instrument, 21 (84%) of the participants presented spherical Earth models, 16 (64%) were able to represent and describe land masses and other features upon it and 11 (55%) possessed emergent notions (implicit and explicit) of gravity acting towards the Earth's surface. Land mass representation was found to be similar to that described from children in geographical research (Wiegand 1995,

1997). While no 'flat' Earths were identified, other alternatives did exist including one dual Earth and one flattened Earth. All of the children involved in this study had been taught astronomy which included the Earth as a cosmic body as part of the National Science Curriculum operating at that time (DfE/WO 1995). Supporting Butterworth et al. (1997), it was suggested that learning about the shape of the Earth at least may indeed be possible in a single conceptual leap without the construction of intermediates. Sharp also presented slight evidence of a statistical association between children's ideas about shape and gravity and shape with land masses and gravity ($p<0.05$) and noted that these seemed to develop together but with gravity lagging some way behind. Interestingly, Sharp noted that 23 (92%) children recognized and picked the Earth from pictures of other Solar System objects including the Sun, the Moon and other planets. This is in stark contrast to the 2 from 16 (13%) American children in the first grade (mean age 6 years 9 months) and only the 1 from 30 (3%) Greek children in the third grade (mean age 8 years 5 months years) able to point to the Earth in a picture of the Solar System reported by Vosniadou and Brewer (1989, 1990).

A summary of all findings concerning children's ideas about the Earth as a cosmic body, at least in terms of its shape and gravitational attraction, is presented as shown (Fig. 2.1). The term synthetic (Vosniadou and Brewer 1992) has been replaced by transitional (Sharp et al. 1997). The summary includes shape information drawn from studies which considered the Earth as part of a broader subject of investigation (e.g. 'ring' Earths from Samoan children in Vosniadou 1994; 'spheroidal' Earths from Asian-Indian children in Samparapungavan et al. 1996; 'suspended' Earths from American-Indian children in Diakidoy et al. 1997; near-spherical Earths from English children in Sharp 1996 and Sharp et al. 1997).

(b) The Sun

Children's ideas about the Sun have received little attention compared with the Earth. Two of the more comprehensive accounts include the summative studies of 6 to 7-year-olds (n=20) and 10 to 11-year-olds (n=42) attending schools in the south-west of England by Sharp (1995, 1996). Some astronomy teaching had already taken place but with only limited attention given to the Sun itself. Both studies made use of an interview-based, multiple-method survey instrument developed by the author. Among the 6 to 7-year-olds, 14 (70%)

Mental Models

Model 1: the Earth is spherical or near-spherical
Children consider the Earth to be spherical or near-spherical in shape and surrounded by sky and space. People live all over the Earth and gravity acts 'inwards' towards its surface or its centre. Scientific with respect to shape and gravity.

Model 2: the Earth is spherical
Children consider the Earth to be spherical in shape and surrounded by sky and space. People can only live 'on top' of the Earth because gravity acts 'downwards'. Scientific with respect to shape, transitional or intuitive with respect to gravity.

Model 3: the Earth is flattened or spheroidal
Children consider the Earth to be shaped like a 'thick pancake' and surrounded by sky and space. People live all over the Earth and gravity acts 'inwards' towards its surface or its centre. Scientific with respect to gravity, transitional with respect to shape.

Model 4: the Earth is hollow
Children consider the Earth to be sort of spherical in shape with the sky covering the ground, a lower hemisphere, like a dome. The ground may be entirely enclosed by sky. People live 'on top'. Gravity acts 'downwards'. Transitional with respect to shape, intuitive with respect to gravity.

Model 5: two Earths exist (dual Earth)
Children may consider one Earth to be flat while the other is shaped like a sphere or both Earths may be spherical. People may live 'on top' of either Earth or both. Gravity acts 'downwards'. Transitional with respect to shape, intuitive with respect to gravity.

Model 6: the Earth is 'flat'
Children consider the Earth to be shaped like a disk, a square, a rectangle or a 'ring' (rarely a triangle). The Earth may be supported by ground, water or suspended in space. People live 'on top'. Gravity acts 'downwards'. Intuitive with respect to shape and gravity.

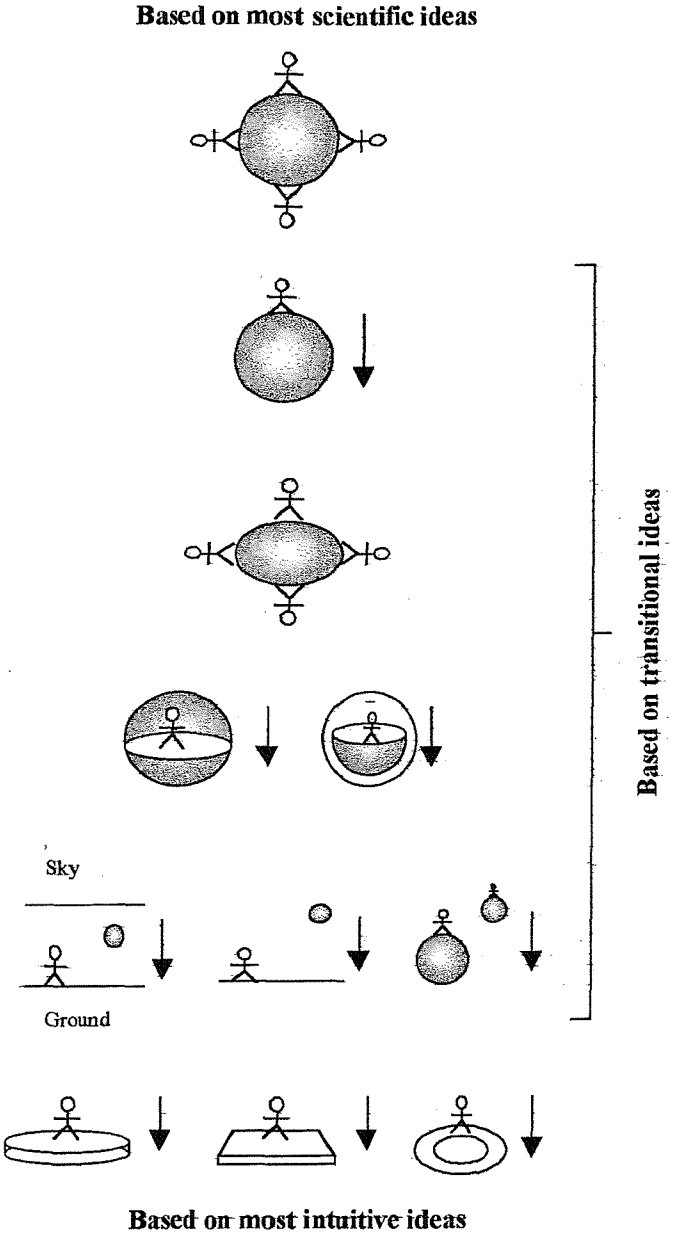

Fig. 2.1 Children's intuitive, transitional and scientific models of the Earth (shape and gravity)

considered the Sun to be spherical in shape, the 'flat' appearance of the Sun in the sky giving rise to various other alternatives including cylinders, disks and hemispheres. Most drawings of the Sun were simple circles annotated in various ways to show Sun's 'rays'. Only 6 (30%) of the children knew that the Sun is a star, the same children describing the Sun as a 'great big ball of fire', 'gas' or 'heat'. A 'planet on fire' was the commonest alternative. Conditions on the Sun were described as 'too hot' to support life by 18 (90%). A general awareness of the Sun's position and apparent daily movement across the sky was demonstrated by 10 (50%). 18 (90%) of the children recognized the Sun from a collection of Solar System objects including the Moon and all nine planets. Again, this was in stark contrast to the 2 from 16 (13%) American children in first grade (mean age 6 years 9 months) and the 2 from 30 (7%) Greek children in the third grade (mean age 8 years 5 months years) able to point to the Sun in a picture of the Solar System reported by Vosniadou and Brewer (1989, 1990). Among the 10 to 11-year-olds, 25 (59%) considered the Sun to be spherical. While alternative shapes included hemispheres, disks and cylinders, 12 (29%) children remained unsure. Most drawings were simple circles but without any 'ray' depiction. 24 (57%) of the children knew that the Sun is a star but 28 (67%) described it mostly as a 'ball of fire'. Again, a 'planet on fire' was the commonest alternative. Conditions on the Sun were considered 'too hot' to support life by 41 (98%). A general awareness of the Sun's position and apparent movement across the sky was demonstrated by 32 (76%). No picture recognition was undertaken. Figures for the Sun's position and apparent movement across the sky for the 6 to 7-year-olds and 10 to 11-year-olds reported by Sharp (1995, 1996) were comparable to those presented in a study of 5 to 11-year-olds also attending schools in England by Osborne et al. (1994). In their study of the Earth and other astronomical bodies, including the Sun, with a relatively small number of Norwegian deaf children, Roald and Mikalsen (2000) found that almost all of the 7, 9 and 11-year-olds involved (n=5, 8 and 5 by age) knew that the Sun was spherical in shape. Roald and Mikalsen divided responses to the question 'What is the Sun made out of?' into four categories: hot matter, cold matter, light or colour, and other. While none of the 7-year-olds indicated that the Sun was made out of hot matter, this was the only category evident among those aged 11. As reported by Vosniadou and Brewer (1989, 1990), 14 from 16 (88%) American children in fifth grade (mean age 11 years 0 months) and the 26 from 30 (87%) Greek children in the sixth grade (mean age 11 years 9 months years) were able to point to the Sun in a picture of the Solar System.

(c) The Moon

Children's ideas about the Moon have also received little attention compared with the Earth. Haupt (1948, 1950) published data about concepts associated with the Moon collected from a number of first grade children attending the Laboratory School of the New Jersey State College at Glassboro in the United States (n=25 approx.). Information about the Moon's surface and composition was revealing. Most of the children knew that the Moon has no real 'face' and a few indicated that 'bumps' and 'craters' made it appear that way because it is so far away. This was taken by the authors to demonstrate a significant appreciation of spatial perspective. The Moon itself was considered by about one-third of the children to be made out of 'rocks' and 'mountains'. Some of the many alternatives presented included 'cheese', 'fire', 'air' and 'water'. Za'rour (1976) explored ideas about the Moon with 220 Lebanese Arab children between 4 years 11 months and 9 years 7 months of age attending various schools in Beirut. Za'rour reported that the majority of the children were not aware of the physical nature of the Moon and were particularly distracted by its changing appearance in the sky. This was most evident in the younger children and among Christians rather than Muslims, a point which Za'rour considered significant given the greater religious importance Muslims attach to the Moon and lunar phenomena (e.g. calendars and holidays). In a study involving 88 Italian fifth grade children (10-year-olds) attending schools in Rome, Noce et al. (1988) reported children's ideas about the Moon's gravitational attraction. Influenced by images of astronauts 'floating' in space, gravity was generally considered absent. Again, two of the more comprehensive accounts of children's ideas about the Moon appear in the summative studies of 6 to 7-year-olds (n=20) and 10 to 11 year-olds (n=42) attending schools in the south-west of England by Sharp (1995, 1996). Some astronomy teaching had already taken place but, as with the Sun, only limited attention was given to the Moon. Among the 6 to 7-year-olds, 11 (55%) considered the Moon to be spherical in shape, the phases of the Moon giving rise to various alternatives including cylinders, hemispheres and 'like a banana'. Most drawings were simple circles annotated with craters where 'rocks have been smashing into it'. None of the children seemed aware of the Moon as the Earth's only natural satellite, describing it instead as 'something that shines', 'comes out at night', 'helps us to see' or 'a planet'. Conditions on the Moon were considered unsuitable to support life by 15 (75%) children and for a variety of reasons including there being 'no trees or oxygen ... nothing to eat or do' and 'no houses' or because people 'would have to keep going back to Earth to get breathing stuff 'cause there's no gravity in space'. Only 3 (15%) of the children recognized

the Moon from a collection of Solar System objects including the Sun and all nine planets, a broadly similar finding to the 0 from 16 (0%) American children in the first grade (mean age 6 years 9 months) and the 1 from 30 (3%) Greek children in the third grade (mean age 8 years 5 months years) able to point to the Moon in a picture of the Solar System reported by Vosniadou and Brewer (1989, 1990). Among the 10 to 11-year-olds, 30 (71%) considered the Moon to be spherical, the phases of the Moon still giving rise to various alternatives including cylinders and hemispheres. All drawings were circles annotated to show 'darker shades with crater holes' and 'mountain things'. None of the children seemed aware of the Moon as the Earth's only natural satellite, describing it instead as simply 'the Moon' or 'like the Earth and other planets'. Conditions on the Moon were considered unsuitable to support life by 40 (95%) individuals because there was 'no air' or 'no gravity', because it was 'too cold', or because there was 'no food or water'. No picture recognition was undertaken. In their study of the Earth and other astronomical bodies, including the Moon, with a relatively small number of Norwegian deaf children, Roald and Mikalsen (2000) noted that few of the 7, 9 and 11-year-olds involved (n=5, 8 and 5 by age) knew that the Moon was spherical in shape. In response to the question 'What is the Moon made out of?', only the 11-year-olds consistently responded 'rock'. As reported by Vosniadou and Brewer (1989, 1990), 8 from 16 (50%) American children in the fifth grade (mean age 11 years 0 months) and the 13 from 30 (43%) Greek children in the sixth grade (mean age 11 years 9 months) were able to point to the Moon in a picture of the Solar System.

2.2.3 The Earth-Sun-Moon System

Phenomena associated with the Earth-Sun-Moon System of most interest here include the day and night cycle, seasonal change and the phases of the Moon. Of these, day and night has received most attention. Where available, information about the relative sizes of the Earth, the Sun and the Moon is also provided.

(a) The day and night cycle

The first recent and systematic study of children's ideas about phenomena associated with the Earth-Sun-Moon System, including what causes day and night, was provided by Klein (1982) with 12 Mexican-American and 12 Anglo-American second grade children (7 to 8-year-olds) from low to low-middle socio-economic groups attending a public school in St. Paul,

Minnesota. Despite having been exposed to the various concepts under investigation earlier, Klein reported from various lines of questioning and the use of illustrations presented at interview that very few of the children involved held scientific models. Only 5 (42%) Mexican-American and 6 (50%) Anglo-American children were correct in knowing that the Sun is the largest of the Earth, the Sun and the Moon (the Earth was the commonest alternative provided) and only 2 (17%) Mexican-American and 4 (33%) Anglo-American children were correct in knowing that the rotation of the Earth is responsible for day and night (the Sun 'popping' up and down vertically was the commonest alternative provided). Klein concluded that either the concepts investigated were too abstract for the majority of children involved or different methods of teaching were required to increase their knowledge and understanding. Klein also noted that Mexican-American children provided more examples of pre-causal thinking than their Anglo-American counterparts raising questions about the relationship between language development and concept development particularly for children for whom English is a second language.

Jones et al. (1987) questioned 16 third grade and 16 sixth grade mixed ability children (9 and 12-year-olds) attending two single-sex schools in Hobart, Tasmania, about the shapes, relative sizes and movements of the Earth, the Sun and the Moon. Information was obtained using a clinical interview technique and a variety of stimulus materials. Though not specifically targeted at the day and night cycle, day and night formed the context for their investigation of the Earth-Sun-Moon System. While many children appeared to hold acceptable scientific views, a number of alternatives were presented. In all cases, sixth graders out performed third:

- 7 (44%) correct shape third grade, 14 (88%) correct shape sixth;
- 3 (19%) correct relative size third grade, 5 (31%) correct relative size sixth;
- 4 (25%) correct day and night third grade, 10 (63%) correct day and night sixth.

Overall, five spatial models of the Earth-Sun-Moon System were identified and described by Jones et al. and these are of particular interest:

- Model 1: Earth-centred 'magic' model. During the day, the Sun would be near and give light. At night, the Sun would mysteriously go away to some distant place and be

replaced by the Moon. Most egocentric model (no sixth graders).

- Model 2: Spinning Earth-centred model. Day and night caused by the Earth spinning while the Sun and Moon remain stationary in space.
- Model 3: Earth-centred model with orbiting Sun and/or Moon. The Earth may be spinning or static in space. Day and night caused by the Sun and/or the Moon orbit the Earth.
- Model 4: Sun-centred model with orbiting Earth and/or Moon. Day and night caused by the Earth spinning while the Earth and the Moon orbit the Sun in the same or concentric orbits.
- Model 5: Sun-centred model with orbiting Earth and with Moon orbiting Earth. Day and night caused by the Earth spinning while the Earth orbits the Sun and the Moon orbits the Earth. Most scientific model.

Jones et al. suggested that these models may form a hierarchy or a developmental pattern of knowledge and understanding. Apart from Model 1, the 'magic' model, they differed less in complexity than in explanatory power. Models 2 to 5, for example, have their own internal logic which for most children could lead to a successful explanation of day and night.

In a study of children's ideas of Earth-Sun-Moon System phenomena among one hundred 9 to 16-year-olds attending a comprehensive school in a semi-rural area of south-west England and the four junior schools feeding into it, Baxter (1989) identified six notions to account for day and night:

- the Sun goes behind a hill;
- clouds cover the Sun;
- the Moon covers the Sun;
- the Sun goes around the Earth once a day;
- the Earth goes around the Sun once a day;
- the Earth spins on its axis once a day.

The notions identified by Baxter were significant in that they reflected day and night as a main area of study rather than movements associated with the Earth-Sun-Moon System as a whole (e.g. Jones et al. 1987). Baxter obtained his information using a research instrument

which required participants to select from a series of statements and accompanying diagrams obtained from children at the pilot stage of his work. Of the 9 to 10-year-olds involved (n=25), all six notions were represented and about 5 (20%) children appeared to correctly know that the Earth spins on its axis once a day. The most common alternative notion, Notion 5, the Earth goes around the Sun once a day, was presented by about 11 (44%). Interestingly, of the 15 to 16-year-olds involved (n=25), only Notions 2 to 5 were represented but still only about 12 (48%) children exhibited scientific conceptualization. A later study of children's ideas about day and night undertaken in England by Osborne et al. (1994) revealed consistent scientific views among 2 from 36 (6%) infants (5 to 7-year-olds), 6 from 31 (19%) lower juniors (8 to 9-year-olds) and 18 from 39 (46%) upper juniors (10 to 11-year-olds). Osborne et al. also noted 8 from 39 (21%) upper juniors able to place the Earth, the Sun and the Moon in the correct order of relative size. Sharp (1995, 1996) found scientific views among 9 (45%) English 6 to 7-year-olds (n=20) and 25 (60%) English 10 to 11-year-olds (n=42). While more 'constructs' of day and night were recorded in both studies by Sharp (8 and 10 respectively), largely as a result of the more interactive methodology involving questioning, manipulating props and drawings, all were broadly similar to those presented by Baxter (1989).

The study of children's ideas about day and night by Vosniadou and Brewer (1994) and those involving Vosniadou and Brewer by Samarapungavan et al. (1996) and Diakidoy et al. (1997) are perhaps the most comprehensive of all those available. Vosniadou and Brewer (1994) reported their findings from the same sample of children involved in their study of the Earth's shape and gravitational field: 60 first, third and fifth graders with mean ages of 6 years 9 months, 9 years 9 months and 11 years 0 months respectively from middle-class backgrounds attending an elementary school in Urbana, Illinois. As before, Vosniadou and Brewer used a 48-item questionnaire (13 items devoted to day and night) consisting of factual and generative questions and opportunities to obtain drawings in the context of individual interviews. Vosniadou and Brewer retained the construct of the mental model to characterize the children's representations. Overall, 38 of the 60 (63%) children could be assigned to one of sixteen logically consistent, empirically accurate and coherent mental models of day and night. The large number of mental models identified was partly due to the authors' handling of the children's explanations and the technical day and night criteria used in their analysis. According to Vosniadou and Brewer, the younger, mostly first grade children (13 from 20 or 65%), formed initial mental models which provided explanations of day and night based on

everyday experience (e.g. the Sun is occluded by clouds or darkness, the Sun moves to a far away place, the Sun and the Moon move behind hills and mountains). The older, mostly third and fifth grade children (7 from 20 or 35% and 11 from 20 or 55% respectively) constructed synthetic models (e.g. the Earth and the Moon orbit the Sun once a day). Because of the technical criteria used (e.g. the Earth rotates west to east once a day, the Sun remains stationary, the Moon orbits the Earth), Vosniadou and Brewer reported only 1 scientific model and from a third grader. Reconsidering Vosniadou and Brewer's own data, and by taking a more 'relaxed' view of day and night involving Earth rotation (no rotational period information was provided), a total of 21 (35%) children presented scientific models, 2 (10%) in the first grade, 7 (35%) in the third grade and 12 (60%) in the fifth grade. As with the Earth, Vosniadou and Brewer suggested that the processes of knowledge acquisition and concept learning were constrained by certain epistemological and ontological presuppositions and beliefs which must be reinterpreted within different explanatory networks before progress can be made. This was most evident with the constraints imposed by Earth shape. All children who considered the Earth 'flat', for example, formed only intuitive mental models of day and night, and many children with synthetic models of Earth shape experienced difficulty forming models of day and night which were consistent. In some instances, these associations were significant ($p<0.001$ or $p<0.01$). Vosniadou and Brewer's findings satisfied their prediction that spherical Earth models were a necessary, but not always sufficient, condition for the acquisition of a scientific model of day and night and reinforced their view that children's learning about day and night, like learning about Earth shape, was a 'slow' and 'gradual' process. In both studies by Samparapungavan et al. (1996) with 19 first and 19 second grade children (mean ages 6 years 2 months and 7 years 11 months respectively) attending two elementary schools in Hyderabad, India, and Diakidoy et al. (1997) with 10 first, 11 third and 5 fifth graders (mean ages not supplied) attending American-Indian elementary and public schools in South Dakota, the processes of knowledge acquisition and concept learning described followed similar paths in all children regardless of cultural variables, though cultural variables did influence specific models constructed as well as the modes of explanation provided for the phenomena explored.

(b) Seasonal change

Children's ideas about what causes the seasons to change are poorly represented in the research literature. The most informative studies undertaken all involved children attending

schools in England. In his study of children's ideas of Earth-Sun-Moon System phenomena among one hundred 9 to 16-year-olds, Baxter (1989) identified six different seasonal change notions:

- cold planets take heat from the Sun;
- heavy winter clouds stop heat from the Sun;
- the Sun moves further away from the Earth in winter;
- the Sun moves to the other side of the Earth to give people living there summer;
- changes in plants;
- the Earth's axis being set at an angle to the Sun.

Of the 9 to 10-year-olds involved (n=25), all six notions were represented. About 5 (20%) children appeared to correctly know that seasonal change involved the tilt of the Earth's axis. The most common alternative notion, Notion 3, the Sun moves further away, was presented by about 16 (64%). Interestingly, of the 15 to 16-year-olds (n=25) involved, only Notions 3 and 5 were represented but still only about 12 (48%) children exhibited scientific conceptualization. Exploring children's abilities to explain why it is hotter in the summer than in the winter, Osborne et al. (1994) revealed that of the one hundred and six 5 to 11-year-olds questioned not one reasonably acceptable scientific account was found. A naturalistic explanation, that the rise in temperature over the summer months was due to the proximity of the Sun, predominated. Sharp (1995, 1996) found partially correct scientific views among 2 (10%) 6 to 7-year-olds (n=20) and 8 (19%) 10 to 11-year olds (n=42). While more 'constructs' about what causes the seasons were recorded in both studies by Sharp (9 and 7 respectively), again as a result of more interactive methodology involving questioning, manipulating props and drawings, all were broadly similar to those presented by Baxter (1989). In all studies, all of the older children involved could name and describe all four seasons experienced in their locality.

(c) Phases of the Moon

Children's ideas about what causes the phases of the Moon are also poorly represented in the research literature. While minor findings involving American children appear in Haupt

(1948, 1950) and Cohen and Kagan (1979), the most informative studies undertaken again involved children attending schools in England. In his study of children's ideas of Earth-Sun-Moon System phenomena among one hundred 9 to 16-year-olds, Baxter (1989) identified five different Moon phase notions:

- clouds cover part of the Moon;
- the shadow of a planet;
- the shadow of the Sun;
- the shadow of the Earth;
- the portion of the illuminated side of the Moon visible from the Earth.

Of the 9 to 10-year-olds involved (n=25), all five notions were represented. About 7 (28%) children appeared to correctly know that the Moon's phases represent the portion of the illuminated side of the Moon visible from the Earth. The most common alternative notion, Notion 4, the Earth's shadow, was presented by about 13 (52%). Interestingly, of the 15 to 16-year-olds involved (n=25), only Notions 2, 4 and 5 were represented and only about 5 (20%) children exhibited scientific conceptualization. Taking a somewhat different approach, Osborne et al. (1994) explored which phases of the Moon children could recognize from pictures and whether or not they could order them in sequence. Not surprisingly, the full Moon was recognized by the greatest number of children at all levels (29 from 36 or 81% of infants, 28 from 31 or 90% of lower juniors, 38 from 39 or 98% of upper juniors) and at least three phases were recognized by more than half of all those involved. Only a small minority of lower and upper juniors, however, were capable of ordering the phases of the Moon correctly (3 from 31 or 10% and 4 from 39 or 10% respectively). While not directly investigated, this was considered indicative of a lack of any model of the cause of the phases of the Moon with which to enable a correct sequence to be generated. Sharp (1995, 1996) found partially scientific views about what causes the phases of the Moon in only 1 (5%) 6 to 7-year-old (n=20) but 17 (40%) 10 to 11-year olds (n=42). While more 'constructs' about what causes the phases of the Moon were recorded in both studies by Sharp (8 and 6 respectively), again as a result of more interactive methodology involving questioning, manipulating props and drawings, all were broadly similar to those presented by Baxter (1989). While in general agreement with Osborne et al. (1994) over children's ability to recognize and sequence the Moon's phases, Sharp found no evidence to suggest that this was

associated with a lack of model.

2.2.4 The Solar System and wider Universe

Children's ideas about certain aspects of the Solar System and wider Universe were first described by Osborne et al. (1994). In their work with one hundred and six children between the ages of 5 and 11 attending schools in London, Osborne et al. began by considering that only individuals who were able to make sense of terrestrial and astronomical distances and scale could begin to appreciate the significance of the Earth on which they live. Children's ideas were evaluated as a result of their performance on sorting activities followed up with various lines of questioning. Osborne et al. later explored children's ideas about stars and planets. Outcomes varied considerably between the different age groups involved but between 50 and 70% of the upper juniors or 10 to 11-year-olds involved (n=39) provided correct responses to most tasks. The numbers of children able to recall the names of all nine planets in the Solar System ranged from between 2 from 36 (6%) infants (5 to 7-year-olds) to 24 from 39 (62%) upper juniors. In the same year, children's ideas about the Solar System were also presented by Sharp and Moore (1994). Working with small groups of 8 and 10-year-olds from a school in the south-west of England, Sharp and Moore presented four qualitatively different models revealed in drawings. These ranged from a Solar System depicting an incomplete and random arrangement of planets and other objects to one which could be described as more complete and scientifically accurate. Sharp and Moore noted that children's drawings or 'maps' of the Solar System could be interpreted geographically in terms of content, location, scale and perspective, as well as scientifically in terms of forces, motions and time. Children's ideas about the Solar System and wider Universe revealed in drawings or 'maps' and responses to interview questions were also presented from 6 to 7-year-olds and 10 to 11-year-olds attending schools in England by Sharp (1995, 1996). Of the younger children, the Solar System and wider Universe consisted almost entirely of planets. Although 1 (5%) child managed to recall six, most managed only three or less (n=20). Other than the Earth, which had been probed extensively earlier, Jupiter, Mars, Saturn, Mercury, Venus and Pluto were mentioned most frequently and, with the exception of Pluto, identified by a small number of children from pictures. About half of the children were completely unaware of anything in space other than the Earth, Sun and Moon. Only four drawings or 'maps' of the Solar System were completed and all were intuitive. Sharp (1995) concluded that children's knowledge of the Solar System was, nevertheless, more extensive than

previously recognized. Of the older children, the Solar System and wider Universe consisted of a greater range of objects. Planets, meteors, comets, asteroids, black holes and galaxies were all mentioned and described with different degrees of accuracy and correctness. Besides the Earth, which had been probed extensively earlier, Mars, Saturn and Jupiter were widely recalled, described in detail and identified from pictures. All of the children involved (n=42) produced drawings or 'maps' of the Solar System from which 8 qualitatively different models of the Solar System were identified. While these varied in detail, 23 (55%) could be described as scientifically accurate, that is heliocentric and relatively complete with all nine planets shown in order. The most common alternative presented was geocentric and incomplete and drawn by 6 (14%) individuals while 5 (12%) children presented completely random and incomplete models. Interplanetary distances and orbital periods were, on the whole, poorly known. Various responses indicated some confusion over why planets remain in orbit around the Sun and little was known about the age and origin of the Solar System itself. Findings from a questionnaire study involving three hundred and fifty two 12 to 15-year-olds at a junior high school in Otsu city, Japan, have also been reported (Suzuki 1998). While older than the age groups of interest here, findings draw attention to spatial perspectives worthy of mention. The purpose of the study in Japan was to investigate how those involved used their knowledge of the Solar System when explaining an astronomical phenomenon such as the movement of a planet. Participants tended to think in two- rather than three-dimensions and did not always know where they were in relation to the objects being viewed.

2.3 Experimental studies

As the work presented here is experimental in nature, experimental studies of children's ideas in astronomy are highlighted in detail (though some findings have already appeared earlier). In all, five experimental studies which include children in the primary age phase (5 to 11 years) have been undertaken. These fall into two main categories: quasi-experimental, involving the use of an experimental and control group, and pre-experimental, involving only an experimental group. All of the studies are experimental in the sense that they set out to deliberately control and manipulate the conditions which determine the events in which they are interested (Cohen et al. 2000).

2.3.1 Quasi-experimental

The real impact of formal teaching on children's ideas in astronomy was first demonstrated in a quasi-experimental comparison of pre- and post-instructional frequency profiles of Earth shape and gravity notions by Nussbaum and Sharoni-Dagan (1983) with one hundred and fourteen 7 to 8-year-olds in three classes at a school in Jerusalem, Israel. In their study, a formal extension of the earlier work by Nussbaum and Novak (1976), the instruction consisted of 6 twenty minute individual audio-tutorial sessions carried out over several weeks. Audio-tutorial sessions were favoured as they eliminated what Nussbaum and Sharoni-Dagan referred to as the teacher variable. The audio-tutorial sessions included explanations of shape and gravity concepts, stories, questions to stimulate thinking, focused observations and the manipulation of physical props. Children's ideas were obtained before and after instruction using methods described by Nussbaum (1979). The audio-tutorial instruction was largely successful in bringing about some changes in ideas and suggested that many children of this age were indeed capable of learning about 'remote' concepts in a meaningful way. Overall, and from those exposed to the sessions, Nussbaum and Sharoni-Dagan reported an impressive decrease in the number of children presenting ideas associated with 'flat' Earths (Notion 1: 36 from 77 or 47% to 30 from 78 or 38%) with a corresponding increase in spherical Earths with gravity acting towards the Earth's surface (Notions 4 and 5: 9 from 77 or 12% to 32 from 78 or 41%). Nussbaum and Sharoni-Dagan were quick to recognize and point out the limitations of their work in terms of both the instructional methods used and the exclusion of a teacher.

In an equally important quasi-experimental study undertaken by Sneider and Ohady (1998), significant gains in over 80 fourth and fifth graders (9 to 11-year-olds), as well as older children, were found after exposure to an experimental treatment involving a constructivist-historical approach to astronomy teaching ($p<0.01$). All of the children involved in the experimental treatment participated in about 16 different idea-challenging activities about the Earth's shape and gravitational attraction, each lasting between 15 and 45 minutes, over a period of about one month. All of the teaching was carried out by class teachers who had attended a three week training course at the University of California at Berkeley. The constructivist-historical approach began by having children consider the views of those who lived thousands of years earlier, including Greek philosophers, and the ideas they had about the shape of the Earth and its gravitational field. This led into more current scientific ideas as

the activities unfolded. Children's ideas were obtained using a pre-test/post-test questionnaire instrument fashioned on the work of Sneider and Pulos (1983). The performance of fourth and fifth graders, which was greater than in all other age groups studied (from 24-72% correct shape and 7-67% correct gravity), suggested to Sneider and Ohady that this was perhaps the best time to teach a unit including the Earth as a cosmic body, the fourth and fifth graders having an 'easier time' unravelling their misconceptions than older children who had incorporated these into their belief systems for longer. The constructivist-historical approach was considered highly successful as a basis for designing instructional programs likely to bring about radical restructuring of core concepts that tended to resist traditional teaching.

While the studies of Nussbaum and Sharoni-Dagan (1983) and Sneider and Ohady (1998) provide excellent examples of how to organize and conduct educational experiments, both are limited in their restriction of the subject matter considered.

In the final quasi-experimental (causal-comparative) study considered here, Diakidoy and Kendeou (2001) compared the effectiveness of two instructional approaches in the acquisition of basic astronomy concepts including Earth shape and day and night cycle among 63 fifth grade children attending a largely metropolitan school in Cyprus (mean age 10 years 5 months). For the purposes of this study, the children remained in their original classes, one of which was randomly designated the experimental instruction group (n=31) while the other was also randomly designated the standard instruction group (n=32). At the outset, the two classes were found to be comparable in terms of academic achievement level. The children's ideas were assessed using a multiple-choice test constructed on the basis of the questionnaire used by Vosniadou and Brewer (1992). Diakidoy and Kendeou acknowledged the lack of sensitivity of such an approach but considered that it should allow the extent to which participants use current scientific explanations to be observed. While the children in the standard instruction group were taught according to the standard textbook-based provision characterized by the Cypriot National Curriculum (materials which normally appeared in the sixth grade), those in the experimental instruction group were taught in a manner which considered their 'preconceptions' and which focused on explanations that would maximize the plausibility of scientific conceptualization. Both groups were taught by Kendeou, a qualified teacher, for 80 minutes, the amount of curriculum instructional time recommended. The results indicated that, while both groups had comparable prior

knowledge of the target astronomy concepts at pre-test, the experimental instruction group made significant advances in terms of knowledge acquisition and concept learning over the standard instruction group which showed no significant pre-test/post-test gains ($p<0.01$, $p<0.001$). Unfortunately, no actual models or details of the changes which took place were provided. Diakidoy and Kendeou concluded that experimental instruction, embedded within the context of collaborative problem-solving activities and whole group discussion, and which considered children's initial ideas, could be more successful in bringing about conceptual change than standard textbook-based instruction when children's notions are incompatible with scientific information. Diakidoy and Kendeou's findings were consistent with other studies involving changes in children's ideas using only textbooks as the medium for bringing about change (e.g. Vosniadou 1991c).

2.3.2 Pre-experimental

As part of the Primary Science Process and Concept Exploration (SPACE) Project (1990-1998), an influential project carried out at the University of Liverpool and King's College, London, Osborne et al. (1994) reported findings of collaborative research conducted with teachers from ten schools in the London area of England aimed at understanding the development of young children's ideas in astronomy throughout the primary age range (see previous sections). This work was pre-experimental in the sense that Osborne et al. aimed to establish whether or not it was possible to encourage changes in children's ideas in a direction which would help them come to a more scientific knowledge and understanding of astronomical objects, events and phenomena. In this respect, the research could also be described as cross-sectional or cross-age. The elicitation of children's ideas pre- and post-intervention was undertaken by individual interview during which time written responses and drawings were also obtained. In total, 106 children were involved, selected to represent a wide range of ability and ethnic background (36 infants or 5 to 7-year-olds, 31 lower juniors or 8 to 9 year olds, 39 upper juniors or 10 to 11-year-olds). In terms of the schools, the teachers, the intervention programme which lasted 6 to 8 weeks, the pedagogical strategies employed and the organizational and management aspects of classrooms, few background details were provided. Many of the teachers involved expressed concerns about their own subject knowledge in the astronomy to be taught and were clearly uncertain about what to expect children to achieve in this area. Funding issues prevented Osborne et al. from providing the in-service support they would have hoped for. Osborne et al. indicated that the

research was not intended to be comprehensive but to give a broad sketch of typical thinking found in many children. As such, the research did not seek to identify actual mental models or changes of model with respect to time in detail, therefore, but to focus on the levels of scientific conceptualization attained. In defining the *a priori* ideas required to bring about scientific conceptualization, Osborne et al. amended their original intentions in favour of the standard objectives set out in a National Science Curriculum which had appeared in schools throughout England and Wales a short time earlier. To this end, their work included reference to children's knowledge and understanding of time and distance, the Earth as a cosmic body, the apparent daily and annual movement of the Sun in the sky and related phenomena including shadows, the appearance of the Moon in the sky, and day and night. Osborne et al. drew attention to the content of the National Science Curriculum as it existed at that time and noted that the extent to which the astronomy component reflected a realistic set of goals that could be achieved by the majority of children of a given age and ability should be treated with a 'healthy scepticism' until it reflected research findings such as those presented. Osborne et al. noted in conclusion that intervention, though poorly specified, had a positive and significant effect in improving children's ideas in most of the areas targeted ($p<0.05$, $p<0.01$). Much of this work was later expanded to appear in the highly acclaimed and commercially produced Nuffield Primary Science scheme (Nuffield-Chelsea Trust 1995).

In a second pre-experimental study also undertaken within the UK, Sharp et al. (1997) deliberately selected three 10 to 11-year-old children, Peter, Paul and Janet (not their real names), who, compared alongside their peers, appeared to hold a diverse and interesting range of ideas in the 'traditional' content areas of astronomy. Peter, Paul and Janet attended two schools in the south-west of England and their ideas were obtained during one-to-one interviews during which time drawings and concept maps were produced. Peter was initially relatively advanced in his ideas, Paul was geocentric with respect to all Earth-Sun-Moon System phenomena and the Solar System and Janet's ideas were all derived from her initial view that the Sun and the Moon were two halves of the same astronomical body. Sharp et al. attempted to investigate how the children's ideas changed with respect to a period of formal astronomy teaching and to relate their findings to current theories of knowledge acquisition and concept learning itself. Teaching involved sharing each others viewpoints, those of others that lived in the past, and those of the present scientific community, extended day- and night-time observations of the sky, focused illustrative and investigative activities, group and individual research, the use of audio-visual materials and slides, making and using concrete

models, teacher and child-led demonstrations, and pencil and paper problem-solving tasks. In summarizing the children's ideas, Sharp et al. made use of the intuitive, transitional and scientific categories of mental model described earlier. With all three children, learning about the Earth, Sun, Moon, day and night and the Solar System proceeded with relative ease compared with learning about seasonal change and the phases of the Moon (conceptual difficulty), which, as with Osborne et al. (1994), raised questions about the relational structure of the defined objectives within the National Science Curriculum. Sharp et al. also noted that, within the limitations of the design, the methods used and the interpretation, the findings provided clear evidence of weak (accretion and tuning) and radical knowledge restructuring in the overall learning process (Vosniadou and Brewer 1987).

2.4 Methodological and other matters

Of the many interesting features to emerge from the review of available research literature presented, the extent to which different authors, including science educators and cognitive psychologists, have used different methods and methodologies to tackle the same problem, that of penetrating children's cognitive structure in order to determine by elicitation how they conceptualize the objects, events and phenomena of astronomy, is particularly noteworthy. At times, while the different studies appear consistent in their findings, direct comparisons between them are not always readily achievable. Despite their frequent similarities, for example, children's ideas collected in essentially different ways will somewhat inevitably produce different outcomes and interpretations and this has certainly been shown to be the case here. It is useful and timely to also revisit the views of Claxton (1993), Von Glaserfeld (1989) and Johnson and Gott (1996) first presented in Chapter 1, who, between them, pointed out that to assume that children's ideas about the objects, events and phenomena of science directly reflect the nature and structure of their prior knowledge and their 'alternative frameworks' is to be 'guilty of a gross oversimplification of their psychology' and that considering a child's as well as a researcher's 'frame of reference' is an essential part of the research process. Most authors have, of course, at least attempted to consider the elicitation process as a potential source of error and bias. Despite the number of research articles available, including those looking at Earth shape, there remains insufficient coverage to reach anything other than broadest of conclusions. These criticisms are best exemplified by considering children's ideas about the Earth's gravitational attraction.

In order to explore children's ideas about the Earth's gravitational attraction, Nussbaum and Novak (1976) developed a method which remained the 'standard' for almost a decade, parts of which continued to reappear from time to time after that. It was mentioned earlier that Nussbaum and Novak tackled this area by way of a series of short tasks and problem-solving activities using various diagrams, pictures and props. These required a prediction and explanation for various free-falling situations occurring at different points on the Earth's surface including rocks dropped from the hands of stick figures standing around the circumference of the Earth, water pouring out of bottles, and rocks dropped into tunnels dug through the Earth. In one scenario involving rocks dropped into tunnels dug right through the centre of the Earth from one point on its surface to another, each child involved was asked how the rock would fall if let go. In order to ensure that participants understood the problem in three dimensions, they were presented with a globe with the movable figure of a girl and a styrofoam ball containing a similar tunnel into which a pencil could be inserted for effect. The intention was to force each child into a more clear-cut choice for using the Earth's core as the point of reference for 'down' rather than its surface which the authors' considered more 'egocentric'. Results have already been presented. On initial reading, it is possible to consider this an imaginative solution to the research problem faced but is this approach all that it seems? Just what did the authors expect the children to do and how did they expect the children to respond? Even a scientific solution to this problem, usually set for physics students at University (e.g. Halliday et al. 1997), is not as spontaneous as the apparent simplicity of the procedure suggests. Assuming that all frictional forces are neglected and that the gravitational attraction of the Earth acting on the rock arises only from that proportion of matter of the Earth internally to the position of the rock at any time, for example, the rock when dropped into the tunnel will exhibit simple harmonic motion. While this level of analysis of the problem is perhaps extreme, it serves to make the point about 'frames of reference'. At the very least, a knowledge and understanding of children's ideas about the Earth's internal structure might have been found useful (e.g. Russell et al. 1993; Lillo 1994; Sharp et al. 1995) but no attempt was made to obtain this information or to even consider it. Vosniadou and Brewer (1992) tackled the Earth's gravitational attraction using factual and generative questions effectively abandoning the task-driven methods of earlier authors. However, this still left room for ambiguity in the language of the questions themselves. Vosniadou and Brewer asked each child, for example, what would happen if they walked for many days in a straight line, would they ever reach the end or the edge of the Earth, and what might happen if they did. These questions were designed to clarify and

distinguish between the Earth model types the authors had predicted the children would bring with them to the interviews. While an improvement over some of the tasks presented by Nussbaum and Novak (1976), perhaps, it is possible to see how some of the children involved might have considered geographical barriers such as rivers or coastlines problematic. For those children, geographical barriers such as rivers and coastlines could easily be interpreted as the end or the edge of the Earth from which they could fall. Their responses might not necessarily indicate, therefore, that they believed the Earth to be 'flat'. Perhaps some children also found the nature of the questions themselves misleading. Baxter (1989) explored children's ideas about the Earth's gravitational attraction by asking them to select from four combined Earth shape and gravity notions presented as statements and accompanying diagrams in a multiple-choice research instrument. The four notions presented were obtained from an earlier pilot and arrived at by asking children to draw what they thought the Earth would look like from space, to add people in terms of where they could live, and to add clouds with rain falling from them (n=20). Using a multiple-choice research instrument clearly restricted the possible range of outcomes during the main study (n=100). A more interactive version of Baxter's method was later used by Arnold et al. (1995) and Sharp (1996). As indicated by Sharp in his own pilot, children found completing this task difficult and confusing, more as a result of attempting to represent complex three dimensional information on to a flat piece of paper than for any other reason. In some cases, for example, people, clouds and rain gave the distinct impression of a 'flat' Earth but discussions about the same drawings with the children, however, revealed that many were adopting quite advanced perspectives using hemispherical projections with rain falling from clouds which couldn't be seen because it was hidden from view. By asking the same children to add only clouds and rain to an additional diagram of the Earth with four stick figures placed equally around its circumference, similar to one of the rock dropping activities of Nussbaum and Novak (1976), only 1 child provided an intuitive response. Of course, as was pointed out by Sharp, children could complete this task by simply knowing that clouds appear overhead and that rain falls from clouds to the surface of the Earth without any scientific knowledge and understanding of gravity at all. Finally, Sharp et al. (1997) and Sharp (1999) attempted to overcome many of the issues raised here by adopting a more direct approach. Using their own drawings of the Earth from space as a stimulus, the children involved were asked about where people lived, if they had ever heard of anybody ever falling off the Earth and if, indeed, anybody could ever fall off the Earth. By adopting this approach, the children were found to use the word 'gravity' more explicitly than ever recorded previously and this could be explored

further.

2.5 Implications for curriculum and pedagogy

Most of the studies of children's ideas in astronomy reviewed present in most cases only a snapshot, even in a developmental sense, of what can be regarded as an overall learning continuum involving the acquisition of astronomical knowledge and the ongoing generation of meaning. Nevertheless, as pointed out by Driver (1981, 1989), such studies can provide valuable information that might lead to improved curriculum development and more effective teaching and learning. Progress towards curriculum development and an overall pedagogy for the effective teaching of astronomy has, however, been limited, though most authors of the studies reviewed have attempted to make some contribution. Even in those studies designed as experiments, the experimental treatments themselves have often lacked depth and breadth of content, ecological validity or adequately described independent variables to be of any widespread use. In terms of the work presented here, curriculum development and effective astronomy teaching encompassed Phases 2 and 4 of the overall research design (Fig. 1.1). While an overview of considerations is provided, Chapters 3, 5 and 6 deal with these aspects in more detail.

2.5.1 A curriculum for astronomy

Mostly with reference to the secondary age phase (11 to 18 years), Gilbert et al. (1982) pointed out that conventional science curricula, which usually either ignore children's ideas, assuming that children come to science lessons 'blank-minded' or 'tabula rasa' and that the learner's blank mind can be filled with the teacher's science, or consider children's ideas inadequately, assuming that the teacher can 'dominate' a science lesson such that the learner's prior knowledge of a science topic to be taught can be directly and easily replaced, have been far from successful in the pursuit of reliable knowledge and leading children towards more conventional scientific ideas. This was supported by Carr et al. (1994) who noted that in extreme cases, many teachers following conventional science curricula hold the view that science knowledge is unproblematic, that science provides the right answers, that truths in science are discovered by observing and experimenting, and that choices between correct and incorrect interpretations of the world are based on common-sense responses to objective data. Teaching on this basis often attempts to transmit scientific ideas that are

equally precise and unambiguous. While teachers insecure in their knowledge of science may find the uncomplicated transmission of knowledge attractive, Carr et al. emphasized, such an orientation towards science teaching usually avoids discussion (since learners lack knowledge worthy of consideration) and any interaction which might reveal a teacher's uncertain knowledge alters the power balance in a classroom (teachers are the fonts of all knowledge). Interestingly, in a study of teachers in the United States, Lightman and Sadler (1993) noted that many of those involved vastly over-estimated gains in scientific conceptualization after astronomy teaching. With the concerns and reservations of Millar (1989) and Matthews (1994) very much in mind, in considering the development of a suitable astronomy curriculum for children in the primary age phase (5 to 11 years) it is useful to begin with the constructivist model of curriculum development provided by Driver and Oldham (1986) and Scott et al. (1992). According to Driver and Oldham and Scott et al., a constructivist approach to curriculum development might begin by making decisions about the scientific content to be taught, what the children should know, understand and be able to do in terms of intended learning outcomes, and the nature of the intellectual journey or intellectual demands involved for children in taking forward or changing their ideas. From this, a suitable programme of experiences and activities which embodies the relevant scientific knowledge, understanding and skills can be constructed, a selection of different intervention and teaching strategies and pedagogical devices can be explored, material resources can be obtained, and, after implementation, the effectiveness of the entire process can be evaluated and improved. The principles within this model of curriculum development were echoed by Vosniadou (1991a, b) in her consideration of a curriculum for knowledge acquisition and concept learning within the sub-domain of astronomy itself. Vosniadou specifically draws attention to establishing the order in which the various concepts that comprise the sub-domain of astronomy are introduced, a point also made strongly by Driver (1981) who noted that curriculum development in science needs to pay as much attention to the structure of thought of the child as it pays to the structure of the science to be taught and that the logical order of teaching a topic may not coincide with the psychological order of learning.

The 'traditional' content elements of the astronomy to be taught here were determined only in part from the minimum statutory requirements set out in the National Science Curriculum effective at the time of the study (DfE/WO 1995). Minimum statutory requirements were supplemented and extended significantly by drawing on extensive teacher evaluation of the

implementation of astronomy within the National Science Curriculum (Russell et al. 1994a-c), full acknowledgement of all available research literature reviewed (particularly Osborne et al. 1994 and Sharp et al. 1997), professional articles disseminating aspects of 'good' practice (e.g. Sharp and Hitchin 1996), all widely and commercially available primary science schemes (e.g. Nuffield-Chelsea Trust 1995) and the combined curricular expertise of Jack, the class teacher of the experimental group, and this author, both having taught astronomy in primary schools before and after the introduction of the National Science Curriculum itself. The 'traditional' content elements of astronomy eventually selected provided what was considered to form the basis of a broad, balanced and relevant astronomy curriculum of most educational benefit and interest to the children involved. The 'traditional' content elements were sequenced as follows:

- introduction to astronomy (Week 1);
- the Earth, the Sun and the Moon (Weeks 2 to 4);
- day and night (Week 5);
- the Solar System and wider Universe (Weeks 6-8);
- seasonal change (Week 9);
- phases of the Moon (Week 10).

The general consideration of content also extended to wider research implications including the role of practical work and evidence (Duveen et al. 1993; Millar et al. 1994; Duggan and Gott 1996, Gott and Duggan 1996; Nott and Wellington 1996), fieldwork (Lucas 1983; Hofstein and Rosenfeld 1996), the use of children's literature (Vosniadou 1991c; O'Toole 1996), the use of models (Grosslight et al. 1991; Abell and Roth 1995), the use of teacher and text-based instructional analogy (Glynn 1991; Brown 1994; Dagher 1994, 1995; Ogborn et al. 1996; Treagust et al. 1996) and the role of metacognition and meta-cognitive awareness (Novak and Gowin 1984; White and Mitchell 1994). It was also the intention to promote where possible the nature of science (Cleminson 1990; Solomon 1995; Solomon et al. 1996) as well as scientific literacy and public understanding (Jenkins 1994; Bingle and Gaskell 1994; Millar 1996a, b, 1997). While only some of these studies are directly relevant to primary education in the UK, and to the teaching and learning of astronomy itself, the research findings and implications of all sources have considerable educational value as a whole. Building on Osborne et al. (1994) and Sharp et al. (1997), astronomy teaching (the

experimental treatment) involved children in sharing each others' ideas, the ideas of people who lived in the past and the ideas of the scientific community today, obtaining, considering and evaluating primary and secondary sources of information and evidence involving extended day- and night-time observations of the sky, illustrative, investigative and issue-based activities, pencil and paper problem-solving tasks, working with scientific models, the creative use of ICT (including multi-media authoring), and a trip to a local observatory. Use was also made of class text books and homework.

2.5.2 Teaching astronomy

Just how do teachers address children's ideas when they are different to those of the science identified in a school science curriculum? While constructivist approaches to science teaching help to overcome the problems associated with the child-centred/discovery-led and teacher-centred/didactic pedagogies presented earlier, they do not necessarily exclude them, and these, together with the relative merits, advantages and disadvantages of other approaches to science teaching implicitly and explicitly embodied within other orientations and how these might impact upon classroom practice, were considered (Brook et al. 1989; Millar 1989; Smith and Neale 1989). According to Fensham et al. (1994), for example, it is the purpose of intervention by the teacher to help promote knowledge acquisition and concept learning and it is knowing when and how to best intervene, how to manage the direction of enquiry and how to help take children's ideas forward to achieve intended learning outcomes that are the questions teachers face every day. Teachers, therefore, should be encouraged to use a range of different strategies contained within all orientations in a balanced way appropriate to the tasks and intended learning outcomes at hand. Again, with the concerns and reservations of Millar (1989) and Matthews (1994) outlined earlier very much in mind, the constructivist teaching models of Nussbaum and Novick (1982), Osborne and Freyberg (1985), Driver and Oldham (1986), Champagne and Bunce (1991), Appleton (1993) and Ollerenshaw and Ritchie (1993) provided clues as to how this might be achieved. All are broadly similar and involve teaching sequences or phases including:

- orientation (arousing children's interest and curiosity, contextualizing work);
- elicitation (identifying, interpreting and acknowledging children's ideas and helping them to clarify what they think);

- intervention (creating opportunities using suitable stimuli which relate to, further explore and challenge children's ideas by exposure to conflict, new evidence, and by testing their limitations and robustness in explaining phenomena and facilitating an exchange of views);
- application (helping children to relate what they have learned to their everyday lives);
- review (helping children to recognize and think about the significance of their learning in terms of changing ideas, what they have found out and how they went about it).

All, of course, must take place within a supportive and non-threatening classroom (Watts and Bentley 1987). Constructivist models of teaching may be useful when the focus of teaching is to bring about knowledge acquisition and concept learning in areas of science where such approaches can be demonstrated to be effective, but such models may not be appropriate on every occasion for the sequences or phases involved can be particularly time consuming. Nor are they necessarily appropriate when the focus of teaching is to develop particular scientific skills, processes or attitudes (Tishman et al. 1995; Goldsworthy et al. 1998 and Wood-Robinson et al. 1999; Harlen 2000). As Scott et al. (1992) pointed out, most constructivist models of teaching include conflict-based strategies but the success of any conflict-based strategy depends upon the time at which conflict occurs and the willingness and ability of the learner to recognize and resolve the conflict. In some instances, conflict-based strategies may also cause a loss of self-confidence and, on occasion, regression from correct to incorrect judgements (Stavy 1991). While recognizing their strengths and limitations, the teaching sequences or phases outlined were nevertheless explored for their teaching and learning potential. Actual examples of constructivist teaching are relatively rare (Smith and Neale 1989, 1991; Neale et al. 1990; Asoko 1993, 1996; Appleton and Asoko 1996; Summers et al. 1998).

It was also considered appropriate here to explore the instructional sequences and events proposed for teaching within the fields of cognitive psychology and information processing. These are useful for they consider the roles of perception, attention, the workings of memory (including encoding, storage and retrieval), remembering, forgetting, thinking, problem solving and reasoning in teaching and learning (e.g. Entwistle 1988; McCown et al. 1996) and are broadly congruent with the basic tenets of contemporary views of teaching and learning science. According to Gagné and Driscoll (1988), for example, teachers should

acknowledge at least nine instructional events that will support the cognitive processes involved in learning if identified learning outcomes are to achieved. These include gaining attention (alertness), activating motivation by introducing objective (expectancy), stimulating recall of prior knowledge (retrieval to working memory), presenting stimulus materials (selective perception), providing learning guidance (encoding and entry to long term memory storage), eliciting performance (responding), providing feedback (reinforcement), assessing performance (reinforcement), and enhancing retention and transfer (cueing retrieval). The most effective lessons contain all nine events but these may appear in a different order where appropriate.

All of the models of teaching considered present their own limitations in the primary classroom where the interactive, mixed ability teaching of a whole class, groups and individuals perhaps doing different things at any one time within any one lesson is a daily occurrence.

2.6 Summary

The review of available research literature presented here, about one-third of which deals with Earth shape and gravity, reveals children's ideas in astronomy to be in a variable state of development across the entire primary age phase (5 to 11 years). For the most part, children's ideas in astronomy can be characterized by three different types of mental model: intuitive, transitional and scientific. For many children, learning astronomy may be slow and gradual and include all three mental model types, for others, particularly those exposed to astronomy teaching at school, scientific conceptualization may take place more directly. Specific conceptual routes and pathways involved in the processes of knowledge acquisition and concept learning in astronomy are, as yet, poorly known but may involve a series of identifiable steps (forwards and backwards) or a single conceptual leap. Factors thought to be associated with the speed and extent to which scientific conceptualization takes place may include certain ontological and epistemological presuppositions and beliefs (further details in Chapter 7), the quality of each child's previous experiences, each child's socio-economic background, intellectual maturity, age and years of schooling, each child's interaction with adults and peers, certain forms of cultural transmission including the time at and extent to which astronomy teaching takes place, the conceptual difficulty of the material presented, and so on. Collected in different ways, children's ideas in astronomy have given rise to different

outcomes and interpretations and these in turn have resulted in different views over their nature and status. Progress towards a curriculum for astronomy in primary schools and an overall pedagogy for the effective teaching of astronomy has been limited. Even in those studies designed as experiments, the experimental treatments in some cases have lacked depth and breadth of content, ecological validity and adequately described independent variables to be of any widespread use. Finally, surprisingly few studies have devoted attention to the content analysis of children's responses themselves, most authors preferring to catalogue and analyze the prevalence of ideas and mental models types alone. Clearly, and despite the contributions which have already been made, much work still remains to be done. The chapter which follows outlines the development of science education in the primary school and with that provides the essential background required in order to address one of the four main research questions presented earlier. The introduction of a National Curriculum for primary science to all maintained schools throughout England and Wales in 1989 presented its own challenges and limitations to the work undertaken here, all of which had to be successfully overcome for it to reach its full potential.

Chapter 3

Astronomy and the National Curriculum for Primary Science

3.1 Introduction

On August 1st, 1989, the introduction of a National Curriculum of subjects to all maintained schools throughout England and Wales brought compulsory science education into the primary sector for the first time. Together with some of the more 'conventional' and 'mainstream' science content prescribed, the inclusion of a formal astronomy component as an established 'sub-domain' within the National Curriculum for primary science, that is, the National Curriculum for science at Key Stages 1 and 2, was regarded as an innovative and long overdue attempt to capitalize on children's interest, curiosity, imagination and enthusiasm in this area and to enrich their experiences of science as a whole. Since then, the requirements for astronomy education provision have diminished and, with that, astronomy's important educational contribution to primary science overlooked. This chapter explores the development and evolution of science education in the primary school including the place of astronomy in the National Curriculum for primary science. In analytical terms, this chapter draws attention to the need for extreme care at times when classroom practices and expectations are driven by 'educational guidelines' and 'curricula' which remain to be fully informed. This will be discussed further in Chapter 7. In practical terms, this chapter draws attention to the challenges and limitations imposed on the identification of schools and teachers available to participate in the research presented here and to consider the experimental treatment as they continued to adjust to frequent changes in the National Curriculum framework itself.

3.2 Science education and the primary curriculum

From the elementary schools of the late 1800s to the primary schools of today, science has played its part in the education of children throughout the UK (Richards 1983; Limond

2001). In the 20 years or so preceding this work, however, the nature of that provision and the extent to which it occurred have changed beyond all recognition.

3.2.1 A century of nature studies: the 1870s to the 1970s

According to Layton (1973), the teaching of science in primary schools throughout the UK appeared to grow, albeit slowly, from about 1870 on when it was restricted almost entirely to the study of nature. In the *Report of the Committee on the Position of Natural Sciences in the Educational System of Great Britain*, for example, Thomson (1918), noting the general neglect of science in schools, recommended that the 'elementary school ... should include in its curriculum the teaching of science in a simple and suitable form' and that this 'should normally include nature study and ... the teaching of arithmetic and handwork'. Interestingly, not long before the *Thomson Report* was published, all trainee teachers in all training colleges since 1904 had to study science until new regulations introduced in 1913 allowed them to study fewer subjects and to omit it altogether. In addition, it is interesting to note that in 1918, nature studies became virtually synonymous with gardening, gardens notably increasing in number and gardening becoming an increasingly popular activity following the end of World War 1. By about the middle of the 1930s, *The Handbook of Suggestions for Teachers* (e.g. BoE 1937), which provided a general curriculum of sorts for those who wished to consider it for some years, pointed out that 'the romance and wonder of science make an especially strong appeal to the young and enhance their natural desire to get to know the world around them and to find an explanation for its phenomena'. Infants (5 to 7 years) were considered to learn science best from 'active experience' including 'indoor and outdoor studies' and the study of 'animate nature'. Juniors (7 to 11 years) were considered to learn best by also studying 'inanimate nature'.

Science as nature studies continued until well into the 1960s and early 1970s and at a time of expansion, development, open-mindedness, 'liberalism', 'egalitarianism' and optimism for the future, some of it undoubtedly generated by the advances made by science and technology and, of course, the race to 'conquer space'. As described by Conran (1983), for example, 'teachers who had been ploughing somewhat lonely furrows and creating pockets of scientific excellence scattered in characteristic, unco-ordinated British fashion' became more aware of what was going on in other classrooms and in other schools', the relatively recently translated works of Piaget began making more of an impact in schools, two major curriculum

development projects, *Nuffield Junior Science* (1964-1966) and *Science 5-13* (1967-1974), appeared, and the teaching of physical sciences began to increase, all against a background of 'Plowdenism' and the emergence of a progressive or child-centred, discovery-led and process-driven approach to teaching and learning in the primary school as a whole (CACE 1967). Both *Nuffield Junior Science* (Wastnage 1967, 1983) and the more significantly Piagetian *Science 5-13* (Parker-Jelly 1983) were both substantially weighted in favour of the processes of science and the notion of science as enquiry, 'hands-on' and 'doing' rather than the content of science which remained subsidiary. Not only did this process-driven approach dominate science education throughout the 1960s and 1970s, it dominated for many years afterwards. Interestingly, the *Oxford Primary Science Project* (Redman et al. 1969), which attempted to identify the content of science that primary children were capable of learning, and which was published at much the same time, lost out to educational ideology and funding (Osborne and Simon 1996).

Towards the end of the 1970s, the influential and widely quoted *National Primary Survey* of over 500 schools and 1000 classrooms in England presented a rather 'bleak' picture of primary science (DES 1978; Black 1983). The range of science in primary schools was considered narrow and the standard of work generally poor. Science was regularly neglected as part of the primary curriculum as a whole or was 'lost', integrated with other subjects in the teaching of broad topics. Shortages of space and resources were also problematic. Primary teachers' limited knowledge and understanding of science was identified as a major issue and support for science was generally insufficient. As a result, science coverage was often superficial and teaching less well matched to the capabilities of children than in other curriculum areas.

3.2.2 Turning the tide: the 1980s and a decade of change

Throughout the1980s, more serious debates about the nature and place of science in the primary curriculum and the balance between content and process emerged (Harlen 1983a). Whether or not primary science was even appropriate for children in the primary years was considered (Isaacs 1983; Squires 1983; Kerr and Engel 1983). At the same time, however, the rather gloomy and dispiriting *National Primary Survey* findings were further substantiated and reinforced by work undertaken by the Assessment of Performance Unit (1980-1984) who surveyed the nature of science education provision for 11-year-olds in over

1000 primary, middle and independent schools in England, Wales and Northern Ireland (DES/WO/DENI 1985, 1988; Harlen 1983b). In England, for example, while about 95% of the schools surveyed included planned science activities in the school curriculum, science only occupied about 5% of actual lesson time. Only about 50% of the schools surveyed had a formal science scheme of work and, similarly, only about 50% reported having a member of staff with responsibility for science. While only about 10% or so of the teachers in the schools surveyed had taken science as a main course in their training, only about 5% or so had an actual science degree. More worryingly, the schools surveyed as a whole spent less than £1 per child per year on science (consumables and non-consumables). As 69% of the schools surveyed reported using *Science 5-13* and *Nuffield Junior Science*, the two most widely available and popular curriculum projects at that time, it was no surprise to find that only about 28% of the teachers involved considered a knowledge and understanding of basic science concepts important. The publication of *Science in Primary Schools* (DES 1983) addressed some of the issues raised. *Science in Primary Schools* considered the variety of ways in which children of primary age could be taught science and to think scientifically and suggested that 'the ideal in learning is achieved when children are led through a rich variety of experiences while along the way the teacher is able to extract, exemplify, reinforce, clarify and relate ideas and knowledge such that the children are provided with education that forms a whole, although they still understand and gain from separate parts'. Unfortunately, this was only considered achievable if teachers had a knowledge and understanding of the requirements of science in terms of process and content and how to strike a balance between the two. In terms of content, living things and their interaction with the environment, materials and their characteristics, energy and materials, and forces and their effects were all suggested as suitable for consideration within the primary curriculum. *Science in Primary Schools* also suggested that subject expertise might be achieved by employing teachers with good science backgrounds who could share and disseminate good science practice.

Later, in the seminal *Science 5-16: A Statement of Policy* (DES/WO 1985), the purpose, goals and expectations of science in primary schools were clearly expressed and articulated for perhaps the first time in almost a century of science teaching. Within the *Statement of Policy*, science was considered to have a place in the education of all children whether or not they were likely to follow a career in science and they should be properly introduced to science in the primary school. Science, it was said, should 'foster a range of desirable personal qualities including curiosity and healthy scepticism, respect for the environment, the critical evaluation

of evidence, an appreciation of a significant part of our cultural heritage and an insight into man's (sic) place in the world'. It was indicated that perhaps the essential characteristic of education in science was that it should introduce children to the methods of science and, at the same time, give opportunities, through practical work and otherwise, for the acquisition of scientific knowledge and understanding. Priorities considered for all ages included children making observations, selecting observations relevant to their investigations for further study, seeking and identifying patterns and relating these to patterns perceived earlier, suggesting and evaluating explanations of patterns, designing and carrying out experiments (including using appropriate forms of measurement and testing suggested explanations for the pattern of observations), communicating and interpreting written and other material (verbally, mathematically and graphically), handling equipment safely and effectively, using knowledge in conducting investigations, and bringing knowledge to bear in attempting to solve technological problems. The *Statement of Policy* endorsed *Science in Primary Schools'* earlier suggestion of living things and their interaction with the environment, materials and their characteristics, energy and materials, and forces and their effects as at least a starting point for the definition of appropriate content. The importance of breadth (that all children should be introduced to the main concepts from the whole range of science and to a range of scientific skills and processes), balance (that all children should be able to continue their study of each of the main areas of science throughout the compulsory age range and all courses should achieve a balance between the acquisition of scientific knowledge and the practice of scientific method) and relevance (by which science education should draw extensively on everyday experience of children and should be aimed at preparing children as effectively as possible for adult and working life) were emphasised. Many obstacles to primary science teaching identified to that point in time were also considered. If children were to make significant progress in their scientific studies, for example, teachers needed to be clear about which scientific concepts were to be used or developed in ways appropriate to the age and maturity of the children in particular pieces of work. Certain facets of science required a carefully organized sequence of teaching if concepts were to be thoroughly grasped and progression from year to year ensured. Together with the publication of *The Curriculum from 5 to 16* (DES 1985, 1989a), the place of science within the primary curriculum as the drive towards a National Curriculum of subjects gained pace seemed assured and an initial template for science established. According to Black (1993), most changes throughout the 1980s were motivated by a desire to realize the purpose of making science education accessible and meaningful to all children and that the sum of the trends was

to produce a science curriculum for the 1980s and 1990s that was fundamentally different to any that had gone before. This applied to both primary (5 to 11 years) and secondary (11 to 18 years) age phases.

Throughout the 1980s and on into the 1990s, substantial attempts were made to support and strengthen the teaching of primary science through the provision of centrally-funded and targeted in-service (Kinder and Harland 1991). The involvement of Local Education Authorities (LEAs), advisory teachers and consultant teachers ensured that some progress was made. The overall impact, however, was far from satisfactory and initial expectations were perhaps too ambitious, particularly in addressing teachers' knowledge and understanding of science (DES 1989b; Kruger et al. 1990a). One later contribution came from the Oxford-based Primary School Teachers and Science Project (PSTS 1988-1993) which, from a wide-ranging survey of English primary teachers' knowledge and understanding of science concepts (e.g. Summers 1992, 1994), produced a series of essential self-help guides (e.g. Mant 1993). Throughout the 1980s and on into the 1990s, a growing knowledge and understanding of the nature and significance of children's ideas in certain areas of science and constructivism as a view of learning science also emerged. Three ground-breaking initiatives led the way. The Learning in Science Project (LISP 1979-1985) at the University of Waikato in New Zealand (Osborne and Freyberg 1985), the Cognitive Acceleration in Science (CASE 1984-1987) Project (Adey and Shayer 1994) and the Children's Learning in Science Project (CLIS 1988-1992) at the University of Leeds in the UK (Driver et al. 1994) all adopted pragmatic research approaches which emphasized the view that science teaching and learning at all levels, though mostly focusing on the secondary age phase (11 to 18 years), might be improved if teachers better appreciated children's ideas about the world in which they lived and considered these ideas in the science they taught.

3.3 Towards a National Curriculum for primary science

Laudable though it might be, it would be too naïve to believe that the idea of a National Curriculum for primary science arose solely from the concerns over the status of primary science presented earlier. Instead, the idea of a National Curriculum for primary science as part of a National Curriculum of other subjects arose from much deeper concerns. By the end of the 1970s, the signs of a breakdown between central Government, Local Education Authorities and, to a lesser extent, teachers and teacher' unions was beginning to show,

largely over growing disillusionment with the educational establishment as a whole (Moon 1994; Pollard and Bourne 1994; Barber 1996). This breakdown was reflected in the famous Ruskin College speech made by Prime Minister of the day, James Callaghan, who called into question the relevance of the school curriculum and the appropriateness of the teaching methods employed, and who made reference to a basic need for 'three Rs' teaching and a case for a curriculum of basic knowledge which included science (Callaghan 1976). Later, strong views over the perceived lack of rigour in primary schools, evidenced by the progressive or child-centred, discovery-led and process-driven 'soft-centred practice' with little attention to learning, were increasingly expressed and promoted by political leaders of all persuasions and the National Inspectorate (Black 1995a) and the nature and practices of primary education, from the organization and management of classrooms to the planning, teaching and assessment strategies employed in individual lessons, became increasingly under attack (Alexander et al. 1992; OFSTED 1993, 1994; HMI 1994; Hargreaves 1994; Kerry and Eggleston 1994; Ward 1996). Education, more and more, became a central and political issue for all parties (Galton et al. 1999; Kelly 1999), the centralization and politicization eventually culminating in the Education Reform Act of 1988 (ERA 1989).

3.3.1 The 1988 Education Reform Act

While attendance at school in England and Wales has been compulsory since about 1870, and religious education compulsory since the Butler Act of 1944, the law has had nothing to say about the content of the school curriculum which, until the Education Reform Act of 1988, was thoroughly embedded in 'localism' (Golby 1988). In effect, the Education Reform Act of 1988 (ERA 1989), the first significant legislation since the Butler Act of 1944 (O'Hear and White 1993; Ashcroft and Palacio1997; Matheson and Grosvenor 2001), made provision for a National Curriculum of subjects, established a legal requirement for all teachers in all maintained schools throughout England and Wales to teach the prescribed National Curriculum of subjects, including science, for the first time, made schools much more publicly accountable for their actions and for the ways they deployed resources within them, and gave Secretaries of State for Education for England and Wales unprecedented powers over the education systems in these two countries. Such was the importance of science at the time, it was included with English and mathematics in what became referred to simply as 'the core'. Like all other subjects within it, the prescribed minimum statutory requirements for science were designed to provide clear information to help teachers implement science in

their schools, to identify targets for children's learning, to raise expectations, to provide a framework for achieving continuity from one year to the next and from one school to another, and to provide parents and other teachers with clear and accurate information in common language (DES 1989c; WO 1989).

3.3.2 Final versions

To date, there have been four 'final' versions of the National Curriculum for primary science (DES/WO 1988, 1989, 1991a, b; NCC 1988, 1991a; SCAA 1994a, b; DfE/WO 1995; DfEE/QCA 1999a, b; QCA 1999) and the 'struggle' to formulate it over the ten years or so since its introduction has been well documented (e.g. Oakley 1993; Jenkins 1995; Black 1995a, b; Ritchie 1996; Peacock 1997). An overview of the different versions together with a chronology of major events is provided (Tables 3.1 and 3.2).

The National Curriculum for primary science began to take form with the Science Working Group (SWG) set up by the Secretary of State for Education and Science in July, 1987, in anticipation of the Education Reform Act of 1988 and its contents. The Science Working Group, Chaired by Professor J.J. Thompson of Bath University, was briefed to recommend Programmes of Study (PoS), which would set out the science that children should be taught, and Attainment Targets (ATs), which would set out the science that children should know and be able to do, within the framework of assessment and reporting arrangements including Levels and Statements of Attainment (LoA and SoA) already determined by the Task Group on Assessment and Testing (TGAT) set up earlier (DES 1988a, b). Like the other core subjects, the National Curriculum for primary science was to be considered in terms of two periods of compulsory schooling: Key Stage 1 for 5 to 7-year-olds (Years 1 and 2 at school) and Key Stage 2 for 7 to 11-year-olds (Years 3 to 6 at school). Secondary science to the end of compulsory schooling included Key Stages 3 and 4. With assessment in mind, children were expected to perform between Levels 1 and 3 in Key Stage 1, most children reaching Level 2 by the end of the Key Stage at age 7, and children were expected to perform between Levels 2 and 5 in Key Stage 2, most children reaching Level 4 by the end of the Key Stage at age 11. The Science Working Group, which first met in September, 1987, and produced its interim report in November of the same year (DES/WO 1987), proposed five main content-based themes within which skills development and the fostering of attitudes should take place: living things and their interaction with the environment; materials and their

Science in the National Curriculum (DES/WO 1989)	Science in the National Curriculum (DES/WO 1991b)	Science in the National Curriculum (DfE/WO 1995)	Science: the National Curriculum for England (DfEE/QCA 1999b)
Attainment Targets AT1: Exploration of science AT2: The variety of life AT3: Processes of life AT4: Genetics and evolution AT5: Human influences on the Earth AT6: Types and uses of materials AT7: Making new materials AT8: Explaining how materials behave AT9: Earth and atmosphere AT10: Forces AT11: Electricity and magnetism AT12: Scientific aspects of IT AT13: Energy AT14: Sound and music AT15: Using light and EM radiation AT16: The Earth in space AT17: The nature of science ATs 7,8 and 14 KS2 only ***Programmes of Study placed after Attainment Targets and Statements of Attainment***	*Attainment targets and strands* AT1: Scientific investigation (i) question, predict, hypothesize (ii) observe, measure and manipulate variables (iii) interpret results and evaluate evidence AT2: Life and living processes (i) life processes and the organization of living things (ii) variation and mechanisms of inheritance and evolution (iii) populations and human influences within ecosystems (iv) energy flows and cycles of matter within ecosystems AT3: Materials and their properties (i) the properties, classification and structure of materials (ii) explanations of the properties of materials (iii) chemical changes (iv) the Earth and its atmosphere AT4: Physical processes (i) electricity and magnetism (ii) energy resources and transfer (iii) forces and their effects (iv) light and sound (v) the Earth's place in the Universe ***Programmes of Study placed alongside Attainment Targets and Statements of Attainment***	*Programmes of Study with strands* Sc1: Experimental and investigative science 1. planning experimental work 2. obtaining evidence 3. considering evidence Sc2: Life processes and living things 1. life processes 2. humans as organisms 3. green plants as organisms 4. variation and classification 5. living things in their environment Sc3: Materials and their properties 1. grouping and classifying materials 2. changing materials 3. separating mixtures of materials Sc4: Physical processes 1. electricity 2. forces and motion 3. light and sound 4. the Earth and beyond Sc3.3 and Sc4.4 KS2 only ***Attainment Targets and level descriptions placed after Programmes of Study***	*Programmes of Study with strands* Sc1: Scientific enquiry ideas and evidence in science investigative skills Sc2: Life processes and living things life processes humans and other animals green plants variation and classification Sc3: Materials and their properties grouping and classifying materials changing materials separating mixtures of materials Sc4: Physical processes electricity forces and motion light and sound the Earth and beyond Sc3 separating mixtures of materials and Sc4 the Earth and beyond KS2 only ***Attainment Targets and level descriptions placed after Programmes of Study***

Table 3.1 Overview of 'final' versions of the National Curriculum for primary science

Date	Comment
June 1987	Task Group on Assessment and Testing (TGAT) set up by Secretary of State for Education and Science to advise on and propose a plan for a National Curriculum involving assessment and reporting in anticipation of the passing of the 1988 Education Reform Act (ERA 1988). Attainment Targets, Levels of Attainment and Standard Assessment Tasks (SATs) proposed (DES 1998a, b).
November 1987	Interim report of the National Curriculum Science Working Group (DES/WO 1987). Working Group set up by Secretary of State for Education and Science to recommend ATs and PoS within the framework of the proposed National Curriculum of subjects.
August 1988	Proposals: Science for ages 5 to 16 (DES/WO 1988). To produce recommendations for Attainment Targets and Programmes of Study for a draft Order.
December 1988	Consultation: Science (NCC 1988). To refine proposals on the basis of consultation.
March 1989	***First version (DES/WO 1989). Implemented August 1989. Astronomy appears as AT16: The Earth in space.***
May 1991	Proposals: Science for ages 5 to 16 (1991) (DES/WO 1991a). To produce recommendations for Attainment Targets and Programmes of Study for a draft Order.
September 1991	Consultation: Science (1991) (NCC 1991a). To refine proposals on the basis of consultation.
December 1991	***Second version (DES/WO 1991b). Implemented August 1992. Astronomy appears as strand (v) the Earth's place in the Universe in AT4: Physical processes***
December 1993	Dearing review of the National Curriculum and its assessment (Dearing 1993). Recommends 'slimming'.
May 1994	Proposals: Science in the National Curriculum (SCAA 1994a). To produce recommendations for Attainment Targets and Programmes of Study for a draft Order.
September 1994	Consultation: The review of the National Curriculum (SCAA 1994b). To refine proposals on the basis of consultation.
January 1995	***Third version (DfE/WO 1995). Implemented August 1995. Astronomy appears as 4. The earth and beyond in Sc4: Physical processes.***
May-July 1999	Consultation materials (DfEE/QCA 1999a). To produce recommendations for Attainment Targets and Programmes of Study for a draft Order.
August 1999	Outcome of consultation (QCA 1999). To refine proposals on the basis of consultation.
November 1999	***Fourth version (DfEE/QCA 1999b). Implemented September 2000. Astronomy appears as the Earth and beyond in Sc4: Physical processes.***

Table 3.2 Chronology of events associated with 'final' versions of the National Curriculum for primary science

characteristics; energy and matter; forces and their effects; and the Earth, atmosphere and space. The Science Working Group seemed clear that Programmes of Study should describe the content required to enable children to reach or surpass the Attainment Targets and that while teaching and learning science should proceed from Programmes of Study to Attainment Targets these should be considered iteratively. The Science Working Group was conscious of 'breaking new ground' and acknowledged the lack of trialling and inadequate research available to it in certain areas as problematic. In a letter to the Secretary of State accompanying the Science Working Group's final report and the first proposals to appear for consultation (DES/WO 1988), Professor Thompson wrote that one of the Group's most difficult tasks was to define specific age-linked Levels of Attainment within the Attainment Targets and that the Science Working Group welcomed the Governments assurance that detailed National Curriculum requirements would not be 'set in concrete'.

Following consultation (NCC 1988), the *first version* of the National Curriculum for primary science, together with non-statutory guidance and other materials, was published (DES/WO 1989; NCC 1989; CCW 1989; NCC/CCW 1989). Front-loaded with 17 different Attainment Targets, each with its own Levels and Statements of Attainment set out in the form of a linear assessment scale, and supporting Programmes of Study, the *first version* was very different to that suggested by the Science Working Group earlier. The 17 Attainment Targets were grouped into two Profile Components (PCs) for the purposes of simplified assessment and reporting. Profile Component 1: Exploration of Science, exclusively science process and AT1, was weighted 50% at Key Stage 1 and 45% at Key Stage 2. Profile Component 2: Knowledge and Understanding, exclusively science content and ATs 2 to 17, was weighted 50% at Key Stage 1 and 55% at Key Stage 2. Notably, and at both Key Stages 1 and 2, AT1: Exploration of science contained explicit reference to children planning, hypothesizing and predicting, designing and carrying out their own investigations, identifying and quantifying variables and constructing fair tests. ATs 2 to 16 were partially familiar as biology, chemistry, physics and the Earth and space sciences (including geology, meteorology and astronomy). Soon after its appearance, however, an urgent review of the structure was undertaken. The 17 Attainment Targets were thought to be providing an obstacle to manageable and sound testing and intelligible reporting to parents and, applying only to Key Stages 3 and 4, the consistency of GCSE examination standards were considered at risk unless the number of Attainment Targets was reduced (DES/WO1991a). Proposed revisions went to consultation (NCC 1991a). In the *second version* (DES/WO 1991b), also published

with non-statutory guidance and other materials (NCC 1991b, 1992), the 17 Attainment Targets were reduced to 4 with associated strands reflecting a more familiar science curriculum dominated by biology, chemistry and physics. AT1: Scientific investigation replaced AT1: Exploration of science but retained attention to children planning, hypothesizing and predicting, designing and carrying out their own investigations, identifying and quantifying variables and constructing fair tests. Attainment Target 1 was still presented separately from the other Attainment Targets. Programmes of Study were placed alongside the Attainment Targets rather than after them. The original 158 individual Statements of Attainment were amalgamated, simplified and reduced to 58 (409 to 175 over all four Key Stages) with some 'shuffling' of position at particular Levels. The two Profile Components were considered unnecessary and removed. Unfortunately, publication of the *first* and *second versions* of the National Curriculum for primary science outpaced the first formal evaluation of its implementation which appeared later (Russell et al. 1994a-c, 1995). Between the *second* and *third versions*, the National Curriculum and its assessment as a whole were reviewed by Sir Ron Dearing (Dearing 1993). Dearing's brief was to identify scope for 'slimming' the National Curriculum even further, to reconsider the linear assessment scale operating throughout all four Key Stages, to simplify testing arrangements, and to improve the overall administration burden which had grown out of all proportion since 1989. Dearing's recommendations led to a further review of the National Curriculum for primary science (SCAA 1994a) during which an attempt was made to clarify the knowledge, understanding and skills to be taught, to remove unhelpful areas of overlap between Key Stages and across subjects, and to rectify any known areas of weakness. Proposed revisions went to consultation (SCAA 1994b). The extent to which the first formal evaluation of the National Curriculum for primary science (Russell et al. 1994a-c, 1995) was considered in this review is not known with any degree of certainty. In the *third version* (DfE/WO 1995), the version in force at the time of the research undertaken here, the Programmes of Study were placed before the Attainment Targets and recognized by their new 'Sc' designation. Level Descriptions replaced Statements of Attainment but were less specific. The linear assessment scale was retained but extended only from Key Stage 1 to Key Stage 3. Sc1: Experimental and investigative science replaced AT1: Scientific investigation with a slightly relaxed emphasis on technical requirements but was still presented separately. The *third version* of the National Curriculum for primary science was accompanied by only limited support materials (SCAA 1995, 1996). Under a brief of 'minimal change' (DfEE/QCA 1999a; QCA 1999), and following a five year moratorium on curriculum development imposed by Dearing

(1993), the 'final' and *fourth version* of the National Curriculum for primary science made its appearance (DfEE/QCA 1999b). The most notable change involved Sc1: Experimental and investigative science becoming Sc1: Scientific enquiry. The values, aims and purposes of the National Curriculum as a whole were restated and the place and nature of science within it clarified. The extent to which independent research, including the Science Process and Concept Exploration (SPACE 1990-1998) Project (e.g. Osborne et al. 1994), the Mathematics and Science Tasks (MAST) Project (e.g. Osborne and Simon 1996), the Science Teaching Action Research (STAR) Project (e.g. Harlen 1997) and the Association for Science Education – King's Science Investigation in Schools (AKSIS) Project (e.g. Watson et al. 1999) influenced the National Curriculum for primary science throughout the 1990s is not known with any degree of certainty.

3.4 Curriculum comments

The impact of the National Curriculum and the National Curriculum for primary science caught everyone by surprise. Teachers took time to adjust to the new requirements and the demands placed upon them to translate and transform policy into practice (Wragg et al. 1989; Bennett et al. 1992; Carré and Carter 1990, 1993; Summers 1994; Smith 1994; Galton 1995). Primary schools were flooded with volumes of documentation for all curriculum areas as well as for science, most of which, including non-statutory guidance and other materials, was unhelpful in any real day to day sense (Davies 1993). Throughout the changes which took place, it quickly became clear that interpretations of requirements and implementation strategies varied widely from school to school and class to class and that those for whom curriculum theory was a passion were far from satisfied. To say that primary schools and primary teachers were largely unprepared for the science curriculum encountered in 1989 and the years which followed would be a gross understatement to say the least.

3.4.1 Interpretation and implementation

According to Oakley (1993), the initial over emphasis placed on Attainment Targets, driven by Levels and Statements of Attainment and the assessment framework which came with the National Curriculum for primary science, tended to spoil the coherence of the science by narrowing its focus and it took time for teachers to realise that Attainment Targets represented what children should know and be able to do and not be taught. Programmes of

Study certainly needed more interpretation and extension before useful schemes of work could be written. An emphasis on content also caused problems initially as this conflicted with the integrated nature of topic work common to primary practice at that time. Topic work became very science-orientated as teachers put effort into ensuring science coverage and delivery. Ironically, Oakley also noted that despite later changes intended to provide help and reduce workload, teachers often relied upon the first and more detailed version of the National Curriculum for primary science in order to clarify and interpret new requirements as they appeared. According to Jenkins (1995), many teachers were initially disorientated by the more advanced requirements of AT1 which went ahead of current practice and expertise. Practical work began to focus on 'consumer-type' and 'variable-type' fair-tests which, based on the choice of investigative questions employed, involved little use of scientific principles at all or presented a rather narrow and unrepresentative view of how scientists actually work (Millar 1997). Explorations and investigations were often undertaken in isolation for the purposes of assessment rather within the context of prescribed content which is how it had been intended. Teachers had little experience of the problems of managing classrooms for such advanced requirements and little experience of selecting investigative tasks well matched to children's experience and skills and usefully linked to concept development. According to Black (1995a, b), the assessment system required curriculum developers to adopt a model of progression in which 'hierarchical dependencies' between different Levels of Attainment could be identified and for some areas of science these had either not been established or as presented in statutory documentation were not evident at all. Black also noted considerable unease at publicly reporting results of newly introduced Standardized Assessment Tasks or SATs (now National Tests) and the relationship between and relative significance and importance of teacher assessment (formative and summative). According to Ritchie (1996), the original Attainment Targets and Programmes of Study were always too ambitious. In agreement with Black, Ritchie pointed out that the suggestion that children learn science in a strictly linear fashion was always likely to be suspect and the nature of the assessment involved (e.g. teacher assessment and SATs) unwieldy and unworkable; the Statements of Attainment and linear assessment scale, at best, an 'educated guess' rather than being more firmly grounded in research evidence. This would inevitably result in superficial science coverage focusing on quantity rather than quality. Both Black and Ritchie also commented that while between all earlier versions of the National Curriculum for primary science wide consultation and amendment did take place, not all of the changes brought about reflected the public view. This, they

suggested, served to reveal the uncertainties in specifying a curriculum both in the level of detail attempted and in its rationale for formulation. The changes seemed to reflect more a level of Government intervention which led to an immediate cynicism among the teaching profession about whether the process of revision was anything other than 'tokenistic'. Finally, and according to many authors (e.g. Barber 1992; Jenkins 1992; White 1992; Black 1993, 1995a, b; Jenkins 1994; Millar 1996a, b; Levinson and Thomas 1997; Hodson 1988, 1998; Donnelly 1994, 2001; Quicke 2001), the National Curriculum for primary science, like the National Curriculum for science at Key Stages 3 and 4, lacked breadth by not promoting the nature of science or the need to improve scientific literacy for public understanding despite the compelling argument presented by Driver et al. (1996). Millar and Osborne (1998) have stated, for example, that many young people appear to complete their compulsory science education with apparent success and yet still lack any familiarity with the scientific ideas they are likely to meet outside school or the kind of knowledge, understanding and skills needed to deal effectively and confidently with contemporary scientific issues in everyday contexts. In order to combat this, Millar and Osborne presented a number of recommendations which they suggested would lead to improvement including that the science curriculum should provide children with a knowledge and understanding of some key ideas about science as well as the ways in which reliable knowledge of the natural world has been and is being obtained and that children should be able to interpret information and discuss scientific issues of importance.

According to the systems analysis of Fortune et al. (1993), the positive changes associated with introducing a National Curriculum for primary science included raising its profile (the provision of pre-National Curriculum science was erratic to say the least), formulating an initial design (pre-National Curriculum science was not designed, it evolved rather haphazardly in a 'local' sense), making known expectations (to operate in a more purposive manner and to manage the education system more effectively), and supplying performance information (to raise standards). Fortune et al. were also quick to point out, however, that transformations in the education system could only be implemented if the schools and the teachers in the education system itself were capable of bringing them about. The fact that the National Curriculum for primary science was never intended to be driven by content or process alone is also commendable. The advantages of science curricula which manage to strike an appropriate balance between the two had been recognized for some time (Koertge 1970). The immediate problem for the National Curriculum for primary science was that

science content and process were presented in isolation allowing them to be interpreted and treated separately. The content vs process debate, which remains to be fully resolved in the minds of many practising teachers, has perhaps always been the single greatest stumbling block for primary science as a whole (Osborne and Simon 1996; Harlen 1998). The House of Commons Education Committee (HCEC 1995), after conducting a wide range of interviews with Government agencies, LEAs, teachers' representatives, teachers, academics, and science institutions, considered that the evidence received at that time demonstrated that the science curriculum in primary schools as a result of the National Curriculum had had a particular benefit in extending the provision of science education and had been largely successful in achieving its aims. While still relatively new compared with science provision pre-1989, primary children were determined to be enthusiastic and interested in science and generally to a degree higher than that witnessed in Key Stage 3. The Committee noted that 'too often there is an abrupt transition from what is an enjoyable practical learning experience in primary school to one that is duller, more factual and less stimulating at the secondary level'. According to central sources at least, standards in primary science also improved (OFSTED 1998b, 1999). Galton (2000) has maintained, however, that standards across the National Curriculum as a whole have in fact not improved in any real sense, pedagogy and the nature of classroom practice has shifted little, children still experience a hiatus in progress when moving from the primary to the secondary phase of their education, and curriculum continuity is still lacking. While there is little doubt that the introduction of a National Curriculum for primary science has raised the profile and changed the nature of science education provision, however, whether or not the 'best' or the 'right kind' of science is being promoted remains to be seen and the notion of 'standards' needs to be clarified.

3.4.2 Theory, ideology and philosophy

Since before and after its introduction in 1989, the National Curriculum for primary science, within the context of the National Curriculum as a whole, has been a topic of discussion in almost all aspects of its formulation. Knight (1989) observed and commented perhaps prophetically that 'the National Curriculum designed to improve children's education is built upon makeshift foundations ... necessarily makeshift because the priority has been to produce ***a*** National Curriculum, not ***the*** definitive curriculum' (original emphasis). According to Kelly (1999), a curriculum may be designed around a delivered syllabus (with education as a form of social and cultural transmission resulting in social and cultural

conditioning or indoctrination), a series of short-term teaching objectives and learning outcomes (with education as instrumental and serving some extrinsic purpose such as to be of benefit to the future prosperity of the country) or long-term goals which guide subsequent practice (with education as development and serving some intrinsic purpose). In fact, Kelly's models of curriculum design are drawn from the liberal-humanist (subject-based), technocratic (outcomes-based), cultural-analyst (culture-centred) and progressive (child-centred) traditions more commonly presented in conventional curriculum theory (e.g. Barber 1996). From all of the evidence presented in the preceding sections, it is possible to see that the National Curriculum for primary science, within the context of the National Curriculum as a whole, reflects a complex interaction of competing model types. Of course, the interaction between competing model types is important. Such interactions, or the lack of them, ultimately determines the type of curriculum arrived at and the values promoted by means of education in a particular national context (Lawton 1989, 1992, 1996). While it is certainly useful and advantageous to base a curriculum around a syllabus of sorts with associated teaching objectives and learning outcomes which are easy to assess, as is very apparent in the design of the National Curriculum for primary science, this can result in a completely static and mechanistic view of teaching and an overly simplistic notion of education and standards ultimately leading to education by 'mastery' and 'assimilation' (Skilbeck 1984). Chapman (1994) has suggested that the presentation of science as serving some utilitarian function including that science is, or can be, of direct employment relevance to young people, that industry requires scientifically competent school leavers, or that education in the sciences develops generic skills, and should therefore be compulsory, as is also very apparent in the design of the National Curriculum for primary science, may be unjustified and that the drive for compulsory science education throughout the 1980s was an 'institutional truth' resting on little more than wishful thinking. As Hodson and Prophet (1994) asked, 'Just whose view of school science is being promoted anyway?' and 'Just whose interests are being promoted by the particular view of school science adopted?'. With these questions in mind, it is the centralization and politicization of the National Curriculum and the National Curriculum for primary science that remains a matter of particular concern. The fact that four different versions of the National Curriculum for primary science appeared in only ten years or so is certainly worrying to say the least and certainly draws attention to the political urgency with which the National Curriculum was hurried into existence as well as the lack of trialling involved. Crawford (1998), for example, stated that the National Curriculum is nothing more than a product of ideological struggle, conflict and compromise

in which central Government and its powerful and dominating agents attempted to 'define and redefine educational goals in response to a changing socio-economic climate'. Willan (1998) wrote that the notion of 'entitlement', with every child having access to a broad, balanced and relevant curriculum, used widely in official documentation to promote the introduction of the National Curriculum, was little more than a 'shibboleth' employed to lend authority to an educational programme that was substantially political rather than educational. As noted by Harlen (1992), primary science leading up to and largely throughout development of the National Curriculum was a relatively poorly researched area compared to secondary science and this applied particularly to research in implementation at the school level and in classroom practice. Harlen recognized that whilst the purposes, goals and expectations of a curriculum may well be stated for political as well as educational reasons, there are dangers associated with making such wide-ranging statements as there is often a considerable difference between national policies and what happens in schools where ideals might never be approached in practice. Kelly (1999) certainly drew attention to the 'de-intellectualization' and stifling of curriculum debate through the lack of independent research to help better understand the education process or failure to consider that research where it existed and there is, perhaps, sufficient evidence in the preceding sections to support this claim. While for some it seems certain that education is undoubtedly one of the major forces in bringing about social and cultural change (e.g. Skilbeck 1982), the extent to which the National Curriculum, including the National Curriculum for primary science, should itself be used in an overtly central and politically determined attempt to bring about and control that change is controversial to say the least.

3.5 Astronomy education provision

The changes to the versions of science described earlier not only affected the overall provision of primary science in the many different ways indicated, they affected some elements of its content more than others. Astronomy 'suffered' particularly badly. By the publication of the *third version*, the version in force at the time of the research undertaken here, astronomy education provision had been perhaps prematurely withdrawn from Key Stage 1 and considerably restructured at Key Stage 2 (Sc4: Physical processes (4) The Earth and beyond, DfE/WO 1995), only a small part of the original content remaining and an obvious degree of continuity and progression both within and between the primary and secondary Key Stages lost. While it is certainly possible to chart the changes in astronomy

education provision as they occurred, the logic and reasoning behind the events which took place are not always so readily transparent. An overview of astronomy education provision in each of the four versions of the National Curriculum for primary science is provided (Table 3.3). Inevitably, and unavoidably, there will be some overlap between the information presented in earlier sections and that which follows. This serves to reinforce the points being made.

3.5.1 First version: the rise of astronomy

From the very outset, it seemed clear that astronomy would make it into the National Curriculum for primary science when it appeared as a component of Earth, atmosphere and space, one of the five original themes proposed in the interim report of the Science Working Group (DES/WO 1987). Astronomy was not unknown in the primary sector before that time, represented as it was in many commercially available primary science schemes including *Nuffield Junior Science* (minor mention) and *Science 5-13* (as Time). Astronomy continued on through the first round of proposals and consultation (DES/WO 1988; NCC 1988), though not without difficulties in specifying individual Levels and Statements of Attainment, into the *first version* as AT16: The Earth in space (DES/WO 1989). In its original form, teachers were obliged to ensure that children across the primary age phase explored a variety of astronomical features and phenomena. At Key Stage 1 (5 to 7 years), infants were expected to 'observe closely their local natural environment to detect seasonal changes, including length of daylight, weather and changes in plants and animals, and relate these to the passage of time' and to 'observe, over a period of time ... the position of the Sun, and where possible the position of the Moon in the sky'. By the end of KS1, it was expected that most infants would, for example, 'be able to explain why night occurs', 'know that we live on a large, spherical, self-contained planet, called Earth' and 'know that the Earth, Moon and Sun are separate bodies'. At Key Stage 2 (7 to 11 years), juniors were expected to 'investigate changes in the night sky, in particular the position of the Moon, through direct observation and by using secondary sources ... use a simple model of the Solar System to attempt explanations of day and night, year length and changes in the aspect of the Moon and elevation of the Sun ... learn about the position and motion of the Earth, Moon and Sun relative to each other'. By the end of KS2, it was expected that most juniors would, for example, 'know that the phases of the Moon change in a regular and predictable manner', 'know that the Solar System is made up of the Sun and planets, and have an idea of its scale'

DES/WO (1989) AT16: The Earth in space	DES/WO (1991b) AT4: Physical processes (v) the Earth's place in the Universe	DfE/WO (1995) Sc4: Physical processes	DfEE/QCA (1999b) Sc4: Physical processes
KS1 Statements of Attainment Children should: Level 1 • be able to describe through talking, or other appropriate means, the seasonal changes that occur in the weather and in living things; • know the danger of looking directly at the Sun; • be able to describe, in relation to their home or school, the apparent daily motion of the Sun across the sky. Level 2 • be able to explain why night occurs; • know that day length changes throughout the year; • know that we live on a large, spherical, self-contained planet, called Earth; • know that the Earth, Moon and Sun are separate bodies. Level 3 • know that the inclination of the Sun in the sky changes during the year; • be able to measure time with a sundial. ***KS1 Programme of Study (placed after AT and SoA)*** Children should observe closely their local natural environment to detect seasonal changes, including day length, weather and changes in plants and animals, and relate these to the passage of time. They should observe, over a period of time, the length of the day, the position of the Sun, and where possible the Moon, in the sky. They should investigate the use of a sundial as a means of observing the passage of time.	***KS1 Statements of attainment*** Children should: Level 1 • be able to describe the apparent movement of the Sun across the sky. Level 2 • know that the Earth, Sun and Moon are separate spherical bodies. Level 3 • know that the appearance of the Moon and the altitude of the Sun change in a regular and predictable manner. ***KS1 Programme of study (placed alongside AT and SoA)*** Children should observe closely the local natural environment to detect seasonal changes, including length of daylight, weather and changes in plants and animals and relate these to the passage of time. They should observe, over a period of time, the length of daylight, the position of the Sun, and when possible the position of the Moon in the sky and its changing appearance.	Withdrawn	Remains withdrawn

Table 3.3 Astronomy education provision throughout 'final' versions of the National Curriculum for primary science

DES/WO (1989) AT16: The Earth in space	DES/WO (1991b) AT4: Physical processes (v) the Earth's place in the Universe	DfE/WO (1995) Sc4: Physical processes 4. the Earth and beyond	DfEE/QCA (1999b) Sc4: Physical processes the Earth and beyond
KS2 Statements of Attainment Children should: Levels 2 and 3 are as KS1 Level 4 • know that the phases of the Moon change in a regular and predictable manner; • know that the Solar System is made up of the Sun and planets, and have an idea of its scale; • understand that the Sun is a star. Level 5 • be able to relate a simple model of the Solar System to day and night and year length, changes of day length, seasonal changes and changes in the inclination of the Sun. ***KS2 Programme of Study (placed after AT and SoA)*** Children should be given opportunities to investigate changes in the night sky, in particular the position of the Moon, through direct observation and by using secondary sources. Children should use a simple model of the Solar System to attempt explains of day and night, year length and changes in the aspect of the Moon and elevation of the Sun. They should be introduced to the principle of the sundial as a means of noting the passage of time. They should learn about the position and motion of the Earth, Moon and Sun relative to each other.	***KS2 Statements of Attainment*** Children should: Levels 2 and 3 are as KS1 Level 4 • be able to explain day and night, day length and year length in terms of the movements of the Earth around the Sun. Level 5 • be able to describe the motion of the planets in the Solar System. ***KS2 Programme of Study (placed alongside AT and SoA)*** Children should track the path of the Sun using safe procedures such as a shadow stick or sundial. They should study, using direct observations where possible, the night sky including the position and appearance of bright planets and the Moon. They should learn about the motions of the Earth, Moon and Sun in order to explain day and night, day length, year length, phases of the Moon, eclipses and the seasons. They should be introduced to the order and general movements of the planets around the Sun.	***KS2 Programme of study*** Children should be taught: (a) that the Sun, Earth and Moon are approximately spherical; (b) that the position of the Sun appears to change during the day, and how shadows change as this happens; (c) that the Earth spins around its own axis, and how day and night are related to this spin; (d) that the Earth orbits the Sun once a year, and that the Moon takes approximately 28 days to orbit the Earth. (aspects of KS3 PoS e.g. Solar System) ***AT4: level descriptions (placed after PoS)*** Level 1 • children recognize that light comes from a variety of sources and name some. Level 2 • children know about a range of physical phenomena and recognize and describe similarities and differences associated with them. Level 3 • children use physical ideas to explain simple phenomena; • children make simple generalizations about physical phenomena. Level 4 (draw also from KS3 PoS) • children describe, explain and make generalizations about physical phenomena. Level 5 (draw also from KS3 PoS) • children apply and use some abstract ideas in descriptions of physical phenomena; • children use models to explain effects observed with physical phenomena.	***KS2 Programme of study*** Children should be taught: (a) that the Sun, Earth and Moon are approximately spherical; (b) how the position of the Sun appears to change during the day, and how shadows change as this happens; (c) how day and night are related to the spin of the Earth on its own axis; (d) that the Earth orbits the Sun once each year, and that the Moon takes approximately 28 days to orbit the Earth. (aspects of KS3 PoS e.g. Solar System) ***AT4: level descriptions (placed after PoS)*** Level 1 • children recognize that light comes from a variety of sources and name some. Level 2 • children know about a range of physical phenomena and recognize and describe similarities and differences associated with them. Level 3 • children use physical ideas to explain simple phenomena; • children make simple generalizations about physical phenomena. Level 4 (draw also from KS3 PoS) • children describe, explain and make generalizations about physical phenomena. Level 5 (draw also from KS3 PoS) • children apply and use some abstract ideas in descriptions of physical phenomena; • children use models to explain effects observed with physical phenomena.

Table 3.3 (cont.) Astronomy education provision throughout 'final' versions of the National Curriculum for primary science

and 'understand that the Sun is a star'. Some juniors might even be expected to 'relate a simple model of the Solar System to day and night and year length, changes of day length, seasonal changes and changes in the inclination of the Sun'. Though, like the rest of the primary science curriculum, easily questionable and open to challenge in terms of actual content and the hierarchical arrangement and relative importance ascribed to individual age-linked statements within it, limitations openly admitted by the original members of the Science Working Group (DES/WO 1987), something of a laudable start had been made, and some measure of breadth, balance and relevance achieved.

3.5.2 Second version: the beginning of the end

Within only two years, the National Curriculum for primary science and astronomy within it looked very different. AT16: The Earth in space (DES/WO 1989) became strand (v) the Earth's place in the Universe within AT4: Physical processes (DES/WO 1991b). No reasons were given for the change in title. Statements of Attainment within the Attainment Target strand were reduced and simplified from 13 to 5 though the Programmes of Study remained virtually identical. Requirements to explain why night occurs at Level 2 moved to a broader statement about day and night at Level 4 and initial reference to the Solar System at Level 4 moved to Level 5. Again, no reasons were given for the changes. Sharp (1993) noted that in the proposals preceding the *second version*, five new Attainment Targets had been suggested to replace the original seventeen (DES/WO 1991a). Interestingly, the five new Attainment Targets closely resembled the five original themes proposed by the Science Working Group. AT9: Earth and atmosphere, AT13: Energy and AT16: The Earth in space were gathered into AT3: Earth and environment bringing all of the Earth and space science elements together (Fig. 3.1). At consultation, however, respondents felt that energy was inappropriately located within Earth and environment and there was an unnecessary overlap with requirements set out in the statutory Order for Geography (NCC 1991a). The National Curriculum Council, the non-Governmental organization responsible for conducting the review, believed that in considering the respondents' positions and adjusting the curriculum accordingly, AT3: Earth and environment became too small with significantly fewer Statements of Attainment than the other Attainment Targets. This resulted in problems of weighting and the significance of the Attainment Target in reporting to parents. The remaining elements of Earth and environment and associated Statements of Attainment were redistributed and AT3, as it had been proposed, was dropped. While astronomy remained, Sharp pointed out that these moves

reflected a lack of understanding of the nature and significance of the Earth and space sciences, particularly in the primary age phase (5 to 11 years), and a 'pre-occupation with inflexible and reductionist classification schemes' on the part of respondents and the National Curriculum Council. Never quite finding their niche within science or geography curricula, and struggling to retain their identity, Sharp went on to suggest that the Earth and space sciences have never been in a position to challenge the traditional and educationally familiar

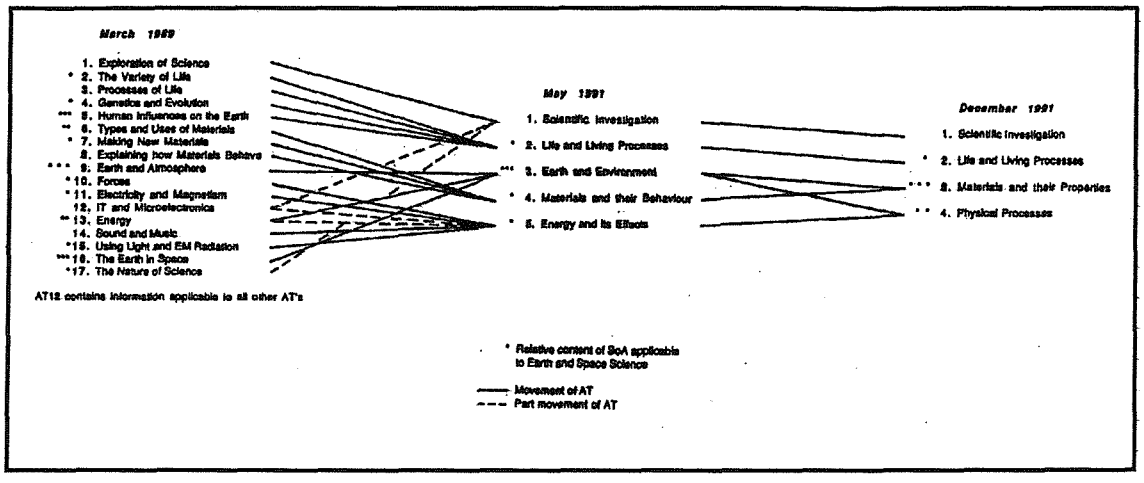

Fig. 3.1 Mapping the movement of the Earth and space sciences 1989-1991 (Sharp 1993)

'three-science' science curriculum offered throughout the secondary age phase (11 to 18 years) and that failing to achieve Attainment Target status, if success or failure could be measured in that way, was a missed opportunity for science education as a whole. Such 'territorialism' was not helpful.

3.5.3 Third version: anecdote, opinion and whim

Between the *second* and *third versions* of the National Curriculum for primary science, the School Curriculum and Assessment Authority (SCAA), the non-Governmental organization which had replaced the National Curriculum Council (NCC), commissioned a substantial evaluation of science in the National Curriculum from Key Stages 1 to 3. This work was undertaken by the Centre for Research in Primary Science and Technology (CRIPSAT) at the University of Liverpool from September 1991 to August 1993 and published one year later

(Russell et al. 1994a-c). The evaluation involved a national questionnaire survey of over 500 primary teachers, a smaller national interview survey of teachers and head teachers and some case study investigations of primary children in schools. Based on evaluation outcomes, six comments and recommendations for KS1 and 2 astronomy requirements were made:

- the KS1 Programmes of Study should link a concept of 'down' to that of the Earth as a spherical body;
- the Statements of Attainment at Level 1 should be extended to include the knowledge that day is due to the presence of the Sun and night to its absence;
- understanding of the phases of the Moon requires a well-developed concept of time and the knowledge that seeing is by the reflection of light so the relevant part of the Level 3 Statement of Attainment should be moved to Level 5;
- the Level 4 Statement of Attainment relevant to day and night is readily accessible at this Level;
- variations in the altitude of the Sun and in day length are both related to the difficult concept of seasonal change and are too demanding at Levels 3 and 4 so should be introduced in KS3;
- the ability to describe the motions of the planets is not conceptually difficult and at Level 5 and is therefore at too high a level.

Interestingly, all of the comments and recommendations, which focused on conceptual difficulty and relational structure, were supported by independent research findings, some published earlier and some later (see Chapter 2). It is interesting to note that at no point in the evaluation was it reported that any participants suggested expanding requirements to clarify and make more useful the Statements of Attainment as they existed. It never seemed to have occurred to anyone, for example, that children might need to know that, in addition to being spherical in shape, the Earth is a planet, the Sun is a star and the Moon is the Earth's only natural satellite. Perhaps more importantly, the evaluation flagged up certain disparities between policy and practice which were noted across science education provision as a whole including astronomy (Russell et al. 1995). These disparities mostly related to teachers' views of the science content which they were required to teach, their assumptions about the relationship between AT1: Scientific investigation and the knowledge and understanding requirements set out in the other Attainment Targets, and ideas associated with the

progression of children's knowledge and understanding of that content. Perhaps not surprisingly, these disparities were associated with conspicuous areas of the science curriculum, including astronomy, in which the subject and pedagogical knowledge of the teachers was not in place with any degree of confidence and this was considered to have implications for science planning, curriculum coverage, the teaching strategies adopted, differentiation and assessment. Simply observing the Moon, for example, was thought by some teachers to serve little purpose unless it led to an explanation of the reasons why the Moon appears to change its shape over time. Of course, simply observing the Moon is an essential part of learning astronomy, not only in terms of its changing appearance, but in terms of its surface features and considering their origin, the development of basic scientific skills including the use of scientific equipment and other resources (e.g. binoculars and telescopes, Moon maps), the history and nature of space exploration including the Moon landings, other socio-cultural influences of the Moon on children's everyday lives, and so on. With respect to the Earth's place in the Universe (DES/WO 1991b), some teachers also made generalized statements of belief to the effect that the perceived abstract nature of the content matter prescribed would be better deferred until children reach a stage at which they are capable of engaging in abstract thought and that the perceived inaccessibility of learning through direct experience required an adoption of didactic teaching methods which was problematic and inconsistent with their 'hands-on' views of 'good science'. The evaluation team concluded that in its extreme form, a belief in 'active learning' had led to the assertion that direct experience was not only advantageous, it was the only way in which children learn. No respondent fully acknowledged the link between science content and process. The evaluation team pointed out that while there were undoubtedly 'developmentally constrained cognitive limits' to children achieving and making progress in some areas of science, the notion of applying some 'stage-developmental limits' dogmatically, as was the case with the Earth and beyond, was restrictive and unnecessarily limiting. Positively, the evaluation team noted that some teachers who had explored the use of concrete models had become more comfortable with the idea of teaching about events that could not be experienced directly.

As the CRIPSAT evaluation drew to a close, the National Curriculum as a whole was under review by Dearing (1993). Draft proposals were prepared for science by SCAA (1994a) which, for the first time, had been written by a group consisting almost entirely of practising teachers within nine weeks and working on a part-time basis (Black 1995a). The lack of involvement of major research groups and identified authorities in their fields was surprising

and worrying (Rosalind Driver, University of Leeds, pers. comm. 1994). At the proposals stage, astronomy, now retitled the Earth and beyond, appeared in both primary Key Stages. At KS1, however, requirements had been 'slimmed' and 'trivialized' to the point of 'hilarity'. Within the Programme of Study, it was suggested that children should only be taught that 'the position of the Sun appears to change over a whole day' and that 'there are seasonal changes in the number of hours of daylight'. Any resemblance to anything broad, balanced, relevant or meaningful had completely disappeared. There was certainly nothing of substance that KS1 teachers of infants would recognize as worthy of teaching or pursuing. At KS2, all reference to the Solar System had been removed. No reasons were provided for any of the proposed changes. Following consultation and on into the *third version* (DfE/WO 1995), more alarming developments had taken place. All KS1 astronomy requirements had been moved to KS2 and these were more tightly focused around objects, events and phenomena associated with the Earth-Sun-Moon System. According to SCAA (1994b), astronomy was removed from KS1 because of the high conceptual demands felt to be present in requirements, not surprising given the nature of the proposals, and, astonishingly, to offset the increase in content as a result of reinstating electricity at KS1, an omission which had been overlooked. No reference was made to the removal of the Solar System at Key Stage 2. Nowhere in SCAA's proposals for the revised science curriculum or in their consultation document is there any explicit reference to the CRIPSAT evaluation which they themselves commissioned (Russell et al. 1994a-c).

While the first three versions of the National Curriculum for primary science had specified the content of science that children should be taught, this had been done without considering the content that children are interested in, the content they are capable of learning and even why they should be learning it. Black and Harlen (1993) discussed the issue of content carefully. Their selection criteria for content included that content should help improve children's knowledge and understanding of everyday events and of the world around them and should be applicable to their experiences, that children should be able to take part in the generation and testing of ideas associated with the content through the use of process skills, that content should be at a level which children can learn with understanding taking into account their limited experiences and maturity, and that content should provide a foundation for later learning in science. Black and Harlen pointed out, however, that many areas of science may well satisfy these simple selection criteria and that their implementation therefore requires additional considerations. These included that the content should engage

the interest of the children, the range of content should be such that emerging ideas are seen to have relevance and meaning, the content should be so related to children's everyday experiences that change in their everyday explanations is possible and can be planned, and the content should be presented so as to give opportunity for the development of science process skills. The National Curriculum for primary science unfortunately adopted a 'blanket-coverage' approach, one adopting the *Science 5-16: a Statement of Policy* (DES/WO1985) view that all children of compulsory school age should be introduced to the main concepts of science from its whole range, a view challenged by Osborne and Millar (1998) who preferred time for opportunity to discuss, reflect and analyze. Initial curriculum overcrowding and expectation in terms of the scientific knowledge, understanding and skills to be taught and learned certainly required that some 'slimming' and rearranging would certainly take place. Throughout, however, reform focused more on aspects of curriculum manageability and the administration of assessment and reporting arrangements than on the nature and essence of science education provision itself and the actual needs of primary teachers and primary children in classrooms. No formal content debate ever took place leaving the 'territorialism' already discussed by Sharp (1993) to go unchecked. Astronomy was clearly unfamiliar to many teachers, primary and secondary, and this they wrongly equated with unsuitable. Similarly, of course, the rise in the dominance of fair-testing in primary schools as a result of perceived AT1 and Sc1 requirements was also problematic for astronomy, for the astronomy content did not lend itself readily to fair-testing. The AKSIS Project team (e.g. Watson et al. 1999), for example, identified six types of essential science investigation, each developing its own range of skills. These included classifying and identifying, exploring, pattern seeking, investigating models, fair-testing itself, and making things or developing systems. In a survey of over 460 investigations in science lessons given by KS2 teachers, the AKSIS team discovered that about 50% were based on fair-testing alone. The team questioned the under-emphasis on the other types of investigation, particularly investigating models, and the subsequent distortion of the science work undertaken. While some support for astronomy has been made available now in the form of an optional but so-called 'exemplar' Scheme of Work for Key Stages 1 and 2 (QCA/DfEE 1998 with amendments 2000) and an Initial Teacher Training National Curriculum for Primary Science (Annex E of DfEE 1998a; DfES/TTA 2002), critics might be forgiven for suggesting that this brought too little too late.

3.5.4 Fourth version: maintaining the status quo

Astronomy in the *fourth version* of the National Curriculum for primary science remained largely as it was (DfEE/QCA 1999b). Following the publication of proposals and throughout consultation (DfEE/QCA 1999a; QCA 1999), the Qualifications and Curriculum Authority, the non-Governmental organization which had replaced SCAA, was at least informed by the author of this work, and no doubt other interested parties, of all recent classroom-based research findings which appeared to demonstrate that the exclusion of astronomy at KS1 and the Solar System from KS2 was detrimental if not damaging to this area of the curriculum and the teaching and learning of it. Despite being told that a 'strong case' had been made, alterations were not possible due to the terms of reference of the review which required 'minimal change' (Martin Hollins, QCA, pers. comm. 1999). It is certainly worth pointing out here that in the UK, the first article drawing attention to astronomy in schools (primary and secondary) appeared in the same year as the National Curriculum for primary science itself (Baxter 1989). Since then, and taking the UK as an example, other studies have replicated and extended that work and provided a clearer indication of the state of development of children's ideas across the primary age phase as a whole (Osborne et al. 1994; Arnold et al. 1995; Butterworth et al. 1997; Sharp 1995, 1996, 1999; Sharp et al. 1997). Whilst acknowledging some of the conceptual, procedural and contextual demands imposed upon individuals as astronomical information increases in complexity and conflicts with everyday experience, those involved in children's ideas research including many practising teachers generally agree that astronomy can be made readily accessible to children in the primary years provided it is presented to them in a developmentally appropriate way and at a developmentally appropriate time (Sadler and Luzander 1988; Baxter 1991; Vosniadou 1991a; Osborne 1991; Bishop 1997; Sharp et al. 1999). Had the National Curriculum for primary science incorporated all of the independent research evidence available to it as it appeared and been properly trialled, remembering that no trialling ever took place, this would have been known and perhaps the charge made by Kelly (1999) of the 'de-intellectualization' and stifling of curriculum debate reduced.

3.6 Practical implications: accommodating educational research

It is important to point out, of course, that all of the changes leading up to and following the introduction of the National Curriculum for primary science were taking place against a

background of intense National Curriculum controversy and debate (Knight 1989; Brighouse and Moon 1990; Barber and Graham 1993; Kelly 1994; Woodhead 1996; ATL 1998), 'top-down' and 'core-periphery' modelling from both central Government and local perspectives, with a clear emphasis on secondary age phase requirements (O'Hear and White 1993; Lawton 1996; Galton 1999), a lack of history and culture of teaching science in primary schools (DES 1978, 1989b), and the emergence of a new accountability and control in the forms of national testing and inspection (Conner 1991; Desforges et al. 1994; Daugherty 1995; Gray and Wilcox 1995; Black 1995b; Ouston et al. 1996; Wilcox and Gray 1996). It is also important to point out too that all of the changes were most acutely felt at Key Stage 1 (Campbell and Neill 1994; Blenkin and Kelly 1994a, b; Cox and Sanders 1994; Pollard et al. 1994). Teacher stress and workload throughout that time were recorded at an all time high with morale correspondingly low (McEwen and Thompson 1997). Not surprisingly, therefore, few of the schools considered suitable to accommodate the requirements of the research presented here were prepared to participate. Big Town CPS was a notable exception.

3.7 Summary

From the elementary schools of the 1800s to the primary schools of today, science has played its part in the education of children throughout the UK. It was not until 1989, with the introduction of a National Curriculum of subjects to all maintained schools in England and Wales, however, that science education, including astronomy, became compulsory for children across the primary age phase (5 to 11 years). The impact of the National Curriculum and the National Curriculum for primary science, that is the National Curriculum for science at Key Stages 1 and 2, caught everybody by surprise. Teachers took time to adjust to the new requirements and the demands placed upon them to transform policy into practice, but for many, this was never fully achieved. The relationship between science content and the processes of science was never clearly articulated and primary teachers' subject and pedagogical knowledge and understanding of science was never fully addressed. Since its introduction, the National Curriculum for primary science has been revised on no fewer than three separate occasions, each revision attempting to improve curriculum manageability by reducing content overload and the administrative burden which had grown out of all proportion. Changes to the different versions of the National Curriculum for primary science not only affected the overall provision of science itself, they affected some elements of its

content more than others. Astronomy, that is AT16: The Earth in space, AT4(v): the Earth's place in the Universe and Sc4(4): the Earth and beyond, together with the Earth sciences including geology and meteorology, 'suffered' particularly badly and for no good reason. The lack of attention to the content of science that children are interested in and the science they are capable of learning, not to mention why they should be learning it, can only be described as lamentable. All of the changes which took place certainly draw attention to the need for extreme care at times when classroom practices and expectations are driven by 'educational guidelines' and 'curricula' which remain to be fully informed. While recognizing and acknowledging its advantages and the benefits it has brought with it, there remains an overwhelming sense, at least in the mind of this author, of a National Curriculum for primary science based on little more than anecdote, opinion and whim and driven by the dogma of central Government and its perceived need to bring about socio-economic and cultural reform. There is certainly sufficient evidence from the 'plight' of astronomy to support this view. The research findings presented and discussed here certainly challenges many of the changes which took place. Such was the speed and extent to which curriculum reform took place, few of the schools considered suitable to accommodate the requirements of the research presented here were prepared to participate. The chapter which follows returns to the main thrust of this work and describes, justifies and critiques the means of data collection and the overall methodology adopted in order to probe cognitive structure and elicit children's ideas.

Chapter 4

Methods and Methodology

4.1 Introduction

All research requires there to be some description, justification and critique of the methods used to collect data and the overall methodology adopted. According to Cohen et al. (2000), research methods are the general or specific techniques used to collect data which will be used as a basis for analysis, interpretation, explanation, inference and prediction, while research methodology refers to the overall process of data collection itself. This chapter focuses attention on the principle means of eliciting children's knowledge and understanding of astronomy within the context of the quasi-experimental design presented earlier. As indicated in Chapter 1, while educational experiments are certainly not conducted by 'men in white coats' working in 'laboratories' attempting to isolate individual factors and observe effects, they still require highly specialized methods and methodologies in order to measure outcomes of interest reliably and with a desired level of precision. This is essential if educational experiments are to be successful in determining the cause of change as a direct result of an experimental treatment. The class teacher's curricular expertise and the equivalence testing of the experimental and control groups involved are dealt with in an extended discussion of methods and methodology associated with implementation of the quasi-experimental design and the school context (see Chapter 5).

4.2 Participants (revisited)

The participants in this study were 62 upper primary, combined Year 5/6 children attending Big Town CPS, an average sized, Local Education Authority (LEA) maintained primary located within the east Devon town of Exmouth in the south-west of England (Howard 1997; OFSTED 1998a). At the time of the study, all of the children were following the Key Stage 2 Programmes of Study of a National Curriculum of subjects, including science, operating in

all maintained schools throughout England and Wales (DfE/WO 1995). The 62 children already constituted two classes of equal numbers with 17 boys and 14 girls in each (n=31). For the purposes of this work, the class taught astronomy by Jack, also the deputy head teacher, was designated the experimental group, the other the control group. Throughout the study, the children remained within their original class. At the start of the 'fieldwork', towards the end of December, 1996, the mean age of the children in the experimental group was 10 years 5 months (median age 10 years 6 months) and the control group 10 years 4 months (median age 10 years 6 months). Equivalence testing indicated that there were no significant differences to be found between the groups in terms of age, socio-economic background, intellectual maturity, science interest and curiosity, and informal experiences of science (see Chapter 5). In terms of ethnicity, all of the children were best described as 'white-British'. As far as could be ascertained, all of the children had been taught National Curriculum science as intact classes since starting school. This included an earlier introduction to astronomy as infants when between 5 and 7 years of age (DES/WO 1989, 1991b; Tables 3.1 and 3.3 in Chapter 3).

4.3 Data collection

During the main 'fieldwork' phases of the research, the children's ideas in astronomy were elicited from the experimental and control groups on two separate occasions (Phase 3 - end December, 1996 and Phase 5 - end March, 1997). The experimental group was also interviewed for a third time later (Phase 6 - end June, 1997). Knowledge and understanding in the 'traditional' content areas of astronomy, the Earth, the Sun, the Moon, phenomena associated with the Earth-Sun-Moon System, and the Solar System and wider Universe, were obtained using a multiple-method survey instrument administered in the form of largely structured one-to-one interviews. A combination of productive questions, shape selection, allowing individuals the opportunity to produce their own annotated drawings, focused activities involving the manipulation of props, picture recognition and, to a lesser extent, word association and concept mapping provided a relatively powerful and non-threatening combination of verbal and non-verbal, phenomenologically and conceptually framed elicitation techniques for obtaining children's ideas and for exploiting their explanatory strengths in different areas (Driver and Erickson 1983; White and Gunstone 1992). By attempting to penetrate cognitive structure in this way, it was considered possible to begin to determine how each child conceptualized and modelled the astronomical objects, events and

phenomena under consideration at first, second and third interview, which for the experimental group meant before and after the experimental treatment and again after a delay of three months. While the survey instrument here made use of individual research methods which are by no means unique in terms of children's ideas research as a whole, the wide ranging combination of methods is much less common.

4.3.1 Instrumentation

According to Travers (1969), educational research instruments are developed for the purpose of helping the researcher organize his or her work and for controlling the researchers attention so that he or she focuses on the particular kinds of outcomes that are under consideration. As mentioned earlier, the children's knowledge and understanding of astronomy were elicited using a multiple-method survey instrument administered in the form of largely structured one-to-one interviews. The instrumentation described was developed and extensively piloted by the author elsewhere (Sharp 1995, 1996, 1999; Sharp et al. 1997). Every effort was taken to ensure that questions were worded and sequenced appropriately, that tasks were doable, and that the props and other research materials used were both familiar and accessible to all participants. The meanings of the terms associated with this instrument are outlined as follows.

(a) Surveys within experiments

Cohen et al. (2000) described surveys as perhaps the most commonly used method in educational research. According to Cohen et al., surveys typically 'gather data at a particular point in time with the intention of describing the nature of existing conditions, or identifying standards against which existing conditions can be compared, or determining the relationships that exist between specific events'. While acknowledging the general outlook of surveys presented by most authors as a one-off 'snapshot' of how things are at the time at which data are collected, Denscombe (1998) considered surveys research strategies rather than research methods for the simple reason that many surveys are actually multi-faceted and usually incorporate many different identifiable research techniques. Of course, the work presented here is not a survey, it is an experiment. Being an experiment means that the work was conducted under conditions which were artificially created to a greater or lesser extent. The work did, however, employ a survey instrument which provided, in effect, a survey of

children's ideas in astronomy on three separate occasions. Unfortunately, some of the broad similarities between certain aspects of surveys and experiments, not to mention other forms of educational research, are frequently overlooked.

(b) Multiple methods

The use of multiple-methods within the survey instrument contrasts with the more widespread and vulnerable single-method approach that characterizes much educational research. Single-method approaches attend to the collection of data with a certain set of assumptions and produces data which need to be recognized as having certain inherent strengths and weaknesses in relation to the aims of the particular research and the practical constraints faced by the researcher (Denscombe 1998). A multiple-method approach produces different kinds of data on the same topic. This allows for seeing things from different perspectives and being given the opportunity to corroborate findings or to triangulate. According to Cohen et al. (2000), triangulation may be defined as the use of two or more methods of data collection in the study of certain elements of human behaviour. The elements of human behaviour of interest here would include responding to interview questions and completing tasks. Probing children's ideas about the day and night cycle, for example, not only required children to respond to questions about causal factors but to demonstrate their knowledge and understanding using props. Ideas were investigated further by allowing children to produce annotated drawings of what causes day and night at a later point in time. The triangulation described here is methodological triangulation. According to Denscombe (1998), while methodological triangulation does not in any way prove that the researcher has 'got it right' or that the data and analyses are absolutely correct, it does, however, give some confidence that the meaning of the data has some consistency across the methods used to collect it and is not bound by any one of them thus allowing expressed ideas to be clarified and refined in a manner unattainable by any one technique alone.

As mentioned earlier, the phenomenologically and conceptually framed techniques incorporated throughout the interview schedule included productive questioning, shape selection, annotated drawings, the manipulation of props, picture recognition and, to a lesser extent, word association and concept mapping. Driver and Erickson (1983) described phenomenologically framed techniques as those which present children with events or phenomena and asks them to make predictions and give explanations for the way things

happen (e.g. using a child's drawing to explore where people live and why they don't fall off the Earth). No restraint is placed on the way the children respond and they may use conceptual categories of their own choice. Driver and Erickson described conceptually framed techniques as those which focus on specific aspects of children's cognitive structure (e.g. concept mapping). Most techniques have been used by most science education researchers at some point in time including those who have attempted to elicit children's knowledge and understanding of astronomy. All techniques are applicable over a wide age range (e.g. 7-18 years), all offer flexibility and depth over written responses only, and all are pertinent and penetrating (e.g. looking for more than simple definitions or factual recall). All questions and tasks were incorporated into the interview schedule which was used as a working template to record 'field notes'.

The value of providing children with well constructed and answerable or productive questions in science education has been recognized for some considerable time. According to Elstgeest (1985), answerable or productive questions fall into several categories which may be described as attention-focusing, measuring and counting, comparing, actionable, and problem-posing. Harlen (2000) has for many years considered questions asked in science as open and closed or subject-centred or person-centred. Open questions leave more options for answering than closed questions which look for answers which are either correct or incorrect. Subject-centred questions focus directly on subject matter while person-centred questions focus on the child and what he or she actually thinks. In eliciting children's knowledge and understanding of astronomy here, the factual and generative question categories of Vosniadou and Brewer (1992) are used. Factual questions provide information regarding children's exposure to certain theoretically important facts, but not about their ability to use these facts in a generative way. It is possible that some children on being asked about the shape of the Earth, for example, might simply say that it is spherical for that is what they have been told by adults. Generative questions may have far greater potential for providing information about cognitive structure. Being asked if people can live all over the Earth without falling off, or what causes day and night, for example, cannot easily be answered with recourse to received adult wisdom. As Vosniadou and Brewer suggested, children presented with generative questions about the objects, events and phenomena of interest to the researcher need to create a mental representation or mental model of them and use this mental representation or mental model to provide answers (e.g. in astronomy). Shape selection required the children to identify and confirm the shape of the Earth, the Sun and the Moon by

selecting from a range of 2D and 3D shapes provided (see also Jones et al. 1987). These included a hand-sized white polystyrene sphere, hemisphere and cylinder, and a hand-sized white card circle, semi-circle and square. Shapes were also used as props to confirm the relative sizes of the Earth, the Sun and the Moon and to clarify and extend ideas about what causes the day and night cycle, seasonal change and the phases of the Moon. Considered views in science education often stress the importance of various forms of communication including the ability to provide descriptions of the world in drawings (Symington et al. 1981). Drawings play an important part in defining, redefining and guiding the construction of an internal model of the world in which all of a child's world-elements are framed (Matthews 1991). Drawings also reflect, among other things, something of children's spatial, mathematical and scientific knowledge, understanding and skills as the essential structures of objects, events and phenomena are mapped on to a drawing surface (Cox 1992). Despite the fact that drawing is an extremely common activity during science lessons in primary schools, contributing as it does to children's sense of enjoyment and to the teaching and learning process, its potential as a research tool still receives relatively little attention (Hayes et al. 1994). Annotated drawings were used extensively in the Science Process and Concept Exploration (SPACE 1990-1998) Project (e.g. Osborne et al. 1994). Annotated drawings in response to particular questions were thought here to be extremely informative and helped to support and clarify the ideas expressed verbally or by manipulating props. Drawings of the Earth, the Sun, the Moon and the Solar System were produced as interviews proceeded. Drawings of what causes the day and night cycle, seasonal change and the phases of the Moon were produced and finished afterwards. Picture recognition, using randomly presented colour images of the Sun, the Moon and the planets taken from children's non-fiction texts supplied to the school and the experimental group during the research, simply involved asking the children if they could identify and name any of the objects on show. Concept mapping is one of many techniques which allows the content, structure and relations of children's ideas to be explored all at the same time (Novak and Gowin 1984). Concept mapping is used throughout science education in a whole manner of different ways and for a whole manner of different purposes (Malone and Dekkers 1984; Ault 1985; Mason 1992; Liu and Hinchey 1996). Concept maps themselves can reveal relationships and hierarchies between concepts (major and subordinate elements), propositions (meaningful connections between elements in words), cross-links (meaningful connections between elements in lines or arrows) and examples (specific objects, events or phenomena). The concept mapping undertaken here was carried out in a limited way with only a small number of children, and in

conjunction with words associated with the Solar System and wider Universe (see also Deese 1962; Johnson 1964) some time after the main phases of interviewing had come to an end. The children involved were introduced to concept mapping using a simple topic familiar and of interest to them (e.g. their favourite sport or hobby). In places, the wide ranging combination of questions and tasks selected resembled something akin to the 'interviews about concepts' and 'interviews about instances and events' described by Osborne (1980), Osborne and Gilbert (1980a, b) and Gilbert et al. (1985).

(c) Validity, reliability and sensitivity or precision

According to Cannell and Kahn (1968) and Cohen et al. (2000) research instruments, and the methods or techniques within them, can be judged in terms of their validity (the extent to which an instrument and the rules for its use adequately measure what they purport to measure) and reliability (the stability and equivalence of a measure), as well as sensitivity or precision (power of discrimination). Validity, reliability and sensitivity or precision are neither wholly independent nor simply inter-related and the relationship between them is complex. While threats to validity, reliability and sensitivity or precision can never be completely erased, their effects can be minimized. Within any given research procedure, validity and reliability are multi-faceted. Face validity is claimed when the questions asked and tasks presented measure what they purport to measure (e.g. by probing children's ideas about the shape of the Earth, the responses obtained indicate, literally on the face of it, to have provided that information). Content validity is claimed when professional judgements are made about the relevance and sampling of content to a particular domain (e.g. by ensuring that the astronomical information sought at interview sufficiently matches that which was taught throughout the experimental treatment). Concurrent or convergent validity is claimed when the results obtained using a particular research instrument are similar to those obtained using another (e.g. by comparing research outcomes here with children's ideas in astronomy obtained elsewhere). Construct validity is claimed when the research outcomes are fair indicators of the operationalized or articulated forms of a construct (e.g. by considering whether or not asking children to draw rain falling from clouds or what happens when rocks are dropped into tunnels cut through the Earth reveal anything about children's ideas about gravity – see Section 2.5 in Chapter 2). The work presented here lays claim to all four aspects of validity. Reliability within any given research instrument is often claimed when the questions asked and tasks presented give consistent results. The multiple-method

research instrument developed and used by this author over time has produced, if nothing else, consistent results. Instrumentation that is overly sensitive to these sources of error is not reliable and may result in instrumentation bias invalidating findings. Methodological triangulation helped monitor and control the internal consistency, validity, reliability, sensitivity or precision and authenticity of responses.

4.3.2 Individual research interviews

According to Good (1963), the interview is a 'process of communication or interaction' and can be classified according to function (e.g. research, diagnostic, therapeutic), the number and arrangement of persons participating (e.g. individual, group), length of contact (e.g. short or prolonged), and according to the roles assumed by the interviewer and the interviewee (e.g. structured, semi-structured, unstructured). Good also noted that the dynamics of interviewing involved more than an 'oral questionnaire'. Interviews are particularly useful for producing data from relatively small numbers of participants which deal with topics in depth and in detail and may be sufficiently flexible to pursue specific lines of investigation or issues of particular interest as they arise. Cannell and Kahn (1968) considered the interview as a 'conversation with a purpose', the purpose being 'information getting'. Cannell and Kahn pointed out, however, that the interview is after more than mere information, it is concerned with the particular qualitative and quantitative forms of information that often result in measurement. Powney and Watts (1987) described the interview as a 'means of collecting talk'. They distinguished between respondent interviews, in which the interviewer retains control throughout, and informant interviews, in which the respondent retains control throughout. Interviewing has been used throughout children's ideas research and for some time. Piaget (1929), for example, used unstructured or clinical interview procedures extensively, arguing that in order to determine a child's notions of reality and causality an interviewer must 'let the child talk freely, without ever checking or side-tracking his [sic] utterance, and at the same time he [sic] must be constantly alert for something definitive, at every moment he must have some working hypothesis, some theory, true or false, which he is seeking to check'. Unstructured or clinical interviews are rarely used in science education today.

In terms of the different definitions provided, the interviews conducted here are best described as largely structured, respondent-type, individual research interviews. By

interviewing for up to one hour, they can also be described as prolonged. According to Denscombe (1998), what distinguishes structured from semi-structured and unstructured or clinical interviews is the degree of control exercised by the researcher over the nature of the responses and the length of the answers allowed by the respondent. Structured interviews typically involve tight control over the format of the questions and tasks presented often to the point of using a set of pre-coded answers from which the respondent can choose. While the latter point does not apply here the former certainly does. Individual or one-to-one interviews are relatively easy to arrange and the ideas expressed throughout only come from one respondent making it easy to locate specific sources of information. Individual or one-to-one interviews also avoid one or more individuals dominating over others. In this work, the research interview served one major purpose. As indicated by Tuckman (1999), the research interview has the potential to provide access to 'what is inside a person's head', allowing the researcher to describe and measure what that person knows and what that person thinks. The research interview also provides access to what experiences have taken place in that person's life and what is occurring at the present. Tuckman noted, importantly, that the research interview provides a means of gathering data about people by 'asking' them rather than by 'observing' them. Of course, the interviews conducted here differ significantly from all of the definitions and features provided earlier in one key aspect. Not only do they involve oral interaction, they intentionally seek to obtain information by other means too.

(a) The process of interviewing

From the works of Cannell and Kahn (1968) and Powney and Watts (1987), together with the general reviews provided by Gall et al. (1996) and Cohen et al. (2000), several important steps in the total process of interviewing were identified:

- creating or selecting an interview schedule (e.g. formulating questions and tasks or other stimuli to evoke response) and a set of rules or procedures for using the schedule;
- conducting the interview;
- recording responses;
- transcribing the interview where appropriate (part or whole);
- delineating and clustering general and specific units of meaning relevant to the research;

- creating a coding or scoring system of measurement into which the recorded responses are to be translated, and a set of rules for making the translation;
- coding or scoring the interview responses;
- analyzing and interpreting outcomes.

Addressing only the first point for the moment, a major challenge for any interviewer lies in formulating an interview schedule itself. In order for a research interview to be successful, the respondents must understand what is required and the information obtained must be accessible to the interviewer. Cannell and Kahn (1968) considered the formulation of questions and tasks to involve complicated cognitive processes. Comparable information about the knowledge and experiences of many respondents is often required and yet this knowledge and experience, as discussed in Chapter 1, is often uniquely organized for each individual. In the construction of questions and tasks, the language of the questions and the nature of the tasks must conform to the vocabulary level and general abilities of the respondents even though they might perceive their content or intention in different ways. It is also important to only use questions or tasks which contain a single idea to avoid confusion. On issues of organizing and sequencing questions and tasks, Cannell and Kahn considered a battery of questions and tasks preferable. Within that battery, questions and tasks should be revisited at different times for the purposes of triangulation. Within a given area (e.g. in astronomy), the sequence of questions should be such that, where possible, they lead the respondents meaningfully through the process of interview with the most difficult questions coming towards the middle or end. The sequence of topics (e.g. Earth, Sun, Moon, Day and night, and so on) should be planned to make the total interview experience as meaningful as possible and to give it a sense of direction and purpose. Transitions from area to area (e.g. Earth, Sun and Moon to Earth-Sun-Moon System) should be facilitated by some appropriate means to make the new material plausible and to relate it to things already discussed. Of course, this said and done, respondents may still, for example, fail to understand the purpose of the question or the task or the kind of answer required. Respondents might lack the information or the knowledge necessary to answer the question or complete the task or the respondents may simply not remember the information requested. Respondents may not be able to verbalize for themselves, draw, or illustrate by any other means, a response with which they are satisfied. Nowhere are these interview points more vividly raised and discussed than in the criticisms of the questioning strategies and tasks associated with

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Piaget's theory of intellectual growth based on stages of cognitive development (Flavell 1963; Bryant 1974; Donaldson 1978; Brown and Desforges 1979).

(b) Conducting interviews and recording responses

All interviews in this work were conducted away from the classroom but in an area of the school familiar to the children and in accordance with the general science interview guidelines provided by Osborne and Freyberg (1985). A short list of the interview guidelines adopted is provided (Table. 4.1). The children were chosen for interview in class register order (arranged by gender and age). Each interview lasted up to about 1 hour while drawings associated with the Earth-Sun-Moon System and concept maps were produced and finished afterwards. Experience of interviewing children of this age indicated to this author that individuals often become noticeably tired and begin to lose interest if engaged for longer. Interviews opened by settling each child in turn alongside the interviewer, putting them at their ease, and introducing them to what was about to take place. It was emphasized to all of the children that their interview was a 'private' matter, the content of which would not be divulged to their class teacher or to anyone else. The children were reminded that when answering the questions or attempting the tasks that it was better to say they 'didn't know' or 'were not sure' rather than to guess or attempt to make something up. Observations, verbal responses and task outcomes were recorded in written 'field notes' and audio-taped. All drawings and concept maps were retained. Audio-tape recording was considered essential if data were to be gathered as fully and as unobtrusively as possible (Powney and Watts 1987) and as objectively as possible (Oppenheim 1992). Again, experience of interviewing children of this age indicated to this author that the use of a tape recorder was rarely a matter of concern on the part of individuals and that the interviewer-child rapport was not noticeably affected or the child's performance inhibited. Audio-tape recording actually has significant advantages (Good 1963). No verbal utterances are lost, the tape record reduces a major source of potential interviewer bias (the conscious and unconscious selection of material to note down or forget – omissions, distortions, elaborations, condensations, and other modifications), and tape recording permits time to devote to the respondents where necessary, particularly when describing drawings or manipulating props. Recordings themselves, however, inevitably result in a translation and transcription prepared by the interviewer, another potential source of error or bias (Gilbert et al. 1985). As each interview progressed,

	Do's	Don'ts
1.	Dress informally and act naturally as far as possible.	Do not dress or behave in a way which indicates that you are an authority figure.
2.	Introduce the nature of the interview and put children at their ease.	Do not rush into the interview and frighten the children.
3.	Try to establish clearly what the children know. Emphasize it is the child's ideas that are important and are being explored.	Do not indicate that there is a given answer to the questions and tasks or respond favourably or unfavourably to what is said or done.
4.	Provide a balance between open and closed or generative and factual questions and tasks. In doing so maintain child confidence.	Do not ask leading questions. Do not provide tasks and materials with which the children are unfamiliar or simply cannot do.
5.	Use questions and tasks which elicit children's ideas whatever those ideas might be.	Do not use questions or questioning strategies which assume a teaching role.
6.	Listen carefully to and observe each child's responses, verbal or otherwise, and follow up points that are not clear.	Do not rush through the interview with little regard for what is being said or done.
7.	Where necessary, or for the audio-record, repeat responses.	Do not modify or change what is being said or done.
8.	Give each child sufficient time to formulate a response and to complete tasks.	Do not rush the children but avoid prolonged silences.
9.	Where children express doubt and hesitation encourage them to share what they are trying to say or do.	Do not allow children to assume that they are being tested.
10.	Be sensitive to possible misunderstandings of, or misunderstandings about, initial questions and tasks.	Do not make any assumptions about what the children are thinking.
11.	Be sensitive to the unanticipated response or task outcome and explore it carefully and with sensitivity.	Follow-up responses and task outcomes that you do not fully understand.
12.	Be sensitive to self-contradictory statements or task outcomes by children.	Try not to forget earlier responses during the same interview.
13.	Be supportive of a child querying the questions and tasks presented, and in this and in other ways, develop an informal atmosphere.	Do not let the interview deteriorate into an interrogation.
14.	Be sensitive to the possibility that children will give an answer simply to fill a silence.	Do not accept an answer without exploring the reasoning behind it.

Table 4.1 Guidelines for science interviews (based on Osborne and Freyberg 1985)

the interviewer was mindful of time and interview stress. Attention was paid to identifying the main points stated, the underlying logic and underpinning ideas, inconsistencies, impressions, and so on, all of which would help in later analysis and interpretation (Denscombe 1998). Towards the end of each interview, the children were invited to recap on their ideas and to clarify anything that required clarification. Normal courtesies were extended for their efforts and giving up their time. All data collected was analyzed later. Over the three main interview phases of the research, 155 individual interviews were conducted and about 120 hours of audio-recording obtained.

(c) Validity, reliability and sensitivity or precision

According to Oppenheim (1992), Denscombe (1998) and Cohen at al. (2000), despite the many advantages of using research interviews as a tool for collecting data, interviews can also be time consuming to undertake, perhaps difficult to code and analyze (particularly when non-standard responses are obtained), and subject to many different interviewer effects. In an interview, both interviewer and respondent influence each other to a greater or lesser extent. As such, every interview is, to a degree, unique no matter how closely the rules of standardizing the interview are obeyed. Interviewer effects, leading to interviewer bias, and how they affect interviews are associated with personal identity (e.g. age, sex, ethnic origin, accent, socio-economic status, personal and professional status, motives, and so on), self-presentation (e.g. appearance, confidence) and personal involvement (e.g. expectations, style, conduct). Gilbert et al. (1985) noted, for example, that discussions during elicitation with some children can be difficult for these are often discontinuous being punctuated by gestures and faltering and irregular pausing. Interviewers often show various qualities of voice delivered with a variety of facial expressions and body postures. For children, the sequence of conversation can be hard to follow and full of inconsequence, confusion and contradictions. In response to interviewer effects, respondents may, for example, differ in motivation to co-operate with the interviewer and to answer accurately and truthfully. Respondents may feel that the interviewer is not sufficiently interested in what he or she has to say or understand how he or she feels. Interviewers may see respondents in their own image and seek only the answers that support their own preconceived notions. Participants are also self-aware and self-conscious and there is also the very real possibility of individual respondents acting or behaving differently from normal to suit the purpose of the research. Good interviewers are attentive, sensitive to the feelings of the respondent, adept at using

prompts and checks, and generally take simple, practical steps to minimize the effects described and the interview bias associated with them in order to retain validity. This includes considering the potential error effects of compensatory rivalry and resentful demoralization (Gall et al. 1996). Factors which contribute to the unreliability of an interview include subject fatigue, emotional strain, the health of the respondent, the physical conditions of the room in which the interviews are conducted, and so on. Only some of these, as indicated, are within the control of the interviewer. Other sources of error and bias associated with reliability can be minimized with interview structure. The subsequent analysis and interpretation of interview protocols, written or tape-recorded, including the derivation of codes and scores, was done without destroying too much of the sensitivity or precision that the researcher has been at such pains to secure (White 1985). As indicated by Powney and Watts (1987), the 'quality of the data collected at interview will depend upon the skill of the interviewer' and no instrumentation or any amount of statistical analysis can rescue an interview-based research project in which the interviewing was poor. The author of this work would consider himself an experienced interviewer of primary-aged children.

4.3.3 Sampling

Only rarely do educational researchers study entire populations as factors associated with expense, time, accessibility and sheer volume of numbers often get in the way (Travers 1969; Kerlinger 1969). Instead they study samples drawn from populations. From these samples they infer the characteristics of a defined population or particular sample frame. Small-scale research, such as that presented here, frequently involves sample sizes of between about 30 and 250. According to Denscombe (1998), several points need to be stressed with respect to the use of small-scale research involving relatively small sample sizes:

- extra attention needs to be paid to the issue of how representative the sample is and caution is needed about the extent to which generalizations can be made on the basis of any research findings;
- the smaller the sample, the simpler the analysis should be, in the sense that the data should be subjected to as few sub-divisions as possible (usually fewer than four in sample sizes of about 30 – two involving gender here);

- inferences drawn from the statistical analyses performed on sample sizes of around 30 should be considered with care and sensitivity.

Of course, small-scale research and limited sample sizes need not invalidate findings. Indeed, the information collected during small-scale research is often particularly suited to both qualitative and quantitative means of data analysis rather than one or the other and this can be advantageous in children's ideas research where both are desirable, and it could easily be argued that the outcomes of small-scale research provide valuable data as a starting point against which other research can be directly compared. In small-scale research, however, particular attention clearly needs to be paid to sampling issues.

Probability sampling is perhaps the most effective sampling technique available to educational researchers. Probability sampling is based on the idea that the probability of selection of each respondent is known and that the sample presents a reasonable cross-section of the population being studied. When the population is large and widely dispersed, as is the case with the population all children in all Local Education Authority (LEA) maintained primary schools throughout England and Wales, random sampling, as it is conventionally understood, is simply not possible. Cluster and stage sampling do, however, offer a solution (Denscombe 1998). The logic behind cluster sampling is that, in reality, it is possible to get a 'good enough' sample by focusing on 'naturally' occurring clusters of the particular thing of interest to the researcher. Stage sampling is an extension of cluster sampling and involves taking samples from samples. Cluster and stage sampling may take place at different levels. In the work presented here, for example, having identified Big Town CPS as a 'naturally' occurring cluster of children, it was then possible to stage sample two of Big Town CPS's three combined upper primary Year 5/6 classes and interview all of the children available in each of them. While neither the school nor the classes of children involved were sampled entirely at random, largely due to certain constraints associated with research requirements (e.g. willingness to participate, free and unlimited access, experience of the class teacher of the experimental group, readiness to negotiate changes to science schemes of work, internal organizational and management issues, ethical issues, and so on), the cluster and stage sampling described did not infringe the randomness associated with the timing of the study, the nature, background and composition of the classes selected and the main focus of the work. There was certainly nothing unusual about the school in terms of its geographical location, catchment, buildings, rooms, resources and adherence to the National Curriculum

and there were no immediate or obvious indications that the school, the teacher of the experimental group or any of the 62 children involved were significantly different from any other school, teacher or children that might otherwise have been chosen or that the findings would, within reason, be unlikely to apply elsewhere (other than in perhaps more ethnically diverse settings). Judgement of the school's and the children's suitability, typicality and homogeneity was supported by external and independent inspection evidence (OFSTED 1998a). Errors associated with sample bias or distortion were, therefore, minimized as far as possible and the sample obtained considered 'good enough'. That said, and in the case here, for example, the 31 children in the experimental group at best might be considered representative of a sample frame which included the entire population of upper primary, 9 to 11-year-old children in all LEA maintained primary schools throughout England and Wales following the National Curriculum, at least in the 1996/1997 academic year, and taught by an experienced teacher with an interest and enthusiasm for primary science. The 31 children in the experimental group at worst might only be considered representative of the 31 children in the experimental group! In so much as children in a classroom act not only as individuals but react together as a social system, that schools are part of a political community of educational institutions, that schools are systems of which the classroom is a part, and that individual teachers feel accountable to pedagogical traditions and societal needs (Good 1963), it can never be absolutely certain which of the two extremes were closest to reality.

The head teacher of Big Town CPS was highly supportive of classroom-based educational research and considered it valuable in terms of staff development and raising school standards. Jack, the deputy head teacher and class teacher of the experimental group, was considered an experienced and effective teacher of primary science who, in wishing to take part, like the children themselves, gave his consent to have his own curricular expertise evaluated and to be interviewed.

4.4 Data analysis

Interviews do not analyse or interpret events they simply record them. The analysis and interpretation of interview data can present a number of difficulties for the information obtained is often talk and talk is not easy to unravel (Powney and Watts 1987). This can be overcome to a certain extent by adopting various means of data analysis. Here, data were systematically reduced according to pre-determined operational parameters and definitions

and subjected to both qualitative and quantitative means of data analysis (Gall et al. 1996; Tuckman 1999). The terms qualitative and quantitative are widely used in educational research but their meanings vary from source to source. This has resulted in their having come to denote contrasting positions in relation to a number of research dimensions or paradigms. For the purposes of this work, the distinction between qualitative and quantitative relates to the *treatment of data* as indicated by Strauss (1987). Qualitatively, data analysis tends to be associated with words as the unit of analysis (Denscombe 1998). Responses can be interpreted in terms of their scientific and non-scientific content, their accuracy and 'correctness' alongside the conceptually or consensually agreed scientific models of the astronomy target systems involved, the language used to express ideas, logic and reasoning, sources of information cited, and consistency. Quantitatively, data analysis tends to be associated with numbers as the unit of analysis (Denscombe 1998). Responses can be collected or transformed into numbers which lend themselves to more powerful statistical procedures. These distinctions are, like any distinctions, far from definitive (see Cohen et al. 2000 for a fuller discussion). Throughout this work, data analysis and interpretation were conducted between the experimental and control groups as a whole, within the experimental and control groups at gender level, and within (intra-) and between (inter-) individual interviews, as described by Powney and Watts (1987). Data analysis and interpretation were undertaken acknowledging the limitations associated with the multiple-method survey instrument and interviewing process, including the processes involved in data-handling, and the validity and reliability of evidence from children's ideas research and the distinction between child and researcher 'frames of reference' (Claxton 1993; Johnson and Gott 1996). As reminded by Tuckman (1999), interviews only probe a part of what respondents say they know rather than what they know and reveal only the bits they choose to give in response to the questions asked.

4.4.1 Qualitative

Revisiting 'field notes' and tape-recorded interview responses was the first step in the qualitative data analysis undertaken here for it brought the researcher close to the data. As indicated by Powney and Watts (1987), interview data lends itself very easily to being reported as quotes extracted from interview protocols or entire transcripts themselves. This has the desirable effect of helping to bring the text alive, of allowing participants to make cogent points, to illustrate examples and to make the findings more 'believable'. As Powney

and Watts pointed out, however, this raises immediate questions about how much is reported and whether full transcripts are always required or not, what level of uncoded data is acceptable, and on what basis does data selection and filtering take place. Denscombe (1998) agreed and suggested that in the analysis of interview data the significance of extracts from responses is always limited by the fact that, to some extent, they are presented out of context and that the process of selecting extracts involves a level of judgement and discretion. The impact of the researcher's own identity and values in the analysis of interview data are acknowledged. Quotes and transcripts, details of prop manipulation, drawings, concept maps, and so on, are presented.

Beyond the use of quotes and transcripts, interview data such as that obtained here is commonly subjected to content analysis (Miles and Huberman 1994). Content analysis usually follows a logical and straight forward procedure: interview protocols are examined thoroughly; interview data are broken down into smaller component units (e.g. Earth, Sun and Moon probes, and so on); categories for analyzing the interview data are identified (e.g. specific responses to items within probes); units are coded in line with the categories identified; the frequency with which the categories occur is counted; and interview data are analyzed in terms of the frequency of the categories and their relationship with other categories that occur. The most usual form of content analysis and coding outcome is the tabulation of information and summary description. All coding performed here was carried out manually from written 'field notes' and tape-recorded responses. Interview protocols were coded first at the level of items within probes, and second at the level of the inferred mental model. At the item level, children's individual responses to the questions and tasks were coded on the basis of the categories identified for each (e.g. the Earth is not quite spherical, round like a ball, circular, and so on). The categories identified reveals the range and type of actual responses obtained for each item within each probe. Comparing response categories alongside information drawn from conceptually or consensually agreed scientific models of the astronomy target systems involved allowed for a measure of 'correctness' (full details Section 4.5). At the inferred mental model level, children's individual responses to the questions and tasks were also examined but this time in combination and coded alongside an expected pattern of responses for different model types (e.g. saying that the Earth is round like a ball, choosing a sphere from a selection of different shapes provided and drawing the Earth as it looks from space indicate a spherical Earth model). Similar methods of coding have worked successfully elsewhere despite differing methodologies (e.g. Vosniadou and

Brewer 1992, 1994; Osborne et al. 1994; Sharp 1995, 1996). This provided confidence in certain aspects of validity (e.g. Do conclusions do justice to the complexity of the area of investigation? Have the units selected been chosen on explicit and reasonable grounds as far as the aims of the research are concerned? How far do findings and conclusions fit with existing knowledge in the area and how far do they translate to other comparable situations?) and reliability (e.g. If someone else did the coding would they have obtained the same results and arrived at the same conclusions?). Of course, by comparing response categories and inferred mental models immediately before and after astronomy teaching takes place, as well as after a delay of three months, changes in knowledge and understanding can be identified and described for individuals as well as for all children within the experimental group, and the quality and effectiveness of learning can be assessed and evaluated relative to the group providing control. With such information available, changes in how the objects, events and phenomena of astronomy are conceptualized at different points in time can be mapped out and learning or conceptual change routes and pathways can be identified (e.g. Targan 1987).

4.4.2 Quantitative

The raw data with which the educational researcher works can sometimes occur naturally in the form of numbers but not here. The interview schedule contained no pre-coded items at all. In content analysis, coding is a fundamental feature of the qualitative data collected at interview. Coded qualitative data provides some scope for quantitative analysis too and attributing numbers to the qualitative data collected at interview for the purposes of detailed and extended quantitative analysis was also considered possible. This proved useful for helping to measure learning in the experimental group relative to the control group, identifying areas within astronomy that the children found easier or more difficult to learn, and drawing attention to any gender issues which may otherwise have gone unnoticed. In addition, the quantitative data obtained also allowed for an exploration of other relationships such as those between learning and age, intellectual maturity and science curiosity.

The quantification of essentially qualitative data was performed by borrowing, adapting and extending methods from other disciplines, notably primary geography, where the numerical treatment of qualitative data has been achieved with some degree of success (e.g. Platten 1995a, b; Harwood and Jackson 1993; Harwood and McShane 1996). Harwood and Jackson's research is taken as the most typical and appropriate example. In this work,

Harwood and Jackson conducted an in-depth assessment of the knowledge and understanding of nine common physical landscape features among a small group of 9 to 11-year-olds attending one primary school in England. During interviews, the children were also required to identify and describe landscape features in pictures and to produce physical landscape features in their own drawings. Findings revealed a wide range of ideas including 'alternative' interpretational frameworks broadly similar in nature to those described in science by Driver and Easley (1979). In order to provide a measure of knowledge and understanding, Harwood and Jackson used a four-point category scale of their own devising. The category scale ranged from 0, in which children's responses showed no evidence of an ability to describe any of the features of interest, to 2+, in which children's responses demonstrated enhanced knowledge and understanding, a large number of correct associations, and only rare errors. Scoring each interview protocol accordingly, Harwood and Jackson were able to analyze and interpret their findings by numerical means. Criticism of their work rests in the lack of discussion of the nature of the data handling and the development, validity and reliability of the scale. With this in mind, it is important to remember that quantitative data are only as good as the methods used to collect or produce them. An attempt to use a similar approach here is, therefore, largely creative, preliminary and exploratory. A similar four-point means of scoring is outlined:

- Score 0 – no response or 'not sure';
- Score 1 – response confused or inconclusive, 'alternative' interpretational framework evident, any correct associations overshadowed by accompanying inconsistencies, errors, mistakes or omissions.
- Score 2 – response indicates a basic knowledge and understanding, correct associations outnumber incorrect associations, inconsistencies, errors, mistakes or omissions exception rather than rule or considered acceptable;
- Score 3 – response indicates enhanced knowledge and understanding, correct associations in almost all instances, inconsistencies, errors, mistakes or omissions rare.

With this four-point scale, it was possible to attribute a score to most types of qualitative data collected at interview. Interview protocols were scored only once and at the level of individual items within probes. In the work undertaken here, it was expected that most children would score either 0, 1 or 2 to most questions or tasks. 3s, as indicated, required

enhanced performance. At the item level, children's individual responses to the questions and tasks were scored on the basis of the same qualitative categories erected previously (e.g. the Earth is not quite spherical – score 3, round like a ball – score 2, circular – score 1, not sure – score 0). From the scored responses it was possible to produce score frequency profiles and score profile percentages suitable for analysis. It was also possible to produce specific item scores within probes and summated scores for each individual child, both with considerable analytical potential also. Unfortunately, the summated scores achievable vary from probe to probe as each contains different numbers of items (full details Section 4.5). Where possible, like probes were matched (e.g. Earth, Sun, Moon and Solar System probes 12 items each, Earth-Sun-Moon System probes 6 items each). At times, therefore, the quantification of essentially qualitative data here provided only comparative rather than absolute measures of performance. Nevertheless, in terms of summated scores, for example, guidelines can be used to indicate the overall nature of the responses obtained:

- 0 to 11 on 12-item probes and 0 to 5 on 6-item probes are low scores and reflect mostly intuitive and transitional and responses;
- 12 to 23 on 12-item probes and 6 to 11 on 6-item probes are intermediate scores and reflect mostly transitional and scientific responses;
- 24 to 36 on 12-item probes and 12 to 18 on 6-item probes are high scores and reflect mostly scientific and advanced scientific responses.

It is important to note here, of course, that the means of scoring adopted produced primary data measured on an ordinal scale which, for summated scores, is subsequently transformed to interval/ratio data. Such data transformations, despite the analytical advantages they bring, are not without their limitations. Siegel (1953), for example, drew early attention to measurements arrived at in this way. According to Siegel, measurement is the process of mapping or assigning numbers to objects and observations or responses in the case here. The kind of measurement which is achieved is a function of the rules under which the numbers were assigned. The operations and relations employed in obtaining the scores define and limit the manipulations and operations which are permissible in handling the scores. The benefit of the transformation undertaken here, for example, is associated with the position of the summated scores on an interval/ratio scale so that the operations of arithmetic may be meaningfully performed on the differences between them. The transformations here assume,

however, that individual item responses collected by whatever means within probes are exactly equivalent (e.g. verbally, props, drawings) and carry equal weight in terms of importance (e.g. in reflecting ability and attainment). This assumption is made in order that the derived interval/ratio scale has a common and constant unit of measurement in order to satisfy the requirements of the subsequent scale manipulations. More recently, and in discussion of the summated rating scales used in quantitative studies of attitudes in science education, Gardner (1996) has linked these assumptions to limitations associated with dimensionality. According to Gardner, unless all items on a given scale inter-correlate with each other, share common variance, and, therefore, measure a common construct, the production of a single summated score can lead to meaningless data at worst or theoretical confusion at best. All inferential analyses conducted here were carried out with these limitations in mind. A further discussion of the validity, reliability, sensitivity and precision of the means of scoring and measurement adopted here is presented in Chapter 7. All numerical calculations were performed using *Minitab* (Minitab 1997), each technique checked once manually for standardization and conformity (Siegel 1956; Hays and Winkler 1970; Gellman 1973a, b).

4.5 Interview schedule

It is essential in any study of this type that the conceptually or consensually agreed scientific models of the astronomy target systems involved are stated explicitly. Without this basic information it would be impossible to plan for teaching, to interpret, code and score interview protocols sensibly, and to assess or judge the children's prior knowledge and understanding of astronomy and any subsequent knowledge acquisition and concept learning which took place. According to Norman (1983), for example, such models are devised as tools for the understanding or teaching of physical systems. They are precise and complete representations that are coherent with scientifically accepted knowledge. This is such an important and yet often sadly neglected part of almost all areas of children's ideas research. For the purposes of this work, conceptually or consensually agreed scientific models in the 'traditional' content areas of astronomy were derived from Zeilik and Gregory (1992) and Kaufmann (1994). The 'traditional' content areas of astronomy considered here are divided into their respective probes (e.g. Earth probe, Sun probe, Moon probe, and so on), each with the items selected for coding and scoring. Coding and scoring examples for the Earth alone

are provided for interest as follows. For a complete interview schedule *pro forma* used with each child and coding and scoring details for all probes see Appendix 1.

The Earth

The Earth is the third planet from the Sun and unique in that it is currently the only planet in the Solar System known to support life. At a distance of about 150 million kilometres, and travelling at about 30 kilometres per second, the Earth orbits the Sun once every 365.25 days. The Earth also rotates on its axis once every 23 hours 56 minutes with a day and night cycle of 24 hours. The Earth's equatorial diameter measures 12 756 kilometres, about 42 kilometres more than the diameter measured from pole to pole. The Earth is, therefore, not entirely spherical in shape (oblate spheroid). About 70% of the Earth's surface is covered by water making it appear mostly blue when observed from space. Surface features on its land masses are wide and varied. Surface temperatures range from 60°C to –90°C. The Earth's atmosphere is dominated by nitrogen and oxygen with traces of other gases. The Earth has one moon, *the Moon*, its only natural satellite. The Earth has a gravitational attraction which keeps our feet firmly on the ground wherever we stand. The Earth's gravitational attraction also keeps the atmosphere in place around it.

E1: Shape (verbal)

Correctness: the Earth is spherical or near-spherical in shape. Scoring: 0 – no response/not sure; 1 – round, circular, other appropriate 2D; 2 – spherical, like a ball, other appropriate 3D; 3 – 'sort of egg shaped'/other as appropriate.

E2: Shape (selection)

Correctness: sphere or sphere with qualification. Scoring: 0 – no response/not sure; 1 – any shape other than sphere; 2 – sphere; 3 – sphere with 'sort of', 'not quite', 'like this but', other as appropriate.

E3: Interpretation of evidence

Correctness: evidence should support spherical or near-spherical Earth. Scoring: 0 – no response/not sure; 1 – evidence provided sound but incorrectly interpreted; 2 – books, posters, video, TV, other, correctly interpreted; 3 – reference to space flight, lunar eclipses or ships at sea.

E4: Drawing

Correctness: view from space with land masses and oceans. Scoring: 0 – no drawing/not sure; 1 – blank 'circle', other; 2 – oceans and land masses other than Anglocentric or 'world map' shown; 3 – Anglocentric or 'world map' representation

E5: Colour

Correctness: from space, the Earth appears mostly blue. Scoring: 0 – no response/not sure; 1 – colours not including blue; 2 – blue and other colours for clouds, polar regions, land masses and oceans; 3 – colour depends on location of observer.

E6: 'Background'

Correctness: other astronomical objects against the blackness of space. Scoring: 0 – no response/not sure; 1 – astronomical objects not mentioned; 2 – selection from Sun, Moon, stars planets, blackness; 3 – all of Sun, Moon, stars planets, blackness

E7: 'Roundness'

Correctness: size of the Earth prevents its 'roundness' from being seen from surface. Scoring: 0 – no response/not sure; 1 – objects get in the way; 2 – reference to the Earth's size or the need to view from space; 3 – reference to lunar eclipse, horizon effects.

E8: Absolute size

Correctness: the Earth is 12 756 km in diameter. Scoring: 0 – no response/not sure; 1 – completely incorrect number; 2 – correct order of magnitude and approximation (e.g. thousands of kms); 3 – 12 756 km.

E9: Relative size

Correctness: the Sun is about 100 times the size of the Earth which is about 4 times the size of the Moon (diameters). Scoring: 0 – no response/not sure; 1 – incorrect sequence; 2 – S>E>M incorrect/without proportions; 3 – S>E>M correct proportions.

E10: Gravity

Correctness: the Earth's gravity is an invisible pulling force. Scoring: 0 – no response/not sure; 1 – objects/people fall from the Earth; 2 – implicit mention (e.g. nowhere to fall from) or explicit mention but incorrect (e.g. pushing force, like a magnet); 3 – explicit mention and correct (pulling force).

E11: Nature

Correctness: the Earth is a planet, an object which orbits the Sun. Scoring: 0 – no response/not sure; 1 – object other than planet; 2 – planet (label only/lack of orbit association); 3 – planet (orbits Sun).

E12: Picture recognition

Correctness: the Earth can be identified by its shape, colour, presence of oceans, atmosphere and land masses. Scoring: 0 – no response/not sure; 1 – wrong choice; 2 – correct choice based on any correct attribute; 3 – correct choice based on any correct attribute and with mention of specific continental outlines.

4.6 Summary

Children's ideas in the 'traditional' content areas of astronomy were obtained here using a multiple-method survey instrument administered in the form of largely structured one-to-one interviews. It was established that a combination of productive questions, shape selection, drawings, prop manipulation, picture recognition and, to a lesser extent, word association and concept mapping would provide a relatively powerful and non-threatening combination of verbal and non-verbal elicitation techniques for exploiting explanatory strengths in different areas. By attempting to penetrate cognitive structure in this way, it was considered possible to begin to determine how each child conceptualized and modelled the astronomical objects, events and phenomena under consideration at first and second interview, which for the experimental group meant immediately before and after an experimental treatment of prolonged astronomy teaching, and again, with the experimental group only at third interview, after a delay of three months. The methods and methodology employed had already been developed and extensively piloted by this author elsewhere. Every effort was taken to ensure that potential threats to validity, reliability and sensitivity or precision with respect to instrumentation and the interview process were identified and minimized. Here, data were systematically reduced according to pre-determined operational parameters and definitions and subjected to both qualitative and quantitative means of data analysis. While neither the school nor the classes of children involved were sampled entirely at random, largely due to certain constraints associated with research requirements, cluster and stage sampling provided a sample which was considered 'good enough'. As an example of small-scale research, with only 31 children in each of the experimental and control groups, particular attention was given to the issue of representativeness and the extent to which

generalizations can be made on the basis of findings. Other than in ethnic diversity (all children 'white-British'), no obvious indication that the school, the class teacher of the experimental group or any of the 62 children involved were significantly different to any other school, class teacher or children that might otherwise have been chosen, or that the findings would, within reason, be unlikely to apply elsewhere, could be detected. The chapter which follows details the implementation of the quasi-experimental design and includes general background details of Big Town CPS together with an extended literature review and discussion of methods and methodology associated with the class teacher of the experimental group's curricular expertise and the equivalence testing of the experimental and control groups.

Chapter 5

Implementation of the Quasi-Experimental Design

5.1 Introduction

It would, of course, be completely impossible and unrealistic to conduct a study of this type without making clear and explicit reference to the implementation of the quasi-experimental design and the school context including the human participants involved. In this rather substantial chapter, important factors including general background details of Big Town CPS, the methods and methodology associated with determining the curricular expertise of Jack, the class teacher of the experimental group, and the extent to which there is equivalence between the experimental and control groups, are considered. The identities of the school, the class teacher of the experimental group and all of the 62 children involved have been concealed in order to respect anonymity and confidentiality.

5.2 Big Town County Primary School

At the time of this work, Big Town CPS was one of eight primary schools located within the east Devon town of Exmouth in the south-west of England. About ten miles from the city of Exeter, and on one of south-west England's most scenic stretches of coastline, Exmouth, with a population of over 30 000 inhabitants, was east Devon's biggest town and a popular summer destination for families of holiday-makers.

5.2.1 General background

According to Howard (1997), Big Town CPS was an average sized, Local Education Authority (LEA) maintained primary which first opened in 1952. Consisting of several buildings, some added to the main site in the 1960s, the school was set in 12 acres of attractive grounds which had been developed for recreational as well as educational purposes

(Fig. 5.1). Proposals to expand further with a new 26-place Nursery Unit to open in time for the 1997/1998 academic year had already been approved by the school's governing body. The school drew its 302 reception to Year 6 children from a mixed catchment identified by owner-occupier homes and both rented and local authority housing. The school's population of children consisted of roughly equal numbers of boys and girls. No children were recorded from ethnic minority families. Children eligible for free school meals numbered 76 or 25.2%, above the national average. While children on the school's special educational needs register numbered 63 or 20.9%, also above the national average, only one child (0.3%) was recorded as actually having a statement of special educational needs. With a staff of ten full-time qualified teachers, class sizes averaged about 30. Eight additional parent-helpers provided voluntary educational support on a part-time basis.

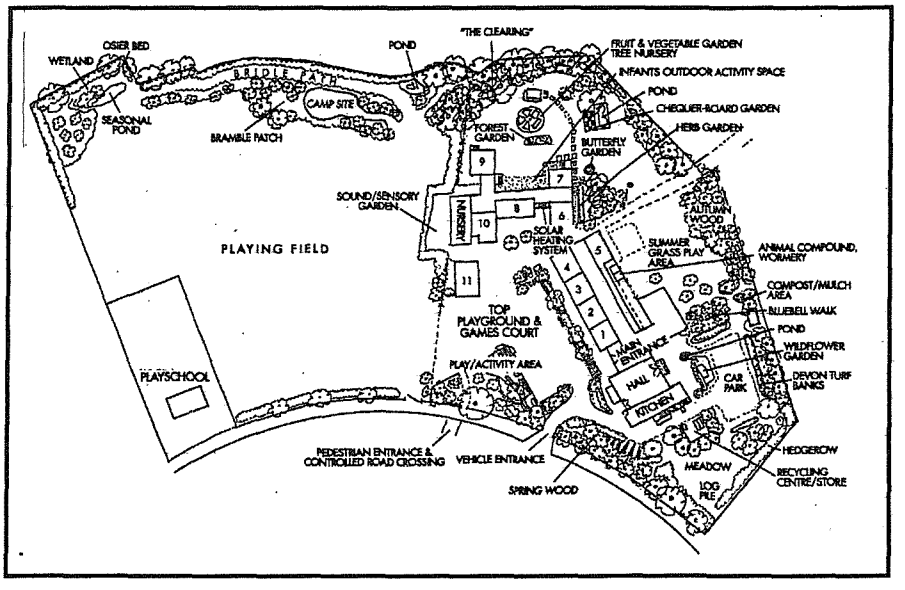


Fig. 5.1 Big Town CPS (from Howard 1997)

Big Town CPS's aim to provide a high quality education leading to achievement and success across the full primary curriculum was evident in its national test results. Attainment at Key Stage 1 based on the percentages of children at Level 2 or above for the 1996/1997 academic year (n=39) was given as follows:

- 77% in reading and 79% in writing in English (national figures 75% and 80% respectively);
- 87% in mathematics (national figure 83%);
- 87% in science (national figure 84% - based on teacher assessment results as national science testing is not undertaken at Key Stage 1).

Attainment at Key Stage 2 based on the percentages of children at Level 4 or above for the 1996/1997 academic year (n=60) was also given as follows:

- 60% in English (national figure 63%);
- 65% in mathematics (national figure 61%);
- 68% in science (national figure 68%).

The subsequent publication of national test result 'league tables' for Key Stage 2 saw Big Town CPS placed third out of the eight primary schools in Exmouth with scores typical of Devon schools as a whole (*The Journal* 1998). Devon, with its 395 primary schools, was placed fifty-fifth out of the one hundred and twenty five English LEAs listed (*Times Educational Supplement* 1998). All positions were based upon aggregate test scores for the core subjects of English, mathematics and science.

5.2.2 OFSTED

About 9 months after the completion of data collection and Phase 6 of the research undertaken here, Big Town CPS was visited and inspected for the first time by the Office for Standards in Education (OFSTED 1998a). The Office for Standards in Education (OFSTED), officially the Office of Her Majesty's Chief Inspector of Schools in England, was set up on 1 September, 1992. OFSTED is a non-ministerial Government department, independent from the Department for Education and Skills (DfES), with a remit to improve standards of achievement and the quality of education in all 24 000 English state-funded schools (and certain other categories of educational provision) by means of regular inspection, public reporting and informed advice. Inspection findings provide useful, independent accounts of schools and the educational standards achieved. The inspection, undertaken by a team of five inspectors in accordance with Section 10 of the School

Inspections Act 1996 (SIA 1996), was conducted over the five day period 23 to 26 March, 1998. During that time, the inspection team completed a total of 19 inspector days in school, including 61 hours of classroom focused observation. OFSTED concluded that progress and attainment across the school from reception to Year 6 was wide and varied but broadly average, educational standards generally meeting or exceeding what was expected nationally for children between the ages of 4 and 11 in English, mathematics and science and all other curriculum areas. The quality of teaching across the school was described as satisfactory or better overall (92% of lessons observed) and very good or better in places (19% of lessons observed). This was considered a strength leading to the promotion of sound educational standards. There were no significant differences in the progress and attainment of boys and girls nor of children from different socio-economic backgrounds. The children in the school were described as having developed appropriate and positive attitudes to learning (attentive, responsive, enthusiastic and interested) and behaviour overall was generally considered good. According to OFSTED (1998a), the science curriculum offered by Big Town CPS was broad and balanced and met all statutory requirements. The existence of a helpful long term plan assisted teachers to ensure progression in teaching scientific knowledge and skills. The presence of an experienced science co-ordinator ensured that mentoring was taking place, albeit limited. The best science teaching was characterized by the setting of relevant tasks, skilful questioning and rigorous and purposeful organization which allowed lessons to proceed with clear direction and pace. Teachers were observed to closely monitor children's work and to intervene effectively where appropriate. Tasks were generally well matched to prior attainment though high attaining children were not always stretched as much as they could have been. Overall, the school was considered to serve its children, their parents and the community very well under the strong and lively leadership of the head teacher and governing body and a committed and supportive staff.

5.3 Whole school teaching and learning policy

According to Howard (1997), Big Town CPS fully embraced the principles set out in the 1988 Education Reform Act (ERA 1989; Fletcher 1990; Flude, M. and Hammer, M. 1990). As such, all children were exposed to a broad and balanced curriculum that promoted the spiritual, moral, cultural, intellectual and physical development of individuals, and the school, in partnership with the community, prepared its children for the opportunities and responsibilities for adult life. Within Big Town CPS, children were mostly taught in mixed

age, mixed attainment classes but with some setting by ability and year group both within and between classes. Throughout the school, teachers sought to achieve a balance between whole class teaching, working with groups and spending time with individuals. The most appropriate and efficient ways of working were employed including some specialist teaching. Consistency and quality were sought after across school. Primary science, for example, was planned and taught to give all children a progressing and deepening knowledge and understanding of scientific ideas and enquiry in situations relevant to their experience, and to appreciate the value and contribution that science made to their everyday lives. In addition, the school attracted a range of visitors and external science speakers, ran a well subscribed after-school science club, and participated in science projects of local and national interest including Learning Through Landscapes (Young 1990) and Earthwise (Van Matre 1990; Cornell 1998). Staff at Big Town CPS believed that they shared a responsibility with parents for helping each child to develop as whole person and fully acknowledged that learning took place within as well as beyond the school boundaries. Staff also recognised that children's rates of progress in learning varied from child to child and that progress varied for the same child at different times. Big Town CPS benefited from an active parent-teacher association and system of home-school liaison. By all accounts, including that from independent inspection evidence (OFSTED 1998a), it might be suggested that Big Town CPS functioned fully and effectively in accordance with contemporary views and models of good practice generally (e.g. Alexander et al. 1992; OFSTED 1993, 1999; Hayes 1999a, b) as well as in science as a National Curriculum subject (e.g. OFSTED 1998b; Harlen 2000; Sharp et al. 2002).

5.4 Curricular expertise

The recent growth and development of primary science, culminating in the introduction of a National Curriculum for science at Key Stages 1 and 2 (DES/WO 1989; DES 1989c), placed primary teachers under particular curricular pressures and challenged the primary profession in England and Wales as a whole (Wragg et al. 1989; Bennett 1992; Carré and Carter 1990, 1993; Smith 1994; Osborne and Simon 1996; Solomon and Lunn 2000). In the years leading up to the appearance of the National Science Curriculum, it had already been noted that perhaps the most severe obstacle to the improvement of science in primary schools was teachers' lack of curricular expertise science appropriate to children of primary age. Primary teachers' general lack of curricular expertise in science was hardly surprising, however, given

that until then, most had received little formal education in science beyond that taught during their own days at school and most had received little formal training in science either before or after entering the profession (e.g. DES 1978, 1989b; DES/WO 1985, 1988; review in Chapter 3). In view of the nature of the work undertaken here, it was considered essential to audit, test and, where appropriate, openly address the curricular expertise of the class teacher of the experimental group, particularly with respect to teaching astronomy.

5.4.1 Categories of knowledge

Shulman (1986, 1987) outlined curricular expertise in terms of three main categories of knowledge that underpin the understanding required by teachers to promote effective teaching and learning in the classroom (see also Grossman et al. 1989). These included:

- subject matter content knowledge;
- pedagogical content knowledge;
- curriculum knowledge.

Shulman's work provides a useful basis for discussion. By subject matter content knowledge, Shulman referred not only to the ideas, concepts, and principles central to a subject but also to how these are organized within the mind of the teacher (its substantive structure) and the ways in which knowledge claims within a subject were established and varified (its syntactic structure). According to Shulman, teachers must not only be capable of defining the 'truths' within a domain, they must be able to explain where these 'truths' come from and why they are accepted and the evidence and reasoning for this. By pedagogical content knowledge, Shulman referred to the 'blending' of subject matter content and pedagogy in terms of how particular topics, problems and issues within a domain are formulated and organized and best adapted to the diverse interests and abilities of learners. Pedagogical content knowledge was also considered to involve understanding what makes a particular domain difficult or easy to learn, the range of ideas that learners of different ages and backgrounds bring with them into the classroom, and the strategies best suited to challenging them. By curriculum knowledge, Shulman referred to the full range of programmes designed for the teaching of a particular domain at a given level and at a given time, the variety of instructional materials available, and when and how particular materials

should be used. Despite some limitations (e.g. Meredith 1995), Shulman's view of curricular expertise is shared by others (e.g. Peterson and Comeaux 1987; Borko and Livingston 1989; Chen and Ennis 1995). More importantly perhaps, Shulman, in addressing 'knowledge growth', asked 'What are the sources of teacher knowledge?', 'What does a teacher know and when does he or she come to know it?' and 'How is new knowledge acquired and a new knowledge base achieved?'. The answers, he suggested, lie in training, meaningful scholarly activity, the experience, wisdom and reflection of practice itself, experience of educational contexts, and being aware of educational ends, purposes and values. Within the context of initial teacher training (ITT) and continuing professional development (CPD) in England and Wales, Shulman's knowledge types are referred to simply as subject knowledge and subject-related pedagogy (e.g. DES 1993; DfEE 1997, 1998; TTA 1998; DfES/TTA 2002).

5.4.2 Subject knowledge and subject-related pedagogy in science and astronomy

Shulman's knowledge categories are as relevant to science and astronomy education as any other subject area of the primary curriculum and a blend of subject knowledge and subject-related pedagogy is indeed important (e.g. Fensham 1988; Kruger et al. 1990a; Brophy 1991; Seddon 1991; Russell et al. 1992; Summers 1992; Bennett et al. 1994; Feasey 1994). The role of subject knowledge in curricular expertise is particularly well understood and teachers' ideas in the biological sciences (Lenton and McNeil 1991; Martin et al. 2000), the material sciences (Kruger and Summers 1989; Schibeci and Hickey 2000), the physical sciences (Kruger et al. 1990b-d; Smith and Peacock 1992; Summers and Kruger 1992; Webb 1992; Heywood and Parker 1997), the environmental sciences (Boyes et al. 1995; Summers et al. 2001) and the Earth and space sciences (Noce et al. 1988; Jones 1991; Ojala 1992; Mant and Summers 1993; Russell et al. 1994b; Summers and Mant 1995a; Spiliotopoulou and Ioannidis 1996; Parker and Haywood 1998; Trend 2000, 2001) are well documented. In summary, findings revealed that many primary teachers' lacked a knowledge and understanding of many important key concepts of science and that their ideas were generally not in accord with those accepted by scientists. In an alarming number of cases, teachers' ideas were, in fact, no different to those held by the children they taught. According to Summers (1994) and Harlen and Holroyd (1997), a poor knowledge and understanding of the subject matter of science is often reflected in poor teaching in the following ways:

- lack of awareness of children's errors, misconceptions and preconceptions and the power of these to interfere with science learning;
- misplaced assumptions that existing knowledge can be ignored or easily changed;
- poor networks of causally related information leading to attributing properties that do not correspond with reality or proposing mechanisms that do not exist;
- use of misleading or inappropriate strategies, explanations and analogies, an inability to suggest alternatives, believing that 'some' means 'all' and equating everyday language with scientific language;
- focus on the processes and skills involved at the expense of content;
- less intellectual input, lower expectations, superficial coverage and unevenness in standards.

While emphasizing subject knowledge at the expense of subject-related pedagogy is less than satisfactory, the significance of good subject knowledge as a requirement for effective science teaching should not be understated (e.g. Bennett 1988; Smith and Neale 1989, 1991; Bennett and Turner-Bisset 1993; Russell et al. 1994a; Aubrey 1994; Osborne and Simon 1996). Newton and Newton (2000) established that the situation surrounding the importance of subject knowledge within curricular expertise may, however, be more complex than originally thought. Analysing the observations of science lesson given by nineteen specialist and thirty one non-specialist or generalist Key Stage 2 teachers in a range of schools in the north-east of England, Newton and Newton reported generally low levels of teacher oral discourse that related explicitly to causes, reasons and explanations in science activities. This was more obvious in teachers of younger children than older children and non-specialists or generalists than specialists. This they attributed generally to a potential lack of subject knowledge and causal understanding in the teachers themselves. However, observations also suggested the following:

- some teachers, including specialists, who knew that their subject knowledge was poor and lacked confidence may have adopted a teaching style that avoided interaction;
- some teachers, including specialists, may have been inclined to a less interactive style by nature;

- some teachers, including specialists, may have taught in a way that reflected their own experiences of school science (e.g. science presented as collections of facts and descriptions of phenomena);
- some teachers with adequate causal understanding of science may believe that such information is beyond the capabilities of most primary children and therefore avoid it.

Newton and Newton's findings echoed an earlier investigation by Lloyd et al. (1998) who noted that even the possession of a relevant qualification and good subject knowledge did not necessarily correspond to a better ability to teach science. Some of the problems encountered by primary teachers in teaching science and the extent to which these are not only associated with a lack of subject knowledge and subject-related pedagogy (see Appendix II for a brief review of studies exploring the development of subject related pedagogy in teachers) but with confidence have also been investigated in detail by Holroyd and Harlen (1996) and Harlen and Holroyd (1997). Working with primary teachers in Scotland, these authors attributed a lack of confidence to personal school experiences, initial and in-service training which was poor or lacking (see also Appleton 1995), pressure and curriculum overload, limited support from colleagues, availability of material resources, and personal views of professional capability as well as lack of subject knowledge. Importantly these authors also noted that a lack of confidence, witnessed by anxiety and feelings of inadequacy, also led to the adoption of a variety of coping strategies, some of which, when applied regularly and over time, may have a severely limiting effect on children learning science. These included:

- teaching as little science as possible or avoiding it because of 'unexpected demands';
- stressing process at the expense of content or teaching biological rather than physical subject matter;
- relying too heavily on illustrative or instruction-based kits, prescriptive texts and work cards at the expense of investigation requiring teacher intervention;
- emphasizing expository teaching at the expense of questioning and discussion;
- avoiding all but the simplest practical work and any equipment that could go wrong;
- seeking the assistance of outside experts wherever possible.

Much recent research has shifted focus from identifying the curricular expertise of teachers and their actions to the study of the beliefs and attitudes which affect them, for beliefs and

attitudes have the very real potential to influence teacher and curriculum effectiveness (Cleminson 1990). In the absence of any formal background or knowledge in the history and philosophy of science, Smith and Neale (1989) pointed out that teachers often have strong, if misguided, beliefs about what science is, how scientific knowledge becomes established, and how it should be taught and learned. Smith and Neale identified five orientations to science teaching and learning which remain valid and in use today (Table 5.1). Somewhat influenced

	Science is	School science is	Learning science is	Teaching science is
Discovery	inquiry, discovery of natural laws, curiosity, creativity	inquiry science, exciting, interesting, 'hands on'	discovering with five senses, being curious, interested, trying out ideas, drawing own conclusions, exciting, fascinating	providing materials and interesting activities, encouraging children to try things, motivating children's interest and curiosity, posing questions, managing activities
Process	scientific method, processes of science	learning scientific method, process approaches	learning steps in scientific method and practising them: observing, drawing conclusions, collecting data, testing hypotheses, inferring, observing teacher model correct steps	demonstrating and teaching steps in scientific method, providing opportunities to practise, maintaining children's correct use of method, managing activities
Didactic/content mastery	body of facts, laws, formulae established by scientists	exposure to content, memorizing known facts, laws and formulae, assimilation of known content	reading text, adding on new information, practising, answering factual questions, watching films, listening to teacher talk, being tested, watching demonstrations	presenting content clearly, showing and demonstrating, getting films, asking factual questions, correcting children's errors, giving clues and hints, providing practice, giving tests
Conceptual change or constructivist	construction and evolution of theories within conceptual ecology, criteria of predictive and explanatory adequacy	focus on fundamental concepts and theories in science, provide opportunities for children to construct and reorganize knowledge	articulating own ideas, predicting, explaining, contrasting alternative explanations, debating and arguing, making sense of discrepant events, solving problems, contrasting evidence and predictions	eliciting children's ideas, providing discrepant events, challenging children to predict and explain, contrasting alternatives, presenting scientific conceptions, providing ways to apply new concepts, encouraging debate

Table 5.1 Orientations towards science (from Smith and Neale 1989)

by the emergence of the 'constructivist' or 'alternative frameworks' movement, Smith and Neale asserted that a lack of a conceptual change or constructivist orientation distorts and weakens conceptual change lessons which were associated with good science practice.

Further, they pointed out that a lack of knowledge of the features of conceptual change teaching could reduce children's conceptual understanding. Carré (1993) also drew attention to the potential conflict between the personal beliefs and attitudes of teachers and those of curriculum developers and the mismatch in expectation between the two during periods of innovation such as that witnessed by the sweeping educational reform associated with the introduction of the National Science Curriculum in England and Wales. According to Carré , personal beliefs and attitudes towards science and the nature of science could easily be formed or influenced by a general awareness of science issues brought about by newspaper reporting or the representations of scientific matter on television and other media in general. This is particularly important when the influence of science affects people ethically, socially, politically and economically and draws further attention to the clear need for scientific literacy and a greater public understanding of science (e.g. Levinson and Thomas 1997; Laugksch 2000). Lakin and Wellington (1994) supported Carré in a Kellyan analysis of the issue and pointed out that all individuals inevitably construct for themselves from their own training and experiences and philosophy of life a set of unique concepts as to what science means. Teachers could, therefore, if unwittingly, be responsible for communicating unclear and complicated messages, secret reservations, and personal separation and personal discomfort with the science content they put across.

Teachers' curricular expertise in astronomy is, of course, worthy of mention in its own right. Primary teachers' knowledge and understanding of astronomy have been investigated in the USA (Cohen 1982), Italy (Noce et al. 1988), Australia (Jones 1991), Finland (Ojala 1992, 1997), Greece (Spiliotopoulou and Ioannidis 1996) and England and Wales (Mant and Summers 1993; Summers and Mant 1995a; Parker and Haywood 1998). Perhaps the most detailed and informative works, undertaken as a result of the *second version* of the National Curriculum for primary science (DES/WO 1991b), are those from England and Wales. Findings generally echo those outlined earlier.

In the first of two Primary School Teachers and Science (PSTS) project studies, Mant and Summers (1993) described the outcomes of interviews designed to explore primary teachers' knowledge and understanding of the Earth's place in the Universe (DES/WO 1991b). Working with an opportunity sample of twenty volunteers from schools mostly in and around Oxfordshire (fifteen women and five men varying widely in age, science background and teaching experience), individuals were probed about their observations of the sky, their

explanations for day and night, the seasons and the phases of the Moon, and the Solar System and wider Universe. Mant and Summers reported that:

- the teachers involved did not have good observational knowledge of what happens in the sky and at times appeared to work backwards from what they thought they should see rather than drawing on first hand observational experience;
- most of the teachers were unable to explain, or gave erroneous explanations for, phenomena associated with the Earth-Sun-Moon System;
- most of the mental models of the Solar System and wider Universe were not in accord with any scientific model;
- aware of their situation, most of the teachers expressed dissatisfaction with existing levels of confidence and knowledge and understanding and indicated the need for support.

In more detail, the position and apparent movements of the Sun, the Moon and stars and planets at different times of the day and night were at times unclear (particularly the Moon, stars and planets). While fifteen teachers (75%) gave scientific accounts for day and night (the most common alternative was that the Earth orbits the Sun in 24 hours), only four teachers (20%) gave scientific accounts of the reasons for seasonal change (the most popular alternative was that the Earth was nearer the Sun in Summer than in winter) and only two teachers (10%) gave scientific accounts of the phases of the Moon (the most common alternative was that something got in the way and obscured the visibility of the whole Moon). From these findings, Mant and Summers established that only four teachers (20%) held a consistent mental model of the Solar System and wider Universe as a whole and the Earth's place within it. The authors concluded that in order to teach astronomy in primary schools as part of the National Science Curriculum, teachers required:

- direct observational experiences;
- knowledge of accurate, scientific models of the Earth in relation to the rest of the Solar System and wider Universe;
- 'real' understanding, in the sense of being able to use these models to explain and predict simple phenomena of the kind targeted by their research, leading to confidence in and ownership of newly acquired knowledge;

- knowledge of the type and range of ideas that children are likely to have about these conceptual areas.

The findings from this survey were used to help produce constructivist-based PSTS project support material (Mant 1993). Broadly similar findings were reported from their second study (Summers and Mant 1995a) which was conducted using a survey questionnaire with another opportunity sample of sixty six practising teachers, also from schools in and around Oxfordshire, and fifty four graduate trainees who had just completed their primary PGCE at Westminster College, Oxford. Despite the short passage of time between studies, there still existed a mismatch between participants' existing knowledge and understanding and the requirements of the National Science Curriculum in this area.

Studies of teachers' knowledge and understanding in science are not always warmly received. Golby et al. (1995) strongly criticized the work of Mant and Summers (1993) which they described as 'typical of its kind'. Suggesting that Mant and Summers, and all other authors publishing in this way, set out to reveal that primary teachers have gaps in their knowledge which are detrimental to their practice, Golby et al. made a strong link between this 'deficit model' and the requirements outlined for improvement and a transmission-reception view of teaching and learning which is contrary to that based upon constructivism and therefore unrealistic and philosophically unsound. Golby et al. implied that such research, which may have involved misleading its participants as to the nature of the enquiry, was ethically improper. Golby et al. also pointed out that Mant and Summers failed to explore or to acknowledge what teachers 'can do' in favour of what they simply 'do not know', neglecting, for example, the role of metacognition and how teachers might actually prepare for what they have to teach. In an equally strong response, Summers and Mant (1995b) rejected all of the claims made against them, arguing forcefully and convincingly that good subject knowledge is an important prerequisite for good teaching, whatever the subject, that possessing good subject knowledge in no way implies a transmission-reception view of teaching and learning, and that Golby et al. misunderstood the role of subject knowledge in constructivist teaching. Summers and Mant also suggested that Golby et al. were somewhat confused and misguided about the nature of science and science education. Summers and Mant accused Golby et al. of 'careless reading', 'inaccuracies' in reporting, being 'out-of-touch' and 'unwilling' to consider any evidence which might challenge their own preconceptions of what science is and what constitutes effective teaching and learning. Careful reading of each work suggests

that while, on balance, Summers and Mant might appear to hold the moral high ground on most issues raised, Golby et al. were correct in drawing attention to what teachers 'can do', to the complexities of teaching and learning at all levels, and that alternative research strategies may be valuable. Clearly there remains a need for empirical and evidence-based studies of acquiring curricular expertise within the complex, interactive nature of knowledge types in classroom situations.

Acknowledging the considerable demands on primary school teachers to teach astronomy, and the fact that it was unlikely that existing primary teachers would have encountered basic astronomy in their own education, Parker and Haywood (1998) tackled the issue of primary teachers' knowledge and understanding of basic astronomical events as required by the *third version* of the National Curriculum for primary science (DfE/WO 1995) somewhat differently. Parker and Haywood focused attention on identifying and informing the essence of subject-related pedagogy including how learners learn and the difficulties they experience as well as the acquisition of subject knowledge and understanding essential to provide causal explanations of the phenomena investigated. This they viewed as integral to a constructivist approach to learning. Exploring the views of eighty nine undergraduate BEd and graduate PGCE trainees (mostly non-science specialists or generalists with varied backgrounds) and practising teachers (mostly science co-ordinators who had previous experience of teaching astronomy) from in and around Manchester, Parker and Haywood provided a metacognitive starting point for these adults to audit their own learning. First, participants were asked to produce annotated diagrams indicating causal explanations for day and night, the seasons and the phases of the Moon. Then, following teaching inputs and different learning experiences, all were asked to indicate whether or not their learning had evolved with respect to their initial ideas and to identify and record the factors which had made a significant contribution. Key features of the learning process identified by the participants included not only the need to be confronted with scientific ideas themselves, but also to be made explicitly aware of the factors which promote access to such ideas as well as the elements which are restrictive in the development of conceptual change and understanding. In particular, these included spatial awareness, two and three dimensional reasoning, language and communication and applying knowledge (c.f. Mant and Summers 1993).

5.5 Curricular expertise and the class teacher of the experimental group

At the time of this work, Jack, the class teacher of the experimental group, was a 36-year-old male with 15 years teaching experience including 6 as a science and ICT co-ordinator and 1 as acting deputy head teacher at two previous schools. He had been deputy head teacher at Big Town CPS for 7 years. Jack had A-levels in biology and physics, a degree in economics and law, and a Post Graduate Certificate in Education (PGCE) with science as elected specialism. By all accounts, Jack was an experienced primary school teacher and a science specialist (DfEE 1998; TTA 1998). Jack's curricular expertise in astronomy was determined more objectively using established tests and procedures where possible and comparing outcomes against published data. Jack participated willingly in all of the tests and procedures described.

5.5.1 Subject knowledge

As indicated earlier, Summers and Mant (1995a) reported the results of research carried out into primary teachers' knowledge and understanding of astronomy as it related to the National Curriculum for primary science at that time (DES/WO 1991b). In this, the second of their two studies, data collection was achieved by means of an individual survey questionnaire completed by an opportunity sample of sixty six practising primary teachers from schools in and around Oxfordshire and fifty four graduate trainees who had just completed their primary PGCE at Westminster College, Oxford. Most of the sample was female (88%), only a small number gave science as their main subject (12%), and teaching experience varied from 'nil' to 37 years. The survey questionnaire consisted principally of 57 statements arranged in 4 sections (see Appendix II). Each statement required mainly a 'true', 'false', 'not sure' or 'don't know' response. Each correct answer received one mark. Jack completed the survey questionnaire at home and in his own time, a departure from the 'test' conditions imposed by the original authors (changes in National Science Curriculum astronomy requirements between the *second* (DES/WO 1991b) and *third versions* (DfE/WO 1995) were of no consequence to the nature of the test itself.) Jack's section scores are provided below:

- Section A: Observations of the sky - 16/20 (80%);

- Section B: The day and night cycle, seasonal change, Moon's phases - 20/20 (100%);
- Section C: The scale of the Solar System 3/3 - (100%);
- Section D: The Solar System and Universe 34/34 - (100%).

Overall, Jack scored 53/57 (93%). Scores in the original survey ranged from 7 (12%) to 51 (89%) with a mean of 31 (54%). Section averages were provided as percentages: Section A - 51%, Section B - 58%; Section C consisted of only three questions; Section D - 61%. Jack's overall and individual section scores were extremely high by comparison. His low Section A score (Questions 7, 12, 14 and 17 answered incorrectly) was consistent with the original respondents and taken to indicate a slightly 'weaker' observational knowledge of the sky around him.

Just as the use of drawings and concept maps are useful for eliciting children's ideas in science, they are also useful for eliciting teachers' ideas too. General details can be found in White and Gunstone (1992). The combination of testing, drawing and concept mapping not only allowed Jack's knowledge and understanding of astronomy to be probed further and more deeply than any one technique alone, it also provided methodological triangulation. Jack's drawings of the Earth, the Sun, the Moon and other stars are provided as shown (Fig. 5.2). The benefits of methodological triangulation were fully discussed in Chapter 4. Accompanying the drawings, Jack's written comments included:

> *'The Earth is a planet – a body orbiting a star. Planets give out no light of their own. Planets are mainly rocky like the Earth or mainly frozen or gaseous like Jupiter.'*
>
> *'The Sun is a star, its energy coming from nuclear reactions in its core – reactions turning hydrogen into helium.'*
>
> *'The Moon is the Earth's only natural satellite. A satellite is a body orbiting a planet.'*
>
> *'A star is a ball of hot gas which gives out heat and light as a result of nuclear reactions deep within it. Stars are different colours: blue, white, yellow and red. Blue stars are the biggest, hottest and live the shortest. Red stars are the smallest, colder and live longest.'*

With respect to the Earth, the Sun and the Moon, Jack also indicated that *'The Sun is about one hundred times bigger than the Earth and the Earth is about three and a half times bigger than the Moon. The Earth is 12 756km in diameter'.*

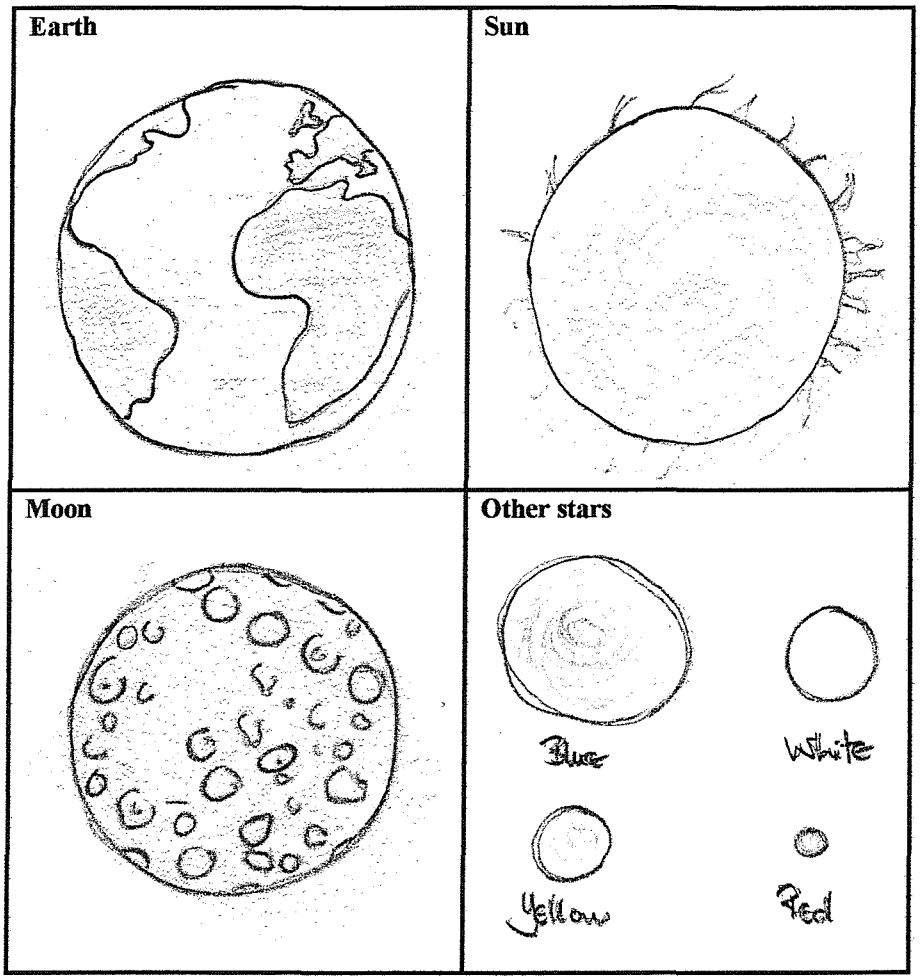


Fig. 5.2 Jack's drawings of the Earth, the Sun, the Moon and other stars

Jack's drawings of what causes day and night, the seasons to change and the phases of the Moon are also provided as shown (Fig. 5.3). Accompanying the drawings, Jack's written comments included:

> *'The Earth rotates once every 24 hours. It is day on the Earth's Sun-facing side, night on the side in shadow. Because the Earth rotates anti-clockwise, the Sun appears to rise in the east and set in the west.'*

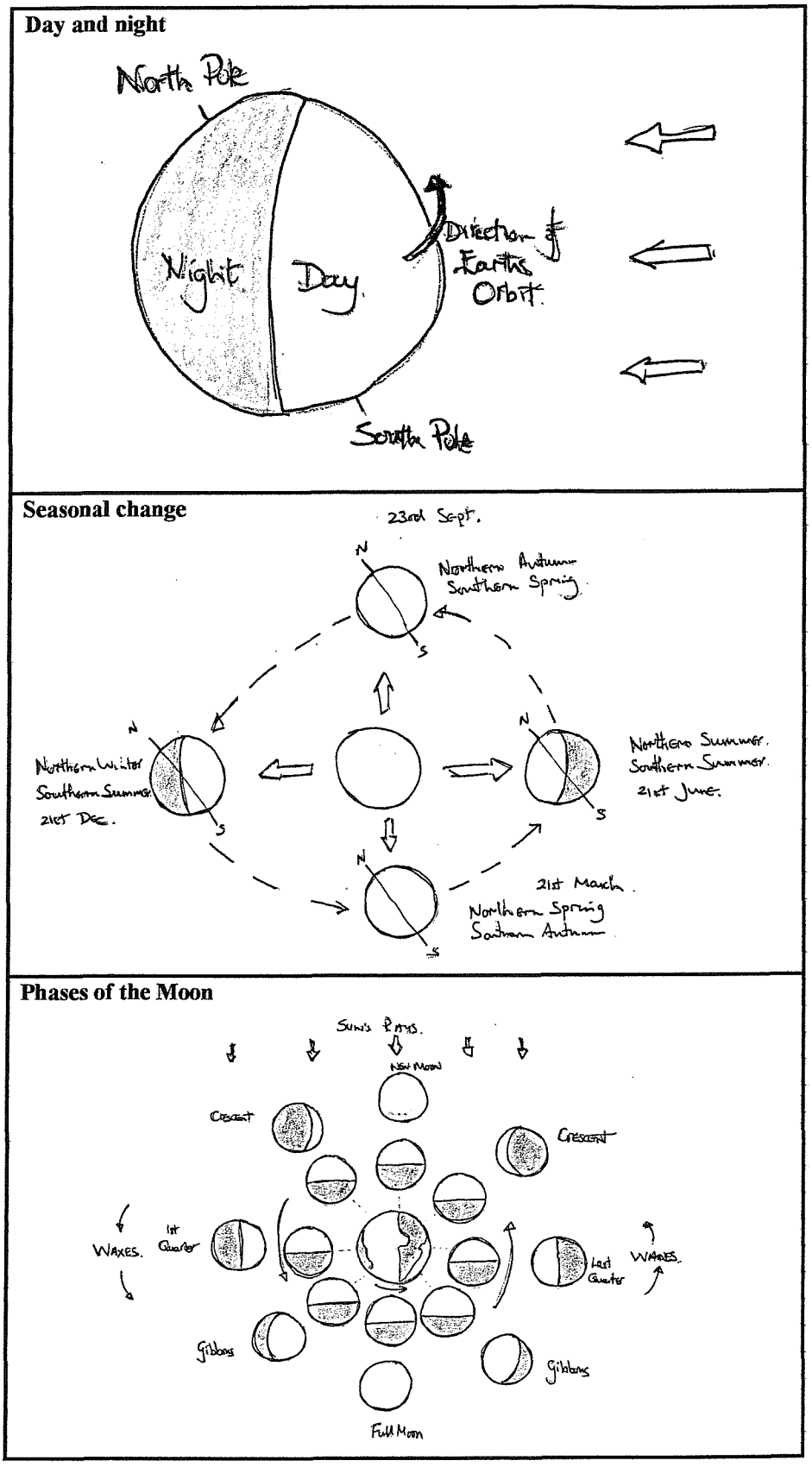


Fig. 5.3 Jack's drawings of Earth-Sun-Moon System phenomena

'If the spinning Earth was upright compared with its orbit around the Sun, day and night would be 12 hours all over. However, the Earth is not upright, it leans over 23.5° from the vertical. During the Earth's orbit, therefore, the North and South poles lean towards the Sun at different times. On about the 21st March, the Sun's rays shine straight down on the equator. On this day the length of day and night are equal everywhere and spring starts in the Northern Hemisphere. On about the 21st June, the Sun is directly above the Tropic of Cancer and the Northern Hemisphere has its longest day. On about the 21st September, the Sun is back above the equator and the Northern Hemisphere autumn starts. On about the 21st December, the Sun is overhead at the Tropic of Capricorn. The Northern Hemisphere has its shortest day in winter. Between summer and winter the day length gradually changes as the Earth moves around in its orbit. This changing day length and the changing angle of the Sun shining on the Earth causes the seasons.'

'Reflected sunlight from the Moon gives us moonlight. Half the Moon is always in sunlight. However, from Earth the actual amount of the Moon we see varies with the changing angle that the orbiting Moon makes with the Earth and Sun.'

Before producing his concept map of the Solar System and wider Universe (Fig. 5.4), Jack was provided with all of the words to use but in random order and asked to link the words with arrows and short explanatory statements or propositions in a way that made sense to him. This task was only partly completed.

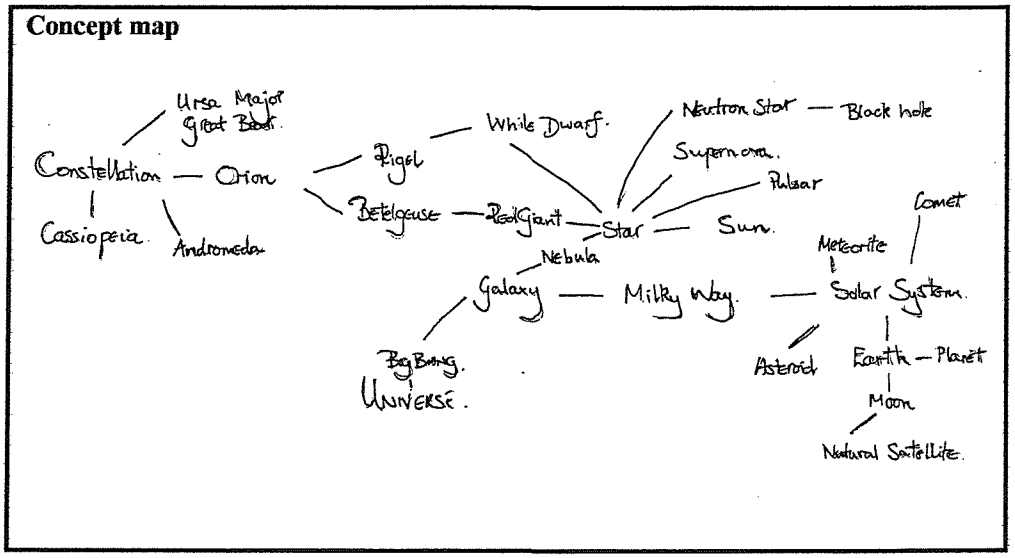


Fig. 5.4 Jack's concept map of the Solar System and wider Universe

Jack's drawings together with his written comments and concept map supported and extended the knowledge and understanding revealed in the test results. His use of scientific vocabulary to express his ideas was particularly noteworthy as was his knowledge and understanding of stars, stellar processes and the Earth-Sun-Moon System. Despite only partly completing the concept map, Jack's knowledge and understanding of the Solar System and wider Universe was clearly integrated and hierarchical. Having established Jack's subject knowledge and understanding of astronomy, the findings were discussed with him. Jack agreed to address his 'weaker' areas and was supplied with the PSTS support materials produced by Mant (1993). Jack and the author of this work also spent many hours talking about astronomy informally.

5.5.2 Subject-related pedagogy

As indicated earlier, Jack was, by all accounts, an experienced primary school teacher and a science specialist (though not necessarily an expert). Jack had taught astronomy on three previous occasions, each occasion lasting a full term or about 10 weeks. Jack indicated that he had taught primary astronomy before the introduction of a National Curriculum for primary science as it was an area of science that had always interested him anyway. Having occasionally observed Jack teach science throughout Phase 2 of the research presented here, it was clear from the nature of his practice that he demonstrated many of the general characteristics that a teacher sensitive to a constructivist view of learning might show in the classroom (e.g. Scott et al. 1992; Appleton and Asoko 1996). These included:

- a prior awareness of the ideas which children bring to learning situations;
- clearly defined conceptual goals and an understanding of how children might progress towards these;
- the use of teaching strategies which involved challenge to, or development of, the initial ideas of children and ways of making new ideas accessible to them;
- provision of opportunities for children to utilize new ideas in a range of contexts;
- provision of a classroom atmosphere which encouraged children to put forward and discuss ideas.

Jack's practice was also consistent with that praised by OFSTED (1998a). Jack's experience and commitment to effective teaching and learning were also evident in his classroom organization (Fig. 5.5). Jack's preference for a mixed seating arrangement which allowed for whole class, group and individual work was commendable. Children sat in mixed gender, mixed attainment groups with between two and six individuals per cluster of tables. The classroom was bright, airy, and spacious with clear lines of sight and no child had their back to the board at any time. Bright, bold and colourful display adorned the classroom walls. Jack and the children had access to two portable computers (Acorn platforms). The school's science resources were stored centrally in a cupboard outside Jack's classroom.

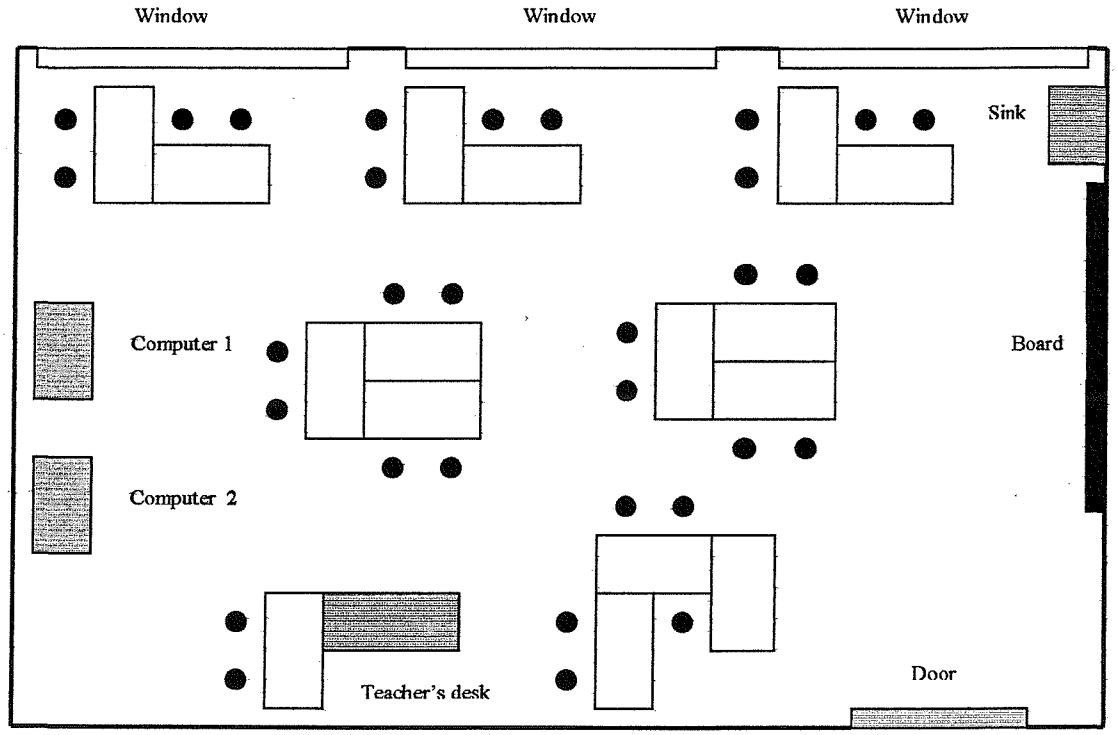


Fig. 5.5 Jack's classroom layout (simplified)

Jack's self-perceived competence to teach science within the National Curriculum of subjects and RE was assessed by adopting methods developed as part of the Leverhulme Primary Project (LPP) based at Exeter University (Wragg et al. 1989). Within the LPP, which considered the responses of 901 teachers in 152 primary schools throughout England and Wales, 77% of the respondents were practising class teachers, 23% were teaching and non-

teaching deputies and head teachers, 78% were female, and teaching experience varied from 1 to 30 years. Only 8% considered themselves science specialists though 13% had responsibility for science. When asked to state how competent they felt with existing knowledge and skills to teach the National Curriculum subjects and RE a clear picture emerged. English and mathematics were the subjects teachers felt happiest with while science appeared near the bottom of the list. In their reduced follow-up survey conducted two years later (Bennett et al. 1992), teachers still regarded themselves as most competent in teaching English and mathematics but science was elevated into third place. A similar study was also undertaken in Scotland with teachers following *National Guidelines for Environmental Studies 5-14* (SOED 1993) by Holroyd and Harlen (1996) reported similar results. Holroyd and Harlen, however, preferred to avoid the notion of perceived competence in favour of perceived confidence for the former is more usually 'inferred by others on the basis of observed performance' rather than determined by the individuals concerned. For the purposes of this work, the two can be considered together. Jack's responses are shown together with the LPP survey summary (Table 5.2). The difficulty index represented a mean

	Response category				Difficulty index (rank)	
	1	2	3	4	1991	1989
1. English	✓				1.25 (1)	1.22 (1)
2. Mathematics	✓				1.45 (2)	1.37 (2)
3. Science	✓				1.79 (3)	2.01 (8)
4. Physical education	✓				1.92 (7)	1.76 (6)
5. History	✓				1.86 (4)	1.62 (3)
6. Geography		✓			1.89 (5)	1.69 (4)
7. Technology		✓			2.40 (10)	2.62 (10)
8. Art			✓		1.91 (6)	1.71 (5)
9. Religious education			✓		2.10 (8)	1.85 (7)
10. Music				✓	2.58 (9)	2.44 (9)

Key to responses:
1 = I feel competent to teach this with existing knowledge and skills.
2 = I'd feel competent to teach this with some help from colleagues.
3 = I'd feel more competent to teach this with in-service help from colleagues.
4 = I don't feel competent to teach this without substantial in-service support.

Table 5.2 Jack's rank ordered perception of competence/confidence in the National Curriculum subjects and RE (from Wragg et al. 1989 and Bennett et al.1992)

competency category score based on the four response categories available. Selected aspects of the LPP survey with particular reference to science were subjected to detailed analysis and

reported separately (Carré and Carter 1990;1993). Within science itself, teachers were asked to respond to how competent they felt in helping children to achieve specific statements of attainment within the original attainment targets. Jack's responses are again shown together with the LPP survey summary (Table 5.3). Some titles and rank ordering were modified to match more closely the *third version* of the National Curriculum for primary science. As was the case in the LPP, it is important to note that Jack's responses are concerned with self-perception rather than objective tests of knowledge and teaching skills themselves and that focus was given to specific items within a complex science provision as a whole. It is also important to note that how Jack perceived his abilities and the nature and quality of the science he taught may be two entirely different things. Nevertheless, Jack perceived science as one of his curriculum strengths and astronomy, as the Earth and beyond, well within his range of knowledge and skills. Interestingly, Jack's responses show broadly similar patterns of competence to the LPP survey results overall despite having been collected some 5 years later.

	Response category				Difficulty index (rank)	
	1	2	3	4	1993	1990
1. Living things	✓				1.27 (1)	1.33 (1)
2. Processes of life	✓				1.40 (3)	1.46 (2)
3. The Earth and beyond	✓				1.47 (4)	1.47 (3)
4. Electricity/magnetism	✓				1.75 (8)	1.92 (9)
5. Forces	✓				1.68 (6)	1.80 (6)
6. Light	✓				1.82 (9)	1.87 (8)
7. Energy	✓				2.01 (10)	2.03 (10)
8. Materials		✓			1.37 (2)	1.54 (4)
9. Sound		✓			1.60 (5)	1.65 (5)
10. Genetics			✓		1.71 (7)	1.83 (7)

Key to responses:
1 = I feel competent to teach this with existing knowledge and skills.
2 = I'd feel competent to teach this with some help from colleagues.
3 = I'd feel more competent to teach this with in-service help from colleagues.
4 = I don't feel competent to teach this without substantial in-service support.

Table 5.3 Jack's rank ordered science-specific perception of competence/confidence in areas of the National Science Curriculum (from Carré and Carter 1990, 1993)

As indicated by Cleminson (1990), Smith and Neale (1989), Carré (1993) and Newton and Newton (2000), for example, personal beliefs and attitudes towards science can influence teacher and curriculum effectiveness and the ways in which science is considered and

presented. Jack's beliefs and attitudes towards science were assessed using the three imaginary teacher portraits prepared by Carré (1993) and which later appeared in Carré and Ovens (1994). The three portraits each contain different elements of Smith and Neale's five orientations towards science (see Table 5.1). While the choice and combination of teacher portraits is far from ideal, Teacher A was considered a problem solver (discovery and process oriented), Teacher B was considered a dominator or a verifier of scientific knowledge (didactic or content mastery orientation), and Teacher C was considered a personal and social constructivist (conceptual change or constructivist orientation). Presented with the three portraits (Table 5.4), Jack commented:

> *'I reject Teacher B and would argue strongly against that model of science teaching. I would advocate Teacher C's model of teaching and see myself as that sort of science teacher although I am also to some degree sympathetic to Teacher A's views.'*

By identifying with Teacher C, and to a certain extent Teacher A, Jack confirmed the constructivist orientation described earlier. Jack's beliefs and attitudes towards science were

Teacher A	Teacher B	Teacher C
Science is hands-on practical work, discovering the world around using all five senses. Initiatives are by children; they pose the questions and I encourage them to work independently. I refrain from giving them clues or science information to help their enquiry. I don't mind if the children use descriptive, non-scientific language.	Science is a collection of laws, an accurate and organized body of knowledge. I present content very clearly and direct practical work to prevent aimless activity. Essentially the children gather essential information and confirm for themselves what are already laid down as core concepts. We always use correct scientific language.	Science is a creation of human mind; truth is formed in the mind of the observer. I assume that children have extensive knowledge about their world and I help them apply and relate what they already know to new problems. I challenge them to reject, reshape or extend their ideas and to justify why they think the way they do. I encourage them to use scientific language when explaining.

Table 5.4 Teacher portraits (from Carré 1993 and Carré and Ovens 1994)

probed more deeply using the nature of science profile developed by Nott and Wellington (1993). Beginning with a 24-statement questionnaire (see Appendix III), Jack was required to respond to each statement using a Likert-type scale ranging from +5 (strongly agree) to –5

(strongly disagree). His individual statement scores were then collected together and presented in one of five pre-determined nature of science category tables. Before any nature of science profile was plotted, some scores were transformed by having their signs reversed and some statement scores were used twice. This treatment of scores was intended by Nott and Wellington to prevent any manipulation of outcome by the respondent. Total scores for the nature of science categories were finally plotted onto five corresponding nature of science category axes and joined with a line to produce a nature of science profile. This was then interpreted using the diagnostic information provided. Nature of science profiles produced in this way are intended to provoke thought and reflection rather than provide a valid measurement on an objective scale. Jack's nature of science profile is presented as shown (Table 5.5).

RP

Statement		Score
1	-	-3
3	-	-4
21	-	-1
12	+	0
14	+	-3
16	+	-2
18	+	-2
20	+	+1
Total		-14

ID

Statement		Score
5	-	+4
11	-	0
19	+	+1
23	+	+1
Total		+6

CD

Statement		Score
2	-	+5
3	-	-4
6	-	-3
8	-	+5
13	+	-2
16	+	-2
18	+	-2
22	+	+4
Total		+1

PC

Statement		Score
7	-	0
9	-	-1
17	-	-3
24	-	-1
15	+	-2
Total		-7

IR

Statement		Score
10	-	+1
21	+	+1
4	+	+3
12	+	0
14	+	-3
Total		+2

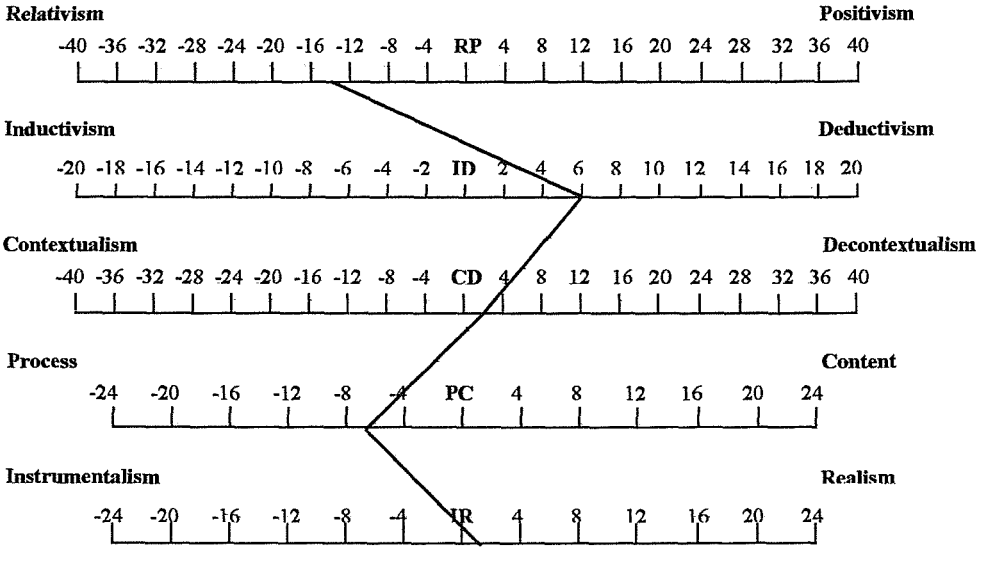


Table 5.5 Jack's nature of science profile (from Nott and Wellington 1993)

Despite a slight tendency towards relativism, deductivism and process, Jack's nature of science profile was largely balanced and showed no strong inclinations one way or the other on any of the category axes. His profile appeared to support his comment on the teacher portrait exercise. Nott and Wellington (1995) later acknowledged that this method probes only academic or subject knowledge rather than knowledge-in-action or subject-related pedagogy and that a better analysis of science orientation might involve critical classroom incidents as case experiences.

5.6 The children

In Chapters 1 and 4, it was noted that unlike their true experimental counterparts, the random selection of schools and classrooms in quasi-experimental designs is not always possible and that the experimental and control groups are not always formed as a result of randomization or matching (Campbell and Stanley 1963). Experimental and control groups can, however, be compared in terms of their equivalence. The information required for equivalence testing was obtained mostly at the time of the children's first interviews or Phase 3 of the overall design (pre-experimental treatment) and considered age, socio-economic background, intellectual maturity, science interest and curiosity, and informal science experiences. Further information for the purpose of test-retest reliability was obtained at the time of the children's second interviews or Phase 5 (post-experimental treatment). To retain clarity and readability within the main body of the text, only summaries of inferential analyses are included. For a full treatment of all quantitative data, including inferential analyses associated with the research findings presented in Chapter 6, see Appendix VIII.

5.6.1 Age

Children change rapidly throughout the primary years with significant differences in their intellectual, physical, social and emotional development measured in months rather than years (Child 1997). Within any given class of children, chronological age can be a significant and sometimes limiting factor on academic 'performance' or attainment however that is measured. Summer-born children (May to August) who are the youngest in their year groups, for example, often appear to 'perform' significantly less well in certain curriculum areas, notably English and mathematics which have received most attention, than their autumn-born (September to December) peers. Summer-borns are often also over-represented

in lower sets or bands (Jinks 1964; Pidgeon 1965) and in groups with special educational needs (Pumfrey 1975; Wilson 2000) as well as poorer attenders (Carroll 1992). Several explanations have emerged to account for these observed birthdate effects. Two of particular importance include:

- length of schooling which is, of course, shorter for summer-borns (Pidgeon and Dodds 1961; Fogelman and Gorbach 1978; Woodhead 1986);
- age-position effects associated with age on entry whereby the youngest children in any year group are disadvantaged regardless of their season of birth or length of schooling (Bookbinder 1967; Choppin 1969; Williams et al. 1970; Kinard and Reinherz 1986; Shepard and Smith 1986).

Both have proved difficult to isolate and study, partly due to the nature of school entry systems (e.g. annual, biannual or termly) and other variables including socio-economic background, but probably combine to the disadvantage of those most likely to be affected (e.g. stress and anxiety associated with very young children's lack of developmental readiness for the formalities of school and the school curriculum reinforced as a result of the lack of opportunities to learn through play, low self-esteem associated with difficulties integrating with established peer groups, and teacher expectancy during which younger children are considered immature and less able than their older classmates). Birthdate effect trends usually continue throughout the secondary years of schooling and into higher education (Russell and Startup 1986). Recent studies conducted within the UK have found significant birthdate effects associated with performance in science, particularly in Key Stage 1 national tests (before they were discontinued) and GCSE results (Giles 1993; Sharp et al. 1994; Massey et al. 1996). The vertical grouping of children in the experimental and control groups required that their chronological ages were reported in detail. Ages were determined to the nearest month from class registers at the time of first and second interviews.

(a) Age statistics associated with mean

Age statistics associated with the mean for both the experimental and control groups are summarized in Table 5.6. The observed difference in the mean ages of the experimental and control groups at first interview, 124.9 months (10 years 5 months) and 124.1 months (10

years 4 months), was not significant (t=0.44, df=60, p=0.66; normality for experimental group D_x=0.116, p>0.15; normality for control group D_c=0.137, p=0.140; F-ratio=1.06). Gender differences in both groups at first interview and the observed differences in the mean ages in both groups between first and second interviews were not significant.

		Experimental group				Control group			
		n	Mean	Range	SD	n	Mean	Range	SD
First interview	Class	31	124.9	112 - 135	6.73	31	124.1	112 - 135	6.54
	Boys	17	126.3	117 - 135	6.92	17	124.9	112 - 132	4.73
	Girls	14	123.1	112 - 131	6.30	14	123.2	112 - 135	8.33
Second interview	Class	31	127.9	115 - 138	6.73	31	127.1	115 - 138	6.54
	Boys	17	129.3	120 - 138	6.92	17	127.9	115 - 135	4.73
	Girls	14	126.1	115 - 134	6.30	14	126.2	115 - 138	8.33

Table 5.6 Age statistics associated with mean (months)

(b) Age statistics associated with median

Unlike means, medians are less affected by extreme values within a distribution and consequently not distorted as a representative average. This is particularly relevant here. Almost all median ages were greater than their corresponding means. Age statistics associated with the median for both the experimental and control groups are summarized in Table 5.7. There were no observed or significant differences in the median ages of the experimental and control groups, 126.0 months (10 years 6 months) and 126.0 months (10 years 6 months), at first interview (W_x=1011.0, W_c=942.0, p=0.632).

		Experimental group				Control group			
		n	Median	Q1	Q3	n	Median	Q1	Q3
First interview	Class	31	126.0	119.0	131.0	31	126.0	119.0	128.0
	Boys	17	128.0	118.5	133.0	17	126.0	123.0	127.5
	Girls	14	123.0	118.5	130.0	14	125.5	115.3	130.3
Second interview	Class	31	129.0	122.0	134.0	31	129.0	122.0	131.0
	Boys	17	131.0	121.5	136.0	17	129.0	126.0	130.5
	Girls	14	126.0	121.5	133.0	14	128.5	118.3	133.3

Table 5.7 Age statistics associated with median (months)

Age statistics associated with the median are easier to visualize in the form of boxplots which clearly show age range, upper and lower quartiles, and median values (Fig. 5.6). Age similarities between the groups are immediately obvious. Gender differences in both groups at first interview and the observed differences in the median ages in the experimental and control groups between first and second interviews were not significant.

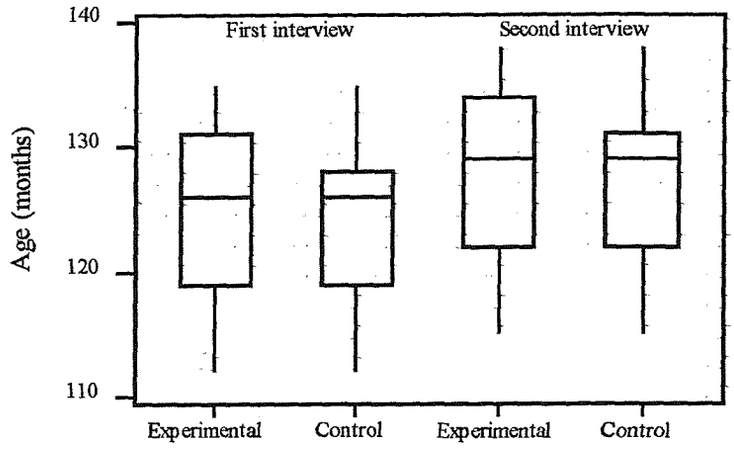


Fig. 5.6 Boxplots of age statistics associated with median

5.6.2 Socio-economic background

For work of this type, the Office of Population Censuses and Surveys (OPCS) classification of social class and socio-economic group based upon 'occupation of father' is the classification most widely used (OPCS 1991) and this is adopted here (Table 5.8). While 'occupation of father' is not the only indicator of class status, and may not be the best, it has proved to be relatively robust. As many of the children in the experimental and control groups were known to live at home with only one parent (e.g. a mother who was the principle salary earner, a non-parental guardian), there are obvious disadvantages to this system. The rigidity of 'occupation of father' was therefore relaxed to include 'head of household' (Hannagan 1982; Hill 2001). 'Head of household' classifications are particularly popular with the Institute of Practitioners in Advertising (IPA) and Market Opinion Research

International (MORI). A review of available literature suggests that there has been no systematic, widespread and longitudinal monitoring of socio-economic background and educational attainment at primary level within the UK since the early Child Development Study reports by Fogelman and Goldstein (1976) and Fogelman et al. (1978). Findings from the Child Development Study, whose subjects were all the surviving children born in one week in March, 1958, showed that social class (and family size) were strongly associated with large differences in reading and mathematics attainment at age 7 and 11 (n=16 000). Children whose fathers were in non-manual occupations or social classes I, II and IIIN generally scored higher on reading and mathematics scores than children whose fathers were in manual occupations or social classes IIIM, IV and V and this trend continued to school leaving age at 16. Despite a lack of studies of this type, there seems little reason to suspect anything different today. According to Reid (1997), for example, while even the National Curriculum has, since its introduction, attempted to establish for all children, regardless of socio-economic background, an entitlement to equal opportunity to a number of areas of learning, including primary science, the idea that access to, interest in and motivation to learn are equally available to all is somewhat naïve. Socio-economic background is also considered here in terms of free school meals provision.

Class category	General description
I	Professional occupations
II	Managerial, employer and technical occupations
IIIN	Skilled non-manual occupations
IIIM	Skilled manual occupations
IV	Partly skilled occupations
V	Unskilled occupations
Other	Residual and inadequately described groups

Table 5.8 Modified OPCS social class categories and socio-economic groups (source OPCS 1991)

(a) Social class

'Head of household' information was obtained sensitively and confidentially on behalf of the author of this work by the class teachers of both the experimental and control groups with the support of the head teacher of Big Town CPS. Social class was then determined using

Standard Occupational Survey criteria (OPCS 1990a, b). Because of the lack of clarity and detail in some responses, social class determination was far from rigorous but satisfactory for comparative purposes. Given the ethical nature of the information collected, and for the purposes of this work, social class categories were not assigned to individual children and no attempt was made to pursue any link between social class and gender or attainment. It was found that OPCS social classes IV and V could not be separated easily and these were combined. The findings are presented as shown (Table 5.9).

		n	I(A)	II(B)	IIIN(C1)	IIIM(C2)	IV/V(D)	Other(E)
Experimental group	Class	31	2	5	4	6	8	6
	(%)		(6.5)	(16.1)	(12.9)	(19.4)	(25.8)	(19.4)
Control group	Class	31	1	3	3	11	5	8
	(%)		(3.2)	(9.7)	(9.7)	(35.5)	(16.1)	(25.8)

Table 5.9 Socio-economic background (IPA and MORI categories also provided)

Statistical analysis suggested that the observed difference in social class profile between the experimental and control groups was not significant (test statistic D_{xc}=0.129, Critical value K_D=0.345 for α=0.05). Social class categories are more easily visualized in a compound bar chart (Fig. 5.7).

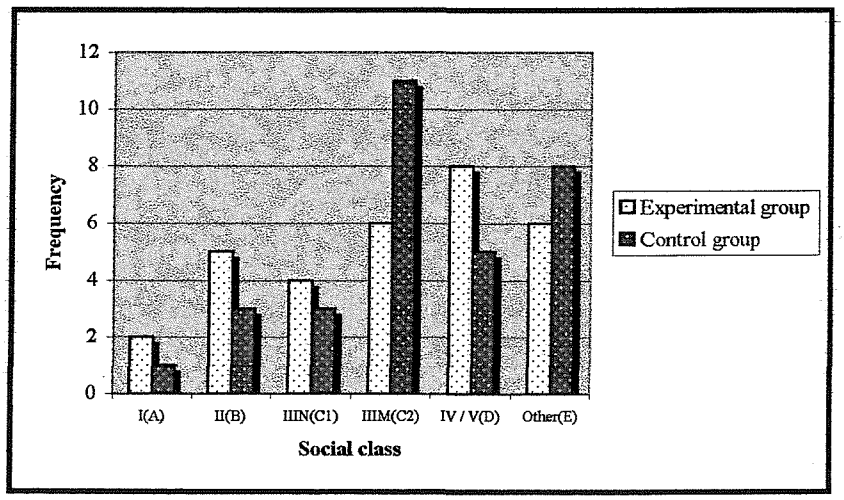


Fig. 5.7 Socio-economic background

OPCS categories I, II and III(N) are frequently taken to represent the 'middle classes' and categories III(M), IV and V the 'working classes'. The 'middle class' and 'working class' backgrounds of the experimental and control groups are presented as shown (Fig. 5.8). Statistical analysis suggested no significant association between the experimental group, the control group and class type (χ^2=0.941, df=1, p=0.332).

	Middle class	Working class	Total
Experimental group	11 (9.4)	14 (15.6)	25
Control group	7 (8.6)	16 (14.4)	23
Total	18	30	48

Fig. 5.8 Chi-square test of independence in social class

Interestingly, further analysis suggested that observed differences between the social class profiles of the experimental and control groups and national data from the General Household Survey (GHS) of 1996/1997 (ONS 1998) were not significant (social class structure of the UK population based on GHS sample: I = 4%, II = 15%, IIIN = 34%, IIIM = 21%, IV = 19%, V = 6%; test statistic D_{xn}=0.090; test statistic D_{cn}=0.230; critical value K_D=0.245 for α=0.05; all figures recalculated to 100% on the basis of no 'other' category). The GHS is a continuous survey running since 1971 and is based each year on a sample of the general population resident in households in the UK. The 1996/1997 survey, conducted between April, 1996, and March, 1997, interviewed over 17 000 people aged 16 and over in nearly 10 000 homes. For the UK as a whole, the 1996/1997 GHS survey estimated 53% of the population 'middle class' and 47% 'working class' (figures neglect regional variation).

(b) Free school meals

In educational research, a useful indicator of socio-economic background can be obtained from the number of children receiving free school meals. Free school meals are generally

provided to children from low income households and those households receiving social benefit payments. The percentage of children eligible for free school meals is known to correlate with children's prior and actual attainment at school and is used in current National Benchmark data for all schools in England (e.g. in OFSTED reports). The numbers of children receiving free school meals in the experimental and control groups is presented as shown (Fig. 5.9). Statistical analysis suggested no significant association between experimental group, control group and free school meals (χ^2=0.413, df=1, p=0.520).

	Free	Not free	Total
Experimental group	7 (6.0)	24 (25.0)	31
Control group	5 (6.0)	26 (25.0)	31
Total	12	50	62

Fig. 5.9 Chi-square test of independence in free school meals

5.6.3 Intellectual maturity

The Goodenough-Harris measure of children's intellectual maturity from drawings of the human figure is derived from a brief, non-verbal test that is relatively easy to administer, score and interpret by non-psychologists (Harris 1963). Though popularly referred to as the 'Draw-a-Man' test, children are actually required to draw pictures of a man and a woman so it will be referred to here as the Goodenough-Harris 'Draw-a-Man/Draw-a-Woman' test or simply G-H test for short. The G-H test itself, though nearing the end of its identified life-span, is still widely used today and has even found limited application beyond the Western culture within which it was first designed (e.g. Phatak 1961; Mehryar et al. 1987). The human figure is one of the first and most favourite things to be drawn by children who strive to represent it as it appears visually, and human figures remain one of the most frequently chosen topics to draw into adolescence. Excellent reviews of the nature, purpose, development and meaning of children's drawings of the human figure are provided by Kellogg (1970), Goodnow (1977) and Cox (1993). The G-H test is based on the assertion that children's drawings of the human figure appear to increase as their mental rather than

chronological age increases regardless of previous academic experiences or art training (Goodenough 1926).

The G-H test was designed for use with children between the ages of 3 and 15 (though it is most reliable between the ages of 5 and 11). Two measures of intellectual maturity are available with the test, one based on a point scale, the other based on a quality scale. The point scale is the most precise but also the most time consuming to score. The Draw-a-Man point scale consists of 73 items which are credited (0 or 1) on the basis of presence or absence of a body part or attention to specific detail. The Draw-a-Woman point scale consists of 71 items which are credited similarly. Single raw scores for each drawing are obtained by simply adding all credited points. Raw scores are converted to standard score equivalents with a mean of 100 and a standard deviation of 15 using separate tables for the drawings of Men and Woman produced by boys and girls. Standard scores on the Man and Woman drawings can be averaged directly. The result was considered by Harris a more reliable estimate of each child's maturity than his or her score on either drawing alone. The quality scale is a series of 12 drawings representing increments in intellectual maturity. The quality scale presents the researcher with a rapid scoring system which involves comparing each child's drawing against the twelve model drawings, accuracy in detail and proportion increasing accordingly. Separate quality scales are provided for Man and Woman drawings. Again, raw scores are converted to standard score equivalents with a mean of 100 and a standard deviation of 15 using separate tables for Man and Woman drawings produced by boys and girls. Standard scores on the Man and Woman drawings can be averaged directly. Since the first appearance of the G-H test, its administration, the standardization of the Man and Woman point scales, the quality scale, the test ceiling, sex differences, validity (criterion), reliability (test-retest, inter-rater, intra-rater, interim), cultural variables, and its use in different contexts have all been reviewed extensively. Perhaps the most objective and detailed reviews and summaries of findings were provided by Burros (1972) and Scott (1981). While the G-H test might be used with some confidence, it may not always fully reflect a child's true ability. Children interested in advanced figures, experimenting with 3D representation, and profiling, for example, may not score as highly as they would do otherwise. Cultural and societal issues associated with dress codes and body part taboos may also be important.

It is important to note that the G-H test measures intellectual maturity and not intelligence. The nature of intelligence and how it might be measured, if at all, has since the earliest days of research in cognitive psychology resulted in considerable disagreement among experts in the field. In broad and general terms, intelligence is often regarded as an individual's capacity to learn, a capacity which might be measured by that individual's singular ability to deal with abstractions and to solve problems – often in the form of answering questions on tests of intelligence. In such cases, a measure of intelligence yields a single index called an intelligence quotient or IQ. In conventional studies, it is widely assumed that a singular faculty of intelligence as measured and revealed by an IQ test does not change much with age, education, training or experience and is a relatively fixed attribute of an individual. Interestingly, children's beliefs about their own intelligence can influence their performance in the classroom (Cain and Dweck 1989). Children who maintain that intelligence is something that can be developed and improved believe that their skills and other abilities can be improved with practise and mastery and failure to perform as expected is something that can be addressed. Children who maintain that intelligence is a fixed entity believe that they are as they were born and that failure to perform as expected leads to feelings of helplessness. A wide variety of tests which purport to measure IQ, revealing both 'g' or 's' factors, now exist and are still in use throughout the world (Sattler 1982). The interpretation and significance of what IQ test results mean and how they are used remains, however, problematic and a source of considerable concern. The recent and controversial views of Herrnstein and Murray (1996), who attempted to assign problems associated with class structure and ethnic differences in intelligence and education, crime, unemployment, welfare, child neglect, poverty and illigitimacy to variations in IQ across the United States serves as possibly the best known example. The concept of a single measure of intelligence as described is for some authors completely unsatisfactory. The emergent theory of Multiple Intelligences (MI theory) proposed by Gardner (1983), for example, has received considerable attention in recent years not least of all for its educational implications (Gardner and Hatch 1989; Gardner 1993). According to Gardner, MI theory 'pluralizes the traditional concept' of intelligence in favour of seven cognitive competences described in terms of a set of abilities, talents or mental skills. Gardner's intelligences include linguistic, logical-mathematical, spatial, bodily-kinesthetic, musical, interpersonal and intra-personal and each 'entails the ability to solve problems or fashion products that are of consequence in a particular cultural setting or community'. In a rival to MI theory, Sternberg (1989) has proposed three components of intelligence, componential, experiential and contextual, each

of which also reflect intelligent behaviours. Interestingly, Harris (1963) described intellectual maturity as the ability to form concepts of increasingly abstract character. At the time of writing, Harris believed intellectual or cognitive activity to require the ability to perceive (i.e. to discriminate likenesses and differences), the ability to abstract (i.e. to classify objects according to such likenesses and differences) and the ability to generalize (i.e. to assign an object newly experienced to a correct class, according to discriminated features, properties or attributes). Taken together, these three factors comprise a simple view of concept formation. Harris contended that the idea of intellectual maturity which appeared to embrace several abilities associated with an individual's concepts of the human figure, and which might be taken as an index or sample of their conceptual maturity as a whole, was an improvement over the singular notion of intelligence popular at that time. Indeed, the G-H test developed and described by Harris might be considered to reflect, in part, abilities within the logical-mathematical and spatial intelligences of Gardner's MI theory, though this suggestion has never been validated. Whether tapping into logical-mathematical and spatial intelligences or not, measures of intellectual maturity derived from the G-H test may be particularly relevant to science education and astronomy where concept learning and spatial associations are important. The study by Arnold et al. (1995) draws attention to just this issue (see Chapter 4). Harris pointed out that while the G-H test does not yield a score that is identical with IQ as determined by other such tests, correlation between intellectual maturity and general intelligence is substantial for children of primary age (more so in verbal and conceptual abilities than in temperament, personality or affective factors). Harris advised caution in using intellectual maturity as a proxy for IQ, however, particularly where important decisions were to be made over a child's education. That said, standard scores of 115 or more (percentile rank 84+) and 85 or less (percentile rank 16-) might still be taken as a general guide to identifying high and low attainers (representing a mean score of 100 +/- 1 standard deviation of 15 in relation to their own age group and sex) and standard scores of 130 or more (percentile rank 98+) and 70 or less (percentile rank 2-) might also be taken as a general guide to identifying gifted children and those with particular learning difficulties (representing a mean score of 100 +/- 2 standard deviations of 15 in relation to their own age group and sex).

The G-H test was administered here in accordance with the manual (Harris 1963). Children in both the experimental and control groups were introduced to the nature of the task as a whole class activity at first and second interviews. Drawings were collected at first and

second interviews to assess test-retest reliability. On each occasion, drawings were produced individually and completed within 1 hour. The children were reminded to draw the best man and woman they could and not just a head and shoulders. All drawings were subsequently scored and raw scores converted to standard score equivalents on the point scale. Inter-rater reliability using the quality scale was determined from test data collected at first interview only. Quality scale measurement is less sensitive and precise than point scale measurement but considerably less time consuming to score. The involvement of a second rater, a female lecturer in education known to the researcher but unfamiliar with the details of the study, helped to evaluate and minimize potential bias associated with subjectivity, gender and group preference effects. Examples of the range of drawings produced are presented as shown (Figs. 5.10a, b).

(a) Point scale measurement

Intellectual maturity statistics (point scale) for both the experimental and control groups are summarized in Table 5.10 (see also Appendix IV for short scoring guides and standard score conversion details for Man and Woman drawing point scales and raw data). The observed difference in the mean class intellectual maturity point scores of the experimental and control groups at test, 100.2 and 98.9, was not significant ($t=0.56$, $df=60$, $p=0.58$; normality for the experimental group $D_x=0.064$, $p>0.15$; normality for the control group $D_c=0.117$, $p>0.15$; F-ratio=1.13). No significant gender differences were observed in either group and test-retest reliabilities for both groups were acceptable.

		Experimental group				Control group			
		n	Mean	Range	SD	n	Mean	Range	SD
Test	Class	31	100.2	83 - 122	8.96	31	98.9	80 - 117	9.53
	Boys	17	100.5	83 - 122	10.11	17	98.6	80 - 117	9.93
	Girls	14	99.9	83 - 114	7.71	14	99.3	81 - 115	9.38
Retest	Class	31	100.7	87 - 115	6.79	31	98.2	82 - 115	8.55
	Boys	17	101.3	88 - 115	7.69	17	98.2	82 - 114	9.21
	Girls	14	99.9	87 - 111	5.70	14	98.1	85 - 115	8.01

Table. 5.10 Intellectual maturity statistics (point scale)

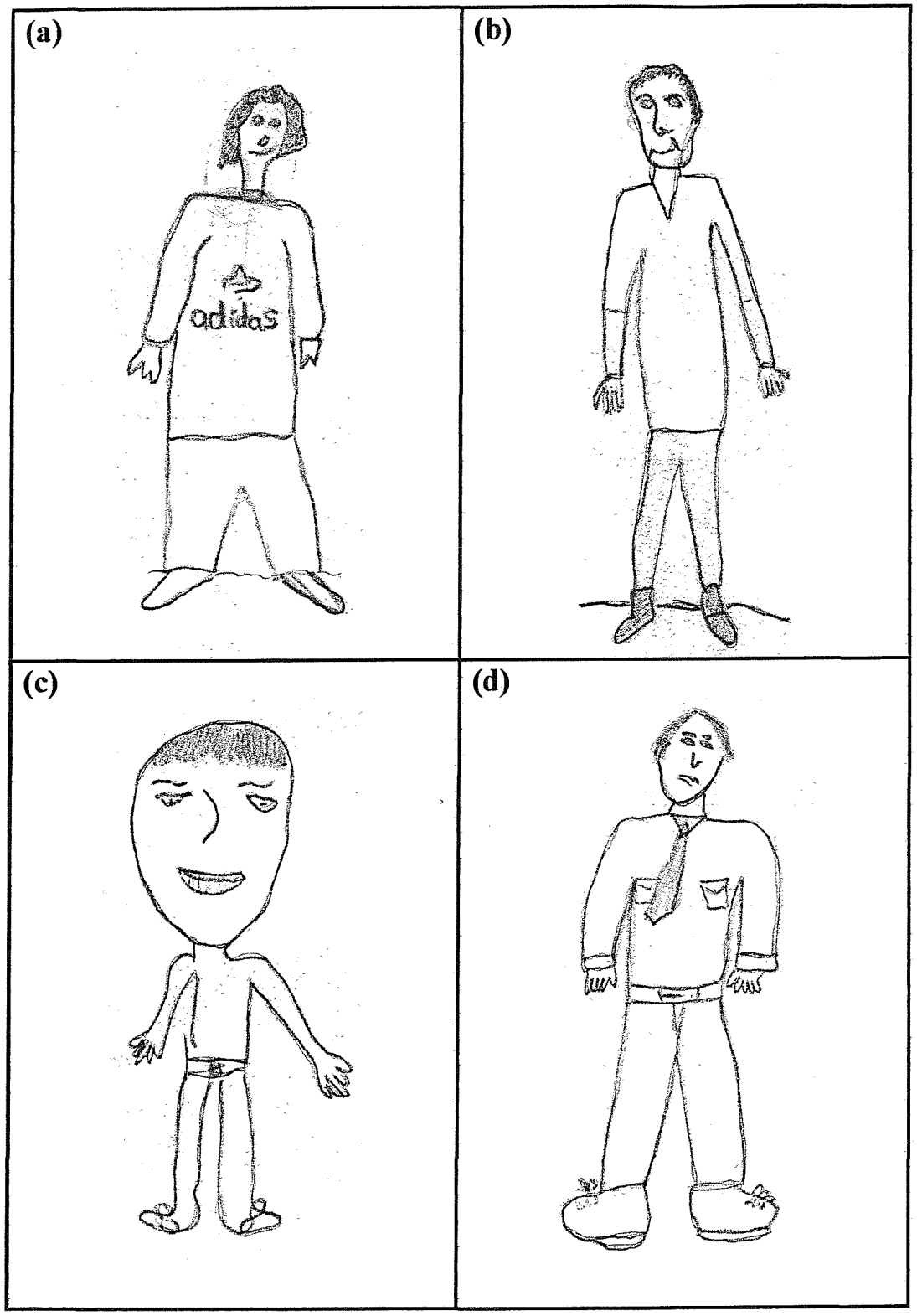


Fig. 5.10a Range of human figure drawings in the G-H test - Man (Harris 1963)

(a) Child 1: Adam (point score 87, raw quality score 5).
(b) Child 12: Liam (point score 116, raw quality score 7).
(c) Child 18: Alice (point score 90, raw quality score 5).
(d) Child 27: Jessica (point score 117, raw quality score 8).

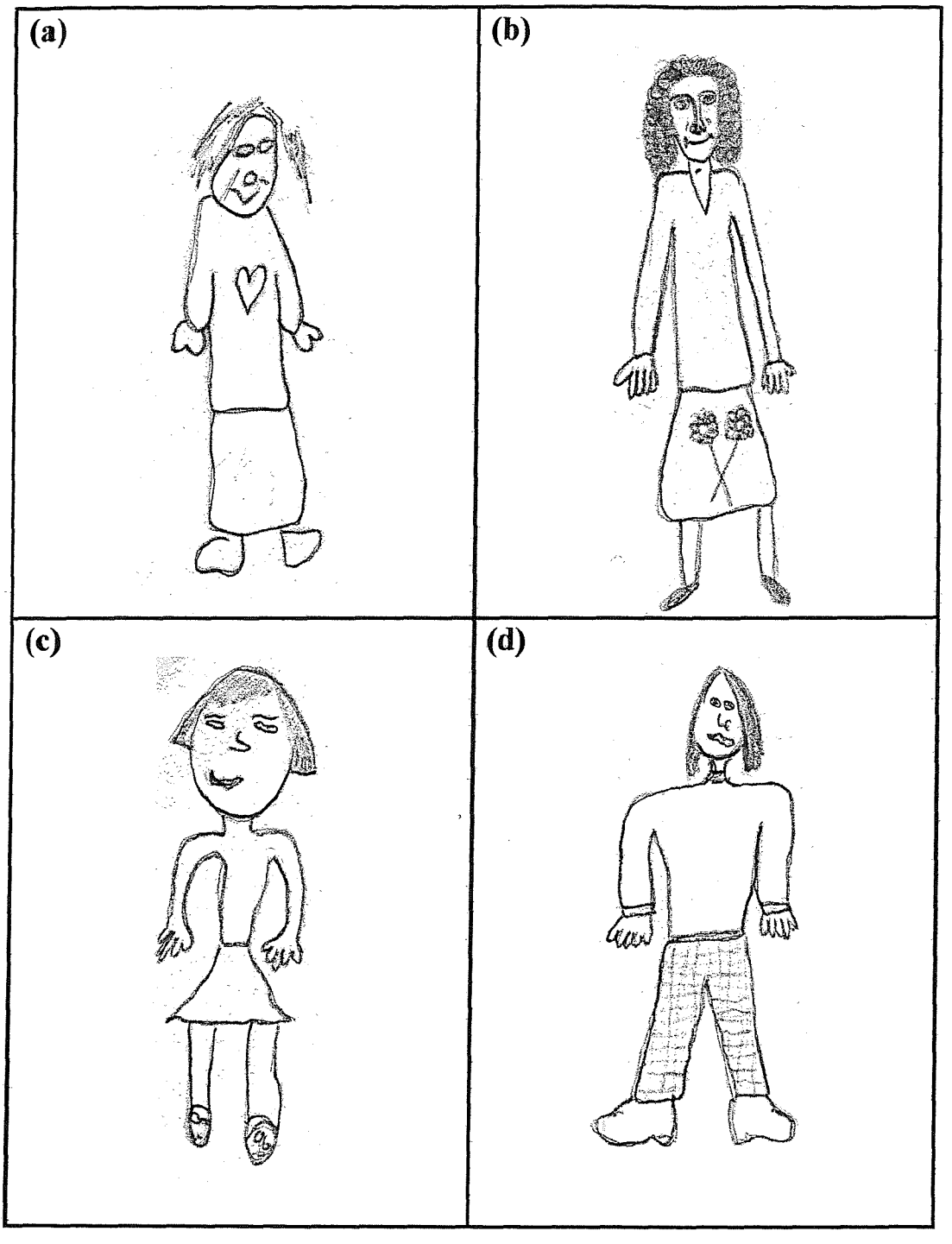


Fig. 5.10b Range of human figure drawings in the G-H test - Woman (Harris 1963)

(a) Child 1: Adam (point score 78, raw quality score 4).
(b) Child 12: Liam (point score 127, raw quality score 8).
(c) Child 18: Alice (point score 94, raw quality score 5).
(d) Child 27: Jessica (point score 110, raw quality score 7).

(b) Quality scale measurement

Intellectual maturity statistics (quality scale) for both the experimental and control groups are summarized in Table 5.11 (see also Appendix IV for raw data). Quality scales were used here to measure inter-rater reliability at test. It is interesting to note that in all cases at test, mean scores obtained using the quality scale were less than the mean scores obtained using the point scale. This reflects the lower precision of the quality scale test measure. Inter-rater reliability for both groups was acceptable. The observed difference in mean intellectual maturity quality scores of the experimental group between Rater 1 and Rater 2, 98.0 and 97.1, was not significant (matched $t=1.92$, $p=0.065$; normality of differences between experimental group and rater $D_{xd}=0.123$, $p>0.15$; F-ratio=1.04) and the correlation between pairs of data was good (Pearson's $r=0.946$, $p=0.000$). The observed difference in mean intellectual maturity quality scores of the control group between Rater 1 and Rater 2, 96.8 and 97.3, was not significant (matched $t=-0.95$, $p=0.348$; normality of differences between control group and rater $D_{cd}=0.058$, $p>0.15$; F-ratio=1.07) and the correlation between pairs of data was also good (Pearson's $r=0.938$, $p=0.000$).

		Experimental group				Control group			
		n	Mean	Range	SD	n	Mean	Range	SD
Rater 1	Class	31	98.0	82 - 122	8.06	31	96.8	80 - 112	8.13
	Boys	17	98.8	82 - 122	9.55	17	97.6	84 - 112	8.19
	Girls	14	97.1	89 - 111	5.99	14	95.9	80 - 107	8.25
Rater 2	Class	31	97.1	82 - 122	7.92	31	97.3	80 - 112	7.86
	Boys	17	97.7	82 - 122	9.04	17	97.8	84 - 112	7.82
	Girls	14	96.4	84 - 107	6.57	14	96.6	80 - 112	8.15

Table 5.11 Intellectual maturity statistics (quality scale)

5.6.4 Science interest and curiosity

According to Ramsden (1998), attitude research in science education has become noticeably less common from a peak of activity witnessed in the 1970s despite increasing evidence that attitude seems to feature prominently in exerting a profound influence in 'levels of

engagement' with the subject. Aspects of attitude research in science which have contributed towards this neglect were identified earlier by Gardner (1975a, b, 1996) and linked to:

- the lack of a theoretical construct or attempt to conceptualize the construct to be measured in terms of exactly what is being explored (e.g. issues associated with definition and meaning including what is actually meant by 'children's attitude towards science');
- research instrument design and methodology (e.g. issues associated with confusion of variables in terms of dimensionality - can attitude really be considered a single, uni-dimensional trait?);
- the lack of relationships between treatment and outcome (e.g. establishing cause and effect).
- the nature and purpose of the research (e.g. can anything be done about attitudes towards science?).

While it is not possible to give a complete treatment of all of these issues here, largely due to the extensive field of attitude research as a whole, a relevant overview is provided.

Attitudes are now widely regarded as having orientation (e.g. towards science), direction (e.g. like or dislike of science or a particular part of a science curriculum), magnitude (e.g. degree of like or dislike) and intensity (e.g. strength of feeling). Most authors provide two useful attitude categories with which to work: attitudes towards science (e.g. interest, curiosity, satisfaction, enjoyment) and scientific attitudes (e.g. respect for evidence, open-mindedness, perseverance, tolerance of the views of others, honesty). In this study, attitudes towards science are the focus, and interest and curiosity are considered in detail.

Attitudes have been defined in different ways depending on the field of research. Bruner (1966) referred to attitudes simply as 'the will to learn', Scott (1968) as 'enduring organizations of motivational, emotional, perceptual and cognitive processes with respect to some aspect of an individual's world', Gagné (1985) as 'internal states that influence an individual's choices of action', and Oppenheim (1992) as 'states of readiness, a tendency to act or react in a certain manner when presented or confronted with certain stimuli'. What all definitions have in common is a strong affective component. While attitudes are generally

considered affective responses to stimuli, and fall within the affective domain, the role of cognition and cognitive processing cannot always be ruled out (Eysenck and Keane 1995). In science education, Gardner (1975a) defined attitudes as 'the emotional reactions of individuals towards science' or in more detail as 'a learned disposition to evaluate in certain ways objects, people, actions, situations or other propositions involved in the learning of science'. Most attitude towards science surveys have looked at the relationship between attitude and some other variable (e.g. gender, achievement, intelligence, personality, socio-economic background, religion, culture and schooling) and most have been sufficiently inconclusive so as to fail to yield clear evidence to support any clear generalizations (Gardner 1975a; Gauld and Hukins 1980; Schibeci 1984; Crawley and Koballa 1994). In most cases, the relationship between attitude and some other variable has been difficult to disentangle (e.g. whether attitude influences achievement or vice versa).

For the attitudes towards science research presented here, the generic science curiosity measure developed by Harty and Beall (1984) for American fifth graders (Year 5/6 equivalent) was considered suitable and selected for use. This was modified to include English spellings throughout. (Since undertaken, an alternative general attitude to science scale for 5 to 11-year-olds has appeared in Pell and Jarvis 2001.) Harty and Beall described the purpose of their development to design and conduct a preliminary validation of a single scale to measure elementary children's curiosity in a science learning context. This, they suggested, could be made available to teachers for measuring and scoring children's curiosity for the purposes of curriculum planning and the implementation and the employment of child motivation techniques. Harty and Beall noted that curiosity has often been discussed as 'an important attribute and influencing factor with respect to human learning' and that the need for a curiosity instrument was, therefore, essential. Harty and Beall established that curiosity was said to be aroused as a result of surprise, doubt, perplexity, contradiction, bafflement, cognitive conflict, novelty, complexity, incongruity, ambiguity, lack of clarity and change and that, in their view, children demonstrated curiosity when they:

- reacted positively to new, strange, incongruous, or mysterious elements in their environment by moving towards them, exploring them, or manipulating them;
- exhibited a need or desire to know more about themselves;
- scanned their surroundings seeking new experiences;

- persisted in examining or exploring stimuli in order to know more about them.

In essence, the Harty-Beall science curiosity measure is a 30-item or 30-statement questionnaire to which children respond using a Likert-type scale (see Appendix V). This scale ranges from 1 (strongly disagree) to 5 (strongly agree). Eight of the items or statements are negatively constructed (statements 5, 6, 10, 15, 21, 25, 28 and 29) requiring children to read and respond with care. An individual curiosity score is obtained by simply adding the response scores together. Scores from the eight negatively stated items or statements are reversed prior to adding. The Likert-type scale was also illustrated by way of five smiling or frowning faces for younger children or those who may experience difficulties with reading and interpretation (not adopted here). Possible total scores range from 30 (low curiosity) to 150 (high curiosity). In use, children are first asked to declare their interest in science. Though not formally defined by Harty and Beall, interest appears to be associated with 'like' or 'enjoy'. Harty and Beall's statistical treatment of their research instrument, which ran to six earlier versions, was exemplary and considered concurrent, predictive and construct validity as well as internal consistency and test-retest reliability. Constructive criticism of the Harty-Beall science curiosity measure was provided by Gardner (1987). Gardner particularly raised issues associated with construct validity, the use of smiley faces, the uncertainty over dimensionality, and the unconvincing interpretation in understanding children's response patterns to certain items or statements. Harty and Beall (1987) provided a robust defence of their work. The Harty-Beall science curiosity measure was administered here in accordance with the authors' instructions. Children in both the experimental and control groups were introduced to the nature of the task as a whole class activity at first and second interviews. On each occasion, the questionnaires were completed individually and within 1 hour. Questionnaires were collected at first and second interview to assess test-retest reliability.

(a) Declared interest

Declared interest for both the experimental and control groups is summarized in Table 5.12. Observed differences in interest profiles of the experimental and control groups at test were not significant (test statistic $D_{xc}=0.064$, critical value $K_D=0.345$ for $\alpha=0.05$). Statistical analysis also revealed no significant association between experimental or control group and

declared interest (χ^2=0.343, df=2, p=0.842). No significant gender differences were observed in either group and test-retest reliabilities for both groups were acceptable.

		Experimental group				Control group			
		Really	Uncertain	Not	Total	Really	Uncertain	Not	Total
Test	Class	9	14	8	31	7	15	9	31
	(%)	(29.0)	(45.2)	(25.8)	(100.0)	(22.6)	(48.4)	(29.0)	(100.0)
	Boys	8	5	4	17	6	7	4	17
	(%)	(47.1)	(29.4)	(23.5)	(100.0)	(35.3)	(41.2)	(23.5)	(100.0)
	Girls	1	9	4	14	1	8	5	14
	(%)	(7.1)	(64.3)	(28.6)	(100.0)	(7.1)	(57.1)	(35.7)	(100.0)
Retest	Class	8	15	8	31	7	15	9	31
	(%)	(25.8)	(48.4)	(25.8)	(100.0)	(22.6)	(48.4)	(29.0)	(100.0)
	Boys	7	5	5	17	7	5	5	17
	(%)	(41.2)	(29.4)	(29.4)	(100.0)	(41.2)	(29.4)	(29.4)	(100.0)
	Girls	1	10	3	14	0	10	4	14
	(%)	(7.1)	(71.4)	(21.4)	(100.0)	(0.0)	(71.4)	(28.6)	(100.0)

Table 5.12 Declared interest in science

(b) Curiosity score

Curiosity score statistics for both the experimental and control groups are summarized in Tables 5.13 and 5.14 (see also Appendix V for raw data). The observed difference in the mean scores of the experimental and control groups at test, 89.5 and 97.7, was not significant (t=-1.50, df=60, p=0.14; normality for the experimental group D_x=0.124, p>0.15; normality for the control group D_c=0.107, p>0.15; F-ratio=1.08). No significant gender differences were observed in either group and test-retest reliabilities for both groups were acceptable.

While low sample sizes excluded the use of inferential statistics to compare response profiles by declared interest, these were nevertheless useful. As might be expected, responses to curiosity statements obtained from children who declared a real interest in science were positively skewed towards the 'strongly agree' part of the scale (5), while those responses to curiosity statements obtained from children who declared no interest in science were negatively skewed towards the 'strongly disagree' part of the scale (1). Response profiles from the experimental and control groups were broadly similar in appearance. Profiles reflect the mean scores arranged by interest in Table 5.14 (see Appendix V).

		Experimental group				Control Group			
		n	Mean	Range	SD	n	Mean	Range	SD
Test	Class	31	89.5	42 - 129	21.77	31	97.7	44 - 139	20.99
	Boys	17	93.2	50 - 129	21.72	17	100.7	44 - 139	23.20
	Girls	14	85.0	42 - 113	21.75	14	94.1	48 - 116	18.14
Retest	Class	31	95.1	69 - 137	18.75	31	99.7	70 - 146	19.06
	Boys	17	97.8	69 - 137	19.83	17	105.2	77 - 146	20.94
	Girls	14	91.9	69 - 129	17.50	14	92.9	70 - 116	14.42

Table 5.13 Curiosity statistics (scores by class and gender)

		Experimental group				Control Group			
		n	Mean	Range	SD	n	Mean	Range	SD
Test	Really	9	102.6	86 - 129	14.04	7	119.3	113 - 139	9.16
	Uncertain	14	96.4	73 - 124	14.97	15	101.9	86 - 127	11.21
	Not	8	62.8	42 - 90	16.02	9	73.9	44 - 93	17.07
Retest	Really	8	111.8	94 - 137	16.39	7	119.6	90 - 146	17.92
	Uncertain	15	93.9	69 - 131	17.38	15	97.7	76 - 128	15.19
	Not	8	80.8	71 - 95	8.86	9	87.4	70 - 112	13.96

Table 5.14 Curiosity statistics (scores by interest)

5.6.5 Informal science experiences

Two of the most comprehensive accounts of informal learning in science were provided by Lucas (1983) and Hofstein and Rosenfeld (1996). There is general agreement among these authors that children are exposed to and learn science not only at school but from a variety of informal sources in a variety of settings and for a variety of reasons. There is also general agreement that most adults are quite probably exposed to and learn science from informal sources alone throughout most of their adult lives. The importance of informal science learning in conjunction with the more formal science learning undertaken at school has significant implications for the public understanding of science and the development scientific literacy. Lucas (1983) made a distinction between the informal sources from which learning takes place into those that are deliberately or intentionally established to teach (e.g. a museum or science centre) and those that teach accidentally or unintentionally (e.g. happening to encounter and watch a science programme on television). Both potentially

impact on the effectiveness of formal school science learning and, similarly, formal school science learning potentially impacts on the effectiveness of learning from informal sources. In Lucas's view, informal learning essentially took place 'out-of-school' and the terms informal and 'out-of-school' were often used synonymously. Hofstein and Rosenfeld (1996) drew closer attention to the problem of what is meant by informal science learning and where it takes place. In their view, the various characteristics or features increasingly used to describe and differentiate informal and 'out-of-school' learning from formal learning (e.g. voluntary, unstructured, unsequenced, non-assessed and not curriculum-based) presented too simplistic a picture. This was later supported by Wellington (1991). Hofstein and Rosenfeld rightly pointed out, for example, that visits to places like museums or science centres, while 'out-of-school', can be voluntary or compulsory, unstructured or structured, and so on, depending on the nature and purpose of the visit, and could, therefore, result in formal as well as informal learning. It would seem inappropriate, therefore, to confuse the location and nature of the learning environment with the nature and purpose or context of learning itself. Hofstein and Rosenfeld favoured a 'hybrid' definition of informal learning, namely that informal learning experiences can occur in variety of learning environments and in a 'continuum of learning contexts' including formal school settings.

Despite the clear importance of understanding the nature and role of informal science learning on the development of scientific literacy in children and adults, and reason to believe that informal science learning experiences can enrich school science and vice versa, relatively little is actually known about how best to bring about integration. Available literature focuses on field trips, zoos, botanical gardens, museums, science centres and fictional and non-fictional media at all levels (Gottfried 1981; Wellington 1990, 1991; Price and Hein 1991; Lucas 1993; Tunnicliffe et al. 1997; Lock 1998). If, as Lucas (1983) and Hofstein and Rosenfeld (1996) pointed out, an individual's knowledge and understanding of science cannot be limited to what is learned in school, then better opportunities to integrate learning contexts must surely be sought. Limiting the types of learning opportunity available by failing to consider the potential influence and value of informal science could be harmful and detrimental to fostering positive attitudes towards science itself. One solution is to involve parents. Parental involvement in their children's education is now taken very seriously by most schools, including Big Town CPS, and home-school partnerships are now reflected in almost all school policies. Home-school partnerships, fostered since the Plowden era (CACE 1967), recognise and attempt to address the simplistic view that parental apathy is often taken

as a causal factor in influencing children's poor progress at school. Home-school partnerships attempt to help bridge the gap between formal and informal learning as a whole by involving parents and families in the wider aspects of school life and where successful establish a supportive school community of benefit to all (e.g. Solomon 1994b).

(a) Accidental or unintentional informal science learning

Information was collected at first interview by simply asking the children where they had encountered astronomy beyond the classroom. A range of informal sources were identified as shown (Table 5.15).

		n	Television	Film/video	Literature	Computer	Holiday	Other
Experimental group	Class	31	27	11	8	14	8	11
	(%)		(87.1)	(35.5)	(25.8)	(45.2)	(25.8)	(35.5)
	Boys	17	17	6	6	9	5	10
	(%)		(100.0)	(35.3)	(35.3)	(52.9)	(29.4)	(58.8)
	Girls	14	10	5	2	5	3	1
	(%)		(71.4)	(35.7)	(14.3)	(35.7)	(21.4)	(7.1)
Control group	Class	31	21	9	10	20	9	13
	(%)		(67.7)	(29.0)	(32.3)	(64.5)	(29.0)	(41.9)
	Boys	14	14	5	6	12	6	10
	(%)		(82.4)	(29.4)	(35.3)	(70.6)	(35.3)	(58.8)
	Girls	17	7	4	4	8	3	3
	(%)		(50.0)	(28.6)	(28.6)	(57.1)	(21.4)	(1.4)

Table 5.15 Children's informal sources of information about astronomy

Similar responses were obtained from both groups: TV programmes on terrestrial and satellite channels included *Star Trek* (original series, Next Generation, Voyager, Deep Space 9), *Babylon 5*, *Space Precinct*, *Third Rock from the Sun*, *X-Files*, *Superman*, *Thunderbirds* and *UFO* while non-fictional sources included *Blue Peter* and *Equinox*; film and video included *Star Trek* (the movies), *Independence Day*, *Star Wars* and *Alien* while non-fictional sources included *Apollo 13*; literature included reference to books, comics, newspapers and magazines; computer use referred mostly to 'space-invader-type' games; holidays included trips to museums, theme parks and space centres including the Natural History Museum, Euro-Disney, the Epcott Space Centre; and other mentions included play (usually 'invader-type' games), toys and conversations with parents. Clear evidence was provided from both

the experimental and control groups of science fiction potentially playing a major part in their informal learning of astronomy. In the experimental group, 79 sources were received from the 31 children in total (mean 2.5 sources per child, boys higher at 3.1 and girls lower at 1.9). The commonest source of information was TV (all 17 boys and 10 girls) which provided about one third (34%) of all responses. In all but one case (film and video), the percentage of sources indicated by boys was greater than that by girls: notably so in the 'other' category where boys were found to mention playing more space games than girls. In the control group, 82 sources were received from the 31 children in total (mean 2.6 sources per child, boys higher at 3.1 and girls lower at 2.1). The commonest source of information was TV (14 boys and 7 girls) which provided about one quarter (26%) of all responses. In all cases, the percentage of sources indicated by boys was greater than that by girls, again, notably so in the 'other' category where boys were found to play more space games than girls. Statistical analyses suggested no significant associations between the experimental group, control group and informal sources of information (TV χ^2=3.321, df=1, p=0.068; film and video χ^2=0.295, df=1, p=0.587; literature χ^2=0.313, df=1, p=0.576; computer χ^2=2.345, df=1, p=0.126; holiday χ^2=0.081, df=1, p=0.776; other χ^2=0.272, df=1, p=0.60).

(b) Deliberate or intentional informal science learning

In this work, deliberate or intentional informal science learning included homework and an evening field trip with parents to the Norman Lockyer Observatory, an informal/formal learning environment in Sidmouth about 10 miles to the east of Big Town CPS. Both were intended to consolidate and extend the astronomy provision at school.

5.7 Summary

In this substantial chapter, reflecting work undertaken implementing the quasi-experimental design at Phases 1, 2 and 3, general background details of Big Town CPS, the methods and methodology associated with Jack's curricular expertise and equivalence testing of the experimental and control groups were presented. At the time of this study, Big Town CPS, an average sized LEA maintained primary, drew its 302 reception to Year 6 children from a mixed catchment identified by owner-occupier homes and both rented and local authority housing. As evidenced by its national test results, its independent OFSTED inspection and

all other information available to this author, Big Town CPS was considered a fairly 'typical' English primary school (albeit with a lack of ethnic diversity) which functioned fully and effectively in accordance with contemporary views and models of good practice, as far as these could be determined, and which served its children, their parents and the community very well. Jack, the class teacher of the experimental group, and deputy head teacher of Big Town CPS, was a 36-year-old male with 15 years teaching experience. By all accounts, Jack was an experienced primary school teacher and something of a science specialist. Jack's curricular expertise in astronomy, that is his subject knowledge and subject-related pedagogy, was found to be exemplary. Jack also displayed an orientation towards science in terms of beliefs and attitudes which could be described as sensitive to a constructivist view of learning. Where slight 'weaknesses' in his knowledge and understanding were determined, Jack agreed to address these using established resources specially designed for teachers of primary science. Extensive equivalence testing of children in the experimental and control groups was undertaken. In terms of chronological age, socio-economic background, intellectual maturity, science interest and curiosity, and informal science experiences, inferential statistical analyses suggested that there were no significant differences between each group or between boys and girls within each group. Factors associated with chronological age, intellectual maturity and science curiosity raise the interesting possibility of subsidiary hypothesis testing associated with learning (see Chapters 6 and 7). In the chapter which follows, full details of the research findings associated with knowledge acquisition and concept learning within the experimental group are presented.

Chapter 6

Research Findings

6.1 Introduction

Recapping, children's ideas research, of which this is an example, essentially seeks to explore how children conceptualize the objects, events and phenomena of science usually by means of their knowledge and understanding of them. The research findings presented here attempt to explore, in just such a manner, children's ideas in the 'traditional' content areas of astronomy and how these ideas change as a result of knowledge acquisition and concept learning. In this chapter, itself also substantial, children's ideas about the Earth, the Sun, the Moon, phenomena associated with the Earth-Sun-Moon System, and the Solar System and wider Universe were obtained using a multiple-method survey instrument administered in the form of largely structured one-to-one interviews. Detailed interviewing of all 62 children, 31 in each of the experimental and control groups, took place during Phases 3 and 5 of the overall experimental design (first and second interviews, pre- and post-experimental treatment) with the experimental group interviewed briefly on one further occasion during Phase 6 (third interview, delayed). The data collected were subjected to both qualitative and quantitative means of analysis (see Chapter 4). While general overviews of knowledge acquisition and concept learning are provided throughout, a broader discussion of the research findings, together with their implications and concluding statements, is presented later (see Chapter 7).

6.2 Activities and outcomes

Throughout Phase 3 of the overall experimental design, the children in the experimental group were taught astronomy in a manner considered sensitive to a constructivist view of learning, one which was thought might effectively lead them towards scientific conceptualization. The experimental treatment itself spanned 10 weeks, each lesson

occupying one 2 hour timetable slot per week. During this time, the children in the experimental group were involved in sharing each others' ideas, the ideas of people who lived in the past and the ideas of the scientific community today, obtaining, considering and evaluating primary and secondary sources of information including that from extended day- and night-time observations of the sky (the latter as homework), illustrative, investigative and issue-based activities, pencil and paper problem-solving tasks, and exploring scientific models. In support, all of the children in the experimental group were provided with access to a wide range of children's astronomy literature including a full set of class textbooks, and computers were used to promote collaborative work in the form of multi-media authoring. An evening trip to the nearby Norman Lockyer observatory in Sidmouth was also arranged. The activities themselves were drawn from a number of commercially available and other sources (see Appendix VI). In terms of learning outcomes, it was anticipated that, following the experimental treatment, most of the children in the experimental group would:

- know and understand that the Earth, the Sun and the Moon are separate spherical (or near spherical) bodies and that the Earth is a planet, the Sun is a star, and the Moon is the Earth's only natural satellite;
- be able to draw the Earth, the Sun and the Moon as they would look from space and to describe some of the main features associated with them;
- know and understand that the Earth supports life and that the Sun and the Moon do not;
- know and understand that the Earth, the Sun and the Moon are different in size (relative or absolute);
- know and understand that the side of the Earth facing the Sun is lit by it and experiences day while the side facing away experiences night, and that the day and night cycle is caused by the Earth spinning on its axis once every 24 hours;
- know and understand that the changes in the seasons are caused by the tilt of the Earth's axis, and that the Earth orbits the Sun once a year;
- know and understand that the side of the Moon facing the Sun is lit by it, that the side facing away is in darkness, and that the phases of the Moon are caused by the amount of the lit side we see as the Moon orbits the Earth in about a month;
- know and understand that the Solar System, as part of a wider Universe, consists of the Sun, nine planets and other objects, that the Sun is at the centre of the Solar System, and that the planets orbit the Sun.

6.3 Notes on presentation and analysis of data

In all of the 'traditional' content areas explored, a first analysis of content is provided in terms of response correctness by item within each probe (e.g. responses scoring a 2 or 3). Though useful, the notion of correctness adopted here lacks the sensitivity required to reveal much about the exact nature of children's ideas themselves not to mention the more substantial as well as subtle changes anticipated as a result of the experimental treatment. Within each area probed, therefore, a detailed presentation and subsequent analysis of content from coded response categories for specific items of particular interest follows. Qualitatively different mental models were identified in all cases from the coded response categories and response category combinations within and between items of particular interest themselves too. Inevitably, and to a certain extent, unavoidably, mental models often included acceptable deviations and semantic ambiguities which, provided these did not seriously detract from, or appear in conflict with, the responses that might be predicted for these models, were considered acceptable. Sufficient differentiation in variation, sometimes indicated within a single mental model itself, was achieved by scoring. The scoring of qualitative data provided score frequency profiles, score profile percentages, specific item scores and summated scores by individual on ordinal and interval/ratio scales suitable for inferential analysis (see Chapters 4 and 7 for further detail and discussion). To retain clarity and readability within the main body of the text, summaries of inferential analyses are included in each of the following sections while a complete data set is presented in full in Appendix VIII. Where possible, all response categories, where listed, are presented in an implied hierarchical order leading always with what might be considered the most plausible, accurate and scientifically correct. Within the wide range of inferential techniques adopted, including multiple linear regression analysis, χ^2 was often severely limited by sample size (or sub-sample size in the case of gender) resulting in too many cells with expected counts less than 5 to be of any systematic use and therefore not reported. Where appropriate, the use of χ^2 is replaced with the more powerful Mann-Whitney test. Pre-experimental treatment analyses consider the range of first interview outcomes from both the experimental and control groups together. Post-experimental treatment and delayed analyses focus mostly on the range of second and third interview outcomes and changes within the experimental group in detail. With this information, knowledge acquisition and concept learning can be

described and assessed. Examples of children's actual responses are provided throughout, though mostly from the experimental group only, and identified in italics.

6.4 The Earth

The Earth is a relatively large, spherical or near-spherical object with a gravitational attraction that keeps our feet firmly on the ground wherever we stand. In this section, children's ideas about the shape of the Earth, how it looks from space, its gravitational attraction and its nature as a planet are of particular interest. While relative size is included as a scored item, relative size is dealt with separately in Section 6.7.

6.4.1 First interview: pre-experimental treatment

Overviews of Earth responses, mental models, score frequency profiles and summated scores from children in the experimental group and control group at first interview (pre-experimental treatment) can be found in Appendix VII.

(a) Correctness

The overall correctness of response in each of the twelve Earth items considered is summarized as shown (Table 6.1). For most items, the general pattern of responses obtained from both groups appears broadly similar. With the exception of items E1 (shape verbal), E7 ('roundness') and E9 (relative size), particularly high frequencies were recorded throughout. None of the children were aware of the absolute size of the Earth (E8).

Earth item	Experimental group			Control group		
	Boys	Girls	Total	Boys	Girls	Total
E1: Shape (verbal)	9 (52.9)	2 (14.3)	11 (35.5)	4 (23.5)	5 (35.7)	9 (29.0)
E2: Shape (selection)	17 (100.0)	13 (92.9)	30 (96.8)	16 (94.1)	14 (100.0)	30 (96.8)
E3: Interp. of evidence	15 (88.2)	9 (64.3)	24 (77.4)	11 (64.7)	14 (100.0)	25 (80.6)
E4: Drawing	17 (100.0)	13 (92.9)	30 (96.8)	17 (100.0)	13 (92.9)	30 (96.8)
E5: Colour	15 (88.2)	13 (92.9)	28 (90.3)	16 (94.1)	13 (92.9)	29 (93.5)
E6: 'Background'	17 (100.0)	13 (92.9)	30 (96.8)	17 (100.0)	10 (71.4)	27 (87.1)
E7: 'Roundness'	9 (52.9)	5 (35.7)	14 (45.2)	8 (47.1)	7 (50.0)	15 (48.4)
E8: Absolute size	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
E9: Relative size	9 (52.9)	5 (35.7)	14 (45.2)	7 (41.2)	7 (50.0)	14 (45.2)
E10: Gravity	16 (94.1)	9 (64.3)	25 (80.6)	15 (88.2)	11 (78.6)	26 (83.9)
E11: Nature	16 (94.1)	11 (78.6)	27 (87.1)	13 (76.5)	9 (64.3)	22 (71.0)
E12: Picture recognition	17 (100.0)	13 (92.9)	30 (96.8)	16 (94.1)	14 (100.0)	30 (96.8)

Table 6.1 Earth correctness by item (frequency and percentage)

(b) The shape of the Earth

Combined response categories for items E1 (shape verbal) and E2 (shape selection) are summarized as shown (Table 6.2). The general pattern of combined responses from both groups appears broadly similar. The most common description of the shape of the Earth in both groups was *'round'* and the most common choice of shape most like the Earth in both groups was a sphere. With some support from other items, notably E3 (interpretation of evidence), E4 (drawing), E6 ('background') and E7 ('roundness'), these combined response categories were used to examine children's ideas about the shape of the Earth further.

Response (verbal/choice)	Experimental group			Control group		
	Boys	Girls	Total	Boys	Girls	Total
Sort of egg shaped/sphere	2 (11.8)	0 (0.0)	2 (6.5)	1 (5.9)	2 (14.3)	3 (9.7)
Sphere(-ical)/sphere	6 (35.3)	2 (14.3)	8 (25.8)	2 (11.8)	2 (14.3)	4 (12.9)
Ball/sphere	1 (5.9)	0 (0.0)	1 (3.2)	1 (5.9)	1 (7.1)	2 (6.5)
Round/sphere	7 (41.2)	7 (50.0)	14 (45.2)	8 (47.1)	4 (28.6)	12 (38.7)
Circle/ sphere	0 (0.0)	2 (14.3)	2 (6.5)	3 (17.6)	4 (28.6)	7 (22.6)
Oval/ sphere	1 (5.9)	0 (0.0)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
Cylinder/sphere	0 (0.0)	1 (7.1)	1 (3.2)	1 (5.9)	1 (7.1)	2 (6.5)
Not sure/sphere	0 (0.0)	1 (7.1)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
Not sure/hemisphere	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	0 (0.0)	1 (3.2)
Round/disk	0 (0.0)	1 (7.1)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)

Table 6.2 Earth shape response categories (frequency and percentage)

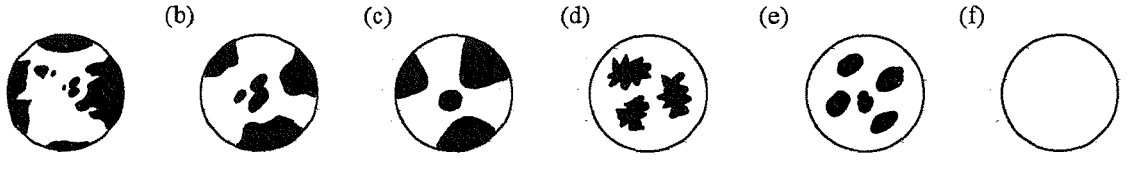
Five mental models were identified. The children in the experimental group presented ideas consistent with Models 1, 2, 3 and 4, the children in the control group Models 1, 2 and 5.

- Model 1: the Earth is nearly spherical (2 children in the experimental group; 3 children in the control group). The children assigned to this model described the Earth as *'sort of egg shaped'*. All selected a sphere as most like the Earth from the different shapes provided. Egg shaped, though not strictly accurate, was considered an acceptable deviation which set this Model apart from Model 2.
- Model 2: the Earth is spherical (27 children in the experimental group; 27 children in the control group). The children assigned to this model described the Earth as *'a sphere'* or *'spherical'*, *'ball shaped'* or *'round like a ball'*, *'round'*, *'a circle'* or *'circular'*, *'oval'* and *'a cylinder'*. All verbal responses were followed by the selection of a sphere as most like the Earth from the different shapes provided. Each of the six verbal responses provided indicate linguistic variation within the spherical model. *'Oval'* and *'a cylinder'*, though perhaps unusual, were considered acceptable deviations given the choice of shape and supporting responses from the other items.
- Model 3: uncertain sphere (1 child in the experimental group; 0 children in the control group). The one child assigned to this model was unable to describe the shape of the Earth verbally but selected a sphere as most like the Earth from the different shapes provided. Responses to other items suggested that this child may indeed have held a spherical Earth model or Model 2.
- Model 4: the Earth is non-spherical (1 child in the experimental group; 0 children in the control group). The one child assigned to this model failed to provide an adequate verbal response or to select a sphere as most like the Earth from the different shapes provided. Responses to other items were also either inconsistent or inconclusive. The 'round/disk' combination suggested that the Earth in this case was perhaps thought flat.
- Model 5: uncertain non-spherical (0 children in the experimental group; 1 child in the control group). The one child assigned to this model was unable to describe the shape of the Earth verbally or to select a sphere as most like the Earth from the different shapes provided. Responses to other items were also either inconsistent or inconclusive. The 'not sure/hemisphere' combination suggested that the Earth in this case was perhaps thought domed or hollow.

Where provided, children's evidence for the shape of the Earth in both groups came mostly from reference to space travel (e.g. *'well, they like go up in rockets and like go around the Earth and see it's a ball shape'*), reference to past historical events (e.g. *'sometimes they tried to sail to the end of the Earth but they never came to it ... they sailed around in circles'*), books, television, globes, comparing the properties of other shapes, and being told. Where provided, the interpretation of evidence did not always support the model held.

(c) Earth drawings and descriptions

Response categories for item E4 (drawing) are summarized as shown (Table 6.3). The general pattern of responses from both groups appears broadly similar. The most common type of drawing produced from both groups showed generalized outlines of land masses almost all of which made contact with the visible margin of their Earth (c). Together with support from other items, notably E5 (colour), E6 ('background'), E7 ('roundness') and E12 (picture recognition), these response categories were used to examine children's ideas about how the Earth looks from space further.



Response	Experimental group			Control group		
	Boys	Girls	Total	Boys	Girls	Total
(a) Global	7 (41.2)	1 (7.1)	8 (25.8)	2 (11.8)	1 (7.1)	3 (9.7)
(b) Anglocentric	4 (23.5)	0 (0.0)	4 (12.9)	2 (11.8)	1 (7.1)	3 (9.7)
(c) Marginal	5 (29.4)	8 (57.1)	13 (41.9)	10 (58.8)	11 (78.6)	21 (67.7)
(d) Internal (irregular)	0 (0.0)	3 (21.4)	3 (9.7)	2 (11.8)	0 (0.0)	2 (6.5)
(e) Internal (smooth)	1 (5.9)	1 (7.1)	2 (6.5)	1 (5.9)	0 (0.0)	1 (3.2)
(f) Blank	0 (0.0)	1 (7.1)	1 (3.2)	0 (0.0)	1 (7.1)	1 (3.2)

Table 6.3 Drawings of the Earth from space (frequency and percentage)

Two mental models were identified. The children in the experimental group and the control group presented ideas consistent with both.

- Model 1: the Earth is an astronomical body of some considerable size with land masses distributed all over (30 children in the experimental group; 30 children in the control group). While each of the drawing types provided appear to indicate stylistic variation along a continuum (a-e), differing only in the attention to detail represented and the descriptive information provided, the notion of each as a discrete model in its own right cannot be entirely discounted. Within the single model adopted here, the lack of recognizable outlines and spatial distributions of land masses in variations (c) to (e) were considered acceptable deviations.
- Model 2: the Earth is an astronomical body of some considerable size but with land masses not represented (1 child in the experimental group; 1 child in the control group). The children assigned to this model were unable or unwilling to complete their drawing (f) though land masses and oceans were described.

While descriptions of the colour of the Earth varied, most children in both groups gave between two and three responses almost all of which included *'blue'* for *'seas'* and *'oceans'*. Other colours included *'green'* and *'brown'* for *'land'*, *'yellow'* for *'deserts'*, and *'white'* for *'clouds'* and *'poles'* or *'ice caps'*. Two children in the experimental group indicated that the colour of the Earth would vary depending on *'how far away you are'*. The colour of the Earth and its land masses allowed almost all of the children to identify it correctly when presented with pictures of all of the planets in the Solar System. When viewed from space, almost all of the children suggested that the Earth would be seen against a background of *'stars'*, *'planets'* and *'darkness'*. The *'Sun'* and the *'Moon'* were also mentioned. Only a little under half of the children were able to resolve the issue of the Earth's 'roundness', responses from those that could being related to location and size (e.g. *'you can't see it all from here, you need to go into space'*, *'the Earth's really big and we're on it, things get in the way'*).

(d) The Earth's gravitational attraction

Response categories for item E10 (gravity) are summarized as shown (Table 6.4). The general pattern of responses from both groups appears broadly similar. The most common descriptions of the Earth's gravitational attraction from both groups included explicit, though only partially correct, as well as implicit reference to gravity itself. These response

categories were used to examine children's ideas about the Earth's gravitational attraction further.

Response	Experimental group			Control group		
	Boys	Girls	Total	Boys	Girls	Total
Explicit (correct)	3 (17.6)	2 (14.3)	5 (16.1)	5 (29.4)	1 (7.1)	6 (19.4)
Explicit (partially correct)	8 (47.1)	2 (14.3)	10 (32.3)	5 (29.4)	5 (35.7)	10 (32.3)
Implicit	5 (29.4)	5 (35.7)	10 (32.3)	5 (29.4)	5 (35.7)	10 (32.3)
Uncertain (not clear)	1 (5.9)	4 (28.6)	5 (16.1)	0 (0.0)	1 (7.1)	1 (3.2)
Not sure	0 (0.0)	1 (7.1)	1 (3.2)	2 (11.8)	2 (14.3)	4 (12.9)

Table 6.4 Earth gravity (frequency and percentage)

Two mental models were identified. The children in the experimental group and the control group presented ideas consistent with both.

- Model 1: gravity acts 'inwards' towards the Earth's surface (25 children in the experimental group; 26 children in the control group). In all cases, children assigned to this model had never heard of anyone ever falling off the Earth other than in occasional reference to *'Norwegian folk tales'* or stories associated with *'Christopher Columbus'* (all quickly pointed out that this could never in fact happen). Three descriptive variations were indicated. In the first, gravity was mentioned explicitly and described as a *'pulling force'*; in the second, gravity was mentioned explicitly but described as a *'pushing force'* or acting *'like a magnet'*; and in the third, gravity was referred to implicitly, usually with reference to shape (e.g. the Earth has *'no edge to fall from'*) or travel (e.g. circumnavigating the Earth involved constantly going *'round and round'*). While the notion of each descriptive variation as a discrete model in its own right cannot be entirely discounted, within the single model adopted here, explicit (partially correct) and implicit mentions of gravity were considered acceptable deviations.
- Model 2: uncertain gravity (5 children in the experimental group; 1 child in the control group). In all cases, children assigned to this model had never heard of anyone ever falling off the Earth but were unable to decide whether this could happen or not.

One child in the experimental group and four children in the control group could not be assigned to any model (*'not sure'*).

(e) Nature of the Earth

Response categories for item E11 (nature) are summarized as shown (Table 6.5). The general pattern of responses from both groups appears broadly similar. The most common response from both groups indicated that the Earth was known to be a planet. With limited support from most other items, these response categories were used to examine children's ideas about the nature of the Earth further.

	Experimental group			Control group		
Response	Boys	Girls	Total	Boys	Girls	Total
Planet (orbits Sun)	6 (35.3)	0 (0.0)	6 (19.4)	5 (29.4)	3 (21.4)	8 (25.8)
Planet	10 (58.8)	11 (78.6)	21 (67.7)	8 (47.1)	6 (42.9)	14 (45.2)
World, ball	0 (0.0)	1 (7.1)	1 (3.2)	0 (0.0)	2 (14.3)	2 (6.5)
Not sure	1 (5.9)	2 (14.3)	3 (9.7)	4 (23.5)	3 (21.4)	7 (22.6)

Table 6.5 The nature of the Earth (frequency and percentage)

Two mental models were identified. The children in the experimental group and the control group presented ideas consistent with both.

- Model 1: the Earth exists in space as a planet (27 children in the experimental group; 22 children in the control group). Two descriptive variations were indicated. In the first, the Earth was known to be a planet with a planet further described as an object that *'goes around the Sun'*. In the second, the Earth was known to be a planet but the nature of planetary objects remained uncertain. The second variation was considered an acceptable deviation.
- Model 2: uncertain nature (1 child in the experimental group; 2 children in the control group). Children assigned to this model seemed unaware that the Earth is a planet and resorted instead to a variety of descriptive responses (e.g. *'the world ... a sphere where people live'* or *'a ball'*).

Three children in the experimental group and seven children in the control group could not be assigned to any model (*'not sure'*).

6.4.2 Second interview: post-experimental treatment

Overviews of Earth responses, mental models, score frequency profiles and summated scores from children in the experimental group and control group at second interview (post-experimental treatment) can be found in Appendix VII.

(a) Correctness

The overall correctness of responses in each of the twelve Earth items is summarized as shown (Table 6.6). Increases in correctness in the experimental group were observed in ten Earth items (E1, 2, 4, 5 and 7 to 12) with a slight decrease in one (E3) and no change in the other (E6). Among the many differences, frequencies associated with items E1 (shape verbal) and E9 (relative size) in the experimental group were notably greater relative to changes in the control group (up 29 percentage points and 26 percentage points respectively). Despite a slight increase in the frequency of correct responses from the experimental group, children's knowledge of the absolute size of the Earth (E8) remained poor.

	Experimental group			**Control group**		
Earth item	Boys	Girls	Total	Boys	Girls	Total
E1: Shape (verbal)	15 (88.2)	6 (42.9)	21 (67.7)	6 (35.3)	4 (28.6)	10 (32.3)
E2: Shape (selection)	17 (100.0)	14 (100.0)	31 (100.0)	16 (94.1)	14 (100.0)	30 (96.8)
E3: Interp. of evidence	14 (82.4)	9 (64.3)	23 (74.2)	10 (58.8)	11 (78.6)	21 (67.7)
E4: Drawing	17 (100.0)	14 (100.0)	31 (100.0)	17 (100.0)	13 (92.9)	30 (96.8)
E5: Colour	17 (100.0)	14 (100.0)	31 (100.0)	17 (100.0)	14 (100.0)	31 (100.0)
E6: 'Background'	16 (94.1)	12 (85.7)	28 (90.3)	16 (94.1)	12 (85.7)	28 (90.3)
E7: 'Roundness'	9 (52.9)	7 (50.0)	16 (51.6)	8 (47.1)	7 (50.0)	15 (48.4)
E8: Absolute size	2 (11.8)	1 (7.1)	3 (9.7)	0 (0.0)	0 (0.0)	0 (0.0)
E9: Relative size	15 (88.2)	10 (71.4)	25 (80.6)	9 (52.9)	8 (57.1)	17 (54.8)
E10: Gravity	15 (88.2)	11 (78.6)	26 (83.9)	15 (88.2)	14 (100.0)	29 (93.5)
E11: Nature	17 (100.0)	13 (92.9)	30 (96.8)	14 (82.4)	12 (85.7)	26 (83.9)
E12: Picture recognition	17 (100.0)	14 (100.0)	31 (100.0)	17 (100.0)	14 (100.0)	31 (100.0)

Table 6.6 Earth correctness by item (frequency and percentage)

(b) Shape of the Earth

Combined response categories for items E1 (shape verbal) and E2 (shape selection) are summarized as shown (Table 6.7). The general pattern of combined responses observed

between groups was no longer similar. In the experimental group, the most common description of the shape of the Earth was *'a sphere'* or *'spherical'* (previously *'round'*). The most common choice of shape most like the Earth remained a sphere.

	Experimental group			Control group		
Response (verbal/choice)	Boys	Girls	Total	Boys	Girls	Total
Bulging sphere/sphere	1 (5.9)	0 (0.0)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
Sort of egg shaped/'sphere'	2 (11.8)	0 (0.0)	2 (6.5)	0 (0.0)	0 (0.0)	0 (0.0)
Sphere(-ical)/sphere	11 (64.7)	6 (42.9)	17 (54.8)	5 (29.4)	4 (28.6)	9 (29.0)
Ball/sphere	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	0 (0.0)	1 (3.2)
3D shape/sphere	1 (5.9)	0 (0.0)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
Round/sphere	2 (11.8)	7 (50.0)	9 (29.0)	8 (47.1)	7 (50.0)	15 (48.4)
Circle/ sphere	0 (0.0)	1 (7.1)	1 (3.2)	2 (11.8)	2 (14.3)	4 (12.9)
Cylinder/sphere	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (7.1)	1 (3.2)
Not sure/hemisphere	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	0 (0.0)	1 (3.2)

Table 6.7 Earth shape response categories (frequency and percentage)

Only three of the original five mental models were identified. The children in the experimental group presented ideas consistent with only Models 1 and 2.

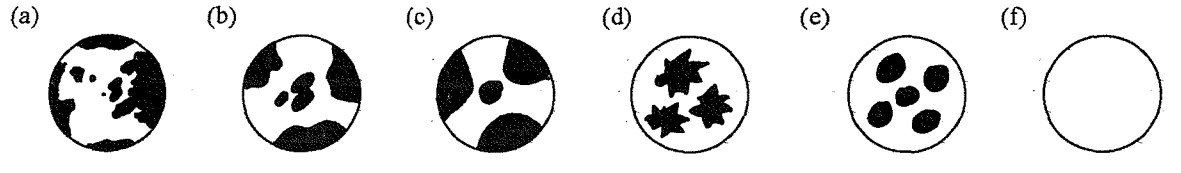
- Model 1: the Earth is nearly spherical (3 children in the experimental group; 0 children in the control group). The children in the experimental group assigned to this model not only described the Earth as *'sort of egg shaped'* but, in one example, as *'because the equator comes out more than the rest of the Earth ... it bulges out'*. Having selected spheres as most like the shape of the Earth from the different shapes provided, one child went on to describe their choice as more *'kind of like a sphere'*.
- Model 2: the Earth is spherical (28 children in the experimental group; 30 children in the control group). Within the experimental group, the six original linguistic variations of spherical Earth were reduced to four with the loss of *'ball shaped'*, *'oval'* and *'a cylinder'* but with the addition of *'it's a 3D shape'*. Two other changes were particularly notable: the increased frequency of descriptions of the Earth as *'a sphere'* or *'spherical'* (up 13 percentage points relative to changes in the control group) and the reduced frequency of descriptions of the Earth as *'round'* (down 26 percentage points relative to changes in the control group).

- Model 3: uncertain non-spherical (0 children in the experimental group; 1 child in the control group). No children from the experimental group were assigned to this model initially.

The two children in the experimental group who presented uncertain spherical and non-spherical ideas initially now provided responses consistent with Model 2. Where provided, children's evidence for the shape of the Earth came from the same sources mentioned earlier. Within the experimental group, however, there was a notable increase and extension in responses which made reference to space travel (e.g. *'when they were up on the Moon they could look back and see it'*, *'the space shuttle has flown right round the Earth'*) and past historical events (e.g. *'people thought the Earth was straight but then Christopher Columbus or somebody, can't remember his name, sailed around it and found it was a round ball'*). The interpretation of evidence supported the Earth shape models in all cases.

(c) Earth drawings and descriptions

Response categories for item E4 (drawing) are summarized as shown (Table 6.8). The general pattern of responses observed between groups was no longer similar. Previously only marginal (c), the most common drawings produced by the experimental group were both marginal (c) and Anglocentric (b).



Response	Experimental group			Control group		
	Boys	Girls	Total	Boys	Girls	Total
(a) Global	5 (29.4)	1 (7.1)	6 (19.4)	2 (11.8)	0 (0.0)	2 (6.5)
(b) Anglocentric	7 (41.2)	4 (28.6)	11 (35.5)	1 (5.9)	1 (7.1)	2 (6.5)
(c) Marginal	4 (23.5)	8 (57.1)	12 (38.7)	13 (76.5)	12 (85.7)	25 (80.6)
(d) Internal (irregular)	0 (0.0)	1 (7.1)	1 (3.2)	1 (5.9)	0 (0.0)	1 (3.2)
(e) Internal (smooth)	1 (5.9)	0 (0.0)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
(f) Blank	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (7.1)	1 (3.2)

Table 6.8 Drawings of the Earth from space (frequency and percentage)

While both of the original mental models were identified, the children in the experimental group presented ideas consistent with Model 1 only.

- Model 1: the Earth is an astronomical body of some considerable size with land masses distributed all over (31 children in the experimental group; 30 children in the control group). Within the experimental group, the five original stylistic variations of this model (a-e) remained. The increased frequency of Anglocentric drawings (b) was particularly notable (up 26 percentage points relative to changes in the control group).
- Model 2: the Earth is an astronomical body of some considerable size but with land masses not represented (0 children in the experimental group; 1 child in the control group). The one child in the experimental group assigned to this model initially now provided responses consistent with Model 1 (c).

While descriptions of the colour of the Earth from children in the experimental group still varied, a wider selection was provided and included occasional reference to *'black'* and *'grey'* with reference to the Earth's *'shadow'*. Viewed from space, the Earth remained visible against a background of *'stars'*, *'planets'*, *'darkness'*, *'the Sun'* and *'the Moon'*. In resolving the Earth's 'roundness', some responses were particularly interesting: *'if you're in a yacht in the sea, you can see the Earth's curve 'cause you can't see where you started the race'* (personal observation) and *'because its ... mm ... when I went in an aeroplane coming back from Spain, I could see the curve of the Earth'* (the Earth's curvature can only be seen in commercial aircraft from Concorde). All of the children in the experimental group identified the Earth from pictures of all the planets in the Solar System.

(d) The Earth's gravitational attraction

Response categories for item E10 (gravity) are summarized as shown (Table 6.9). The general pattern of responses observed between groups was no longer similar. In the experimental group, the most common descriptions of the Earth's gravitational attraction included explicit and correct as well as implicit reference to gravity (previously explicit but only partially correct and implicit).

Response	Experimental group			Control group		
	Boys	Girls	Total	Boys	Girls	Total
Explicit (correct)	10 (58.8)	3 (21.4)	13 (41.9)	4 (23.5)	2 (14.3)	6 (19.4)
Explicit (partially correct)	0 (0.0)	1 (7.1)	1 (3.2)	7 (41.2)	5 (35.7)	12 (38.7)
Implicit	5 (29.4)	7 (50.0)	12 (38.7)	4 (23.5)	7 (50.0)	11 (35.5)
People fall	0 (0.0)	1 (7.1)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
Not clear	2 (11.8)	1 (7.1)	3 (9.7)	0 (0.0)	0 (0.0)	0 (0.0)
Not sure	0 (0.0)	1 (7.1)	1 (3.2)	2 (11.8)	0 (0.0)	2 (6.5)

Table 6.9 Earth gravity (frequency and percentage post-experimental treatment)

In addition to the two original mental models, the responses provided by the children in the experimental group indicated the presence of a third not previously identified.

- Model 1: gravity acts 'inwards' towards the surface of the Earth (26 children in the experimental group; 29 children in the control group). Within the experimental group, while the three original descriptive variations remained, two changes were particularly notable: the increased frequency of explicit (correct) responses (up 26 percentage points relative to changes in the control group) and the reduced frequency of explicit (partially correct) responses (down 35 percentage points relative to changes in the control group).
- Model 2: gravity acts 'downwards' (1 child in the experimental group; 0 children in the control group). Not previously identified. The one child in the experimental group assigned to this model provided initial responses consistent with Model 3. Although this child had never heard of anyone ever falling off the Earth, it was suggested that they could particularly if they travelled too far around the Earth's circumference from a starting point in the Northern Hemisphere. It was not clear where they would fall to.
- Model 3: uncertain gravity (3 children in the experimental group; 0 children in the control group). Three of the five children in the experimental group assigned to this model initially now provided responses consistent with Model 1.

One child in the experimental group and two children in the control group could not be assigned to any model (*'not sure'*).

(e) Nature of the Earth

Response categories for item E11 (nature) are summarized as shown (Table 6.10). The general pattern of responses observed between groups was no longer similar. The most common response from the experimental group indicated that the Earth is a planet, an object in orbit around the Sun (previously planet).

	Experimental group			Control group		
Response	Boys	Girls	Total	Boys	Girls	Total
Planet (orbits Sun)	17 (100.0)	12 (85.7)	29 (93.5)	7 (41.2)	2 (14.3)	9 (29.0)
Planet	0 (0.0)	1 (7.1)	1 (3.2)	7 (41.2)	10 (71.4)	17 (54.8)
Round thing	0 (0.0)	1 (7.1)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
Not sure	0 (0.0)	0 (0.0)	0 (0.0)	3 (17.6)	2 (14.3)	5 (16.1)

Table 6.10 The nature of the Earth (frequency and percentage)

Both of the original mental models were identified and the children in the experimental group continued to presented ideas consistent with both.

- Model 1: the Earth exists in space as a planet (30 children in the experimental group; 26 children in the control group). Within the experimental group, while the two original descriptive variations remained, two changes were particularly notable: the increased frequency of responses indicating that the Earth is a planet, an object in orbit around the Sun (up 71 percentage points relative to changes in the control group) and the reduced frequency of the Earth labelled simply a planet (down 74 percentage points relative to changes in the control group).
- Model 2: uncertain nature (1 child in the experimental group; 0 children in the control group). The one child in the experimental group assigned to this model provided an initial response of *'not sure'*. They now indicated that the Earth was a *'round thing'*.

Five children in the control group could not be assigned to any model (*'not sure'*).

6.4.3 Summary of inferential analyses

For a full treatment of the quantitative data see Appendix VIII.

(i) Pre-experimental treatment

At first interview, overall scores in the experimental group ranged from 8 to 27 with a mean of 20.0 (SD 3.77). Score profile percentages included 15.6% 0s, 13.7% 1s, 59.1% 2s and 11.6% 3s. 1 child scored between 0 and 11 (3%), 26 children between 12 and 23 (84%) and 4 children between 24 and 36 (13%). Overall scores in the control group ranged from 9 to 26 with a mean of 19.2 (SD 4.27). Score profile percentages included 18.8% 0s, 12.1% 1s, 59.1% 2s and 9.9% 3s. 2 children scored between 0 and 11 (6%), 23 children between 12 and 23 (74%) and 6 children between 24 and 36 (19%). The observed differences between the experimental group and control group in overall mean scores, score profile percentages and median scores in items of particular interest (E1, E2, E4, E10 and E11) at first interview were not significant.

Boys in the experimental group appeared to score more highly than the girls overall and the observed difference in their mean scores, 21.7 and 17.9 (SDs 2.31 and 4.21), was significant ($t=3.00$, $df=19$, $p=0.007$; normality for boys $D_{xb}=0.067$, $p>0.15$; normality for girls $D_{xg}=0.136$, $p>0.15$; F-ratio=3.32 which is significant at $\alpha=0.05$) though this was not reflected in an analysis of the score profile percentages by gender. In those items of particular interest (E1, E2, E4, E10 and E11), observed differences in median scores between boys and girls were significant in E1 (shape verbal: $W_{xb}=324.0$, $W_{xg}=156.5$, $p=0.018$), E4 (drawing: $W_{xb}=343.5$, $W_{xg}=152.5$, $p=0.001$) and E11 (nature: $W_{xb}=323.0$, $W_{xg}=173.0$, $p=0.015$). No significant gender differences were observed in the control group.

(ii) Post-experimental treatment

At second interview, overall scores in the experimental group ranged from 12 to 31 with a mean of 22.9 (SD 4.16), a significant change from before (matched $t=-6.36$, $p=0.000$, normality of differences in experimental scores $D_{dx}=0.081$, $p>0.15$; F-ratio=1.22). Score profile percentages included 13.7% 0s, 6.7% 1s, 54.3% 2s and 25.3% 3s, again a significant change from before (test statistic $D_x=0.137$, critical value $K_D=0.120$ for $\alpha=0.01$). No children scored between 0 and 11 (0%), 16 children between 12 and 23 (52%) and 15 children between 24 and 36 (48%). Overall scores in the control group ranged from 10 to 25 with a

mean of 19.3 (SD 3.55). Score profile percentages included 16.1% 0s, 11.6% 1s, 67.2% 2s and 5.1% 3s. 1 child scored between 0 and 11 (3%), 25 children between 12 and 23 (81%) and 5 children between 24 and 36 (16%). None of the changes observed between interviews were significant. More importantly, however, the mean gain in individual scores from children in the experimental group (O_3-O_1) and control group (O_4-O_2), +2.9 and +0.1 (SDs 2.57 and 2.92), was significant (t=4.11, df=60, p=0.000; normalities D_{dx}=0.081, D_{dc}=0.053, p>0.15; F-ratio=1.29) as was the post-experimental treatment analysis of the score profile percentages (test statistic D_{xc}=0.201, critical value K_D=0.120 for α=0.01). In those items of particular interest (E1, E2, E4, E10 and E11), observed differences in median scores between the experimental group and control group were significant in E1 (shape verbal: W_{x2}=1167.0, W_{c2}=786.0, p=0.003), E4 (drawing: W_{x2}=1185.0, W_{c2}=768.0, p=0.000) and E11 (nature: W_{x2}=1283.0, W_{c2}=670.0, p=0.000). Within the experimental group, multiple linear regression analysis using age, intellectual maturity and science curiosity as independent predictor variables was significant (R^2=0.469, F=7.93, p=0.001, df=3), with each predictor contributing to the differences in summated scores between individuals.

Boys in the experimental group continued to significantly outscore the girls overall (means 24.5 and 21.1, SDs 3.32 and 4.41 respectively; t=2.45, df=29, p=0.021; normality for boys D_{xb}=0.113, p>0.15; normality for girls D_{xg}=0.133, p>0.15; F-ratio=1.76) but again this was not reflected in an analysis of the score profile percentages by gender. Observed differences in median scores between boys and girls were significant in only item E1 (shape verbal: W_{xb}=335.0, W_{xg}=161.0, p=0.005). No significant gender differences were observed in the control group.

6.4.4 Knowledge acquisition and concept learning

Within the experimental group at first interview, and before the experimental treatment, children's declared knowledge and understanding as probed suggested that their concept of the Earth in space was already reasonably well developed. In terms of the Earth's shape, how it looks from space, its gravitational attraction and its nature, predominantly scientific models were evident (Table 6.11), though almost all of the scientific models identified contained acceptable deviations in the form of linguistic, stylistic and descriptive variation to a greater or lesser degree.

	Pre-experimental Total	+/-	Post-experimental Total	+/-	Delayed Total
Shape	29 (93.5)	+2	31 (100.0)	0	31 (100.0)
Drawing	30 (96.8)	+1	31 (100.0)	-1	30 (96.8)
Gravitational attraction	25 (80.6)	+1	26 (83.9)	0	26 (83.9)
Nature	27 (87.1)	+3	30 (96.8)	-2	28 (90.3)
Shape + drawing	28 (90.3)	+3	31 (100.0)	-1	30 (96.8)
Shape + drawing + gravity	24 (77.4)	+2	26 (83.9)	-1	25 (80.6)
Shape + drawing + nature	25 (80.6)	+5	30 (96.8)	-3	27 (87.1)
Shape + drawing + gravity + nature	23 (74.2)	+3	26 (83.9)	-2	24 (77.4)

Table 6.11 Summary of scientific mental models of the Earth (frequency and percentage)

At second interview, and after the experimental treatment, despite only small increases in the frequencies of scientific models and combinations of scientific models observed (Table 6.11), features associated with knowledge acquisition and concept learning in the experimental group relative to the control group can be summarized as follows:

- descriptions of the Earth's shape revealed a slight reduction in linguistic variation with a corresponding and significant improvement in the use of correct scientific vocabulary;
- drawings of the Earth from space revealed a significant improvement in style with increases in Anglocentric representation;
- accounts of the Earth's gravitational attraction revealed a substantial improvement in descriptions of gravity mentioned explicitly as a *'pulling force'*;
- accounts of the nature of the Earth revealed a significant improvement in descriptions of the Earth as a planet, an object in orbit around the Sun;
- the experimental treatment appeared to close the gap in the differences observed between boys and girls (correctness, response categories, median scores in all but one item of particular interest and mean score);
- the number of children with summated scores in the 24 to 36 range, reflecting more 2s and 3s, increased notably with a corresponding and significant increase in score profile percentages, overall mean score and mean gain;
- the predictor variables age, intellectual maturity and science curiosity all contributed significantly to the differences in summated scores between individuals.

Interestingly, the experimental treatment did little to improve knowledge and understanding of the Earth's absolute size. Knowledge acquisition and concept learning in the experimental

group are perhaps best accounted for in terms of mostly weak (accretion and tuning) rather than radical restructuring. This provides at least one explanation to account for the apparent mismatch between the extent of the qualitative and quantitative changes described and the small increases in the frequencies of scientific mental models observed. Nowhere is the relationship between response categories, mental models, knowledge acquisition, concept learning and the weak restructuring implied here more dramatically and vividly illustrated than in the mapped movements or routes and pathways in children's ideas immediately before and after the experimental treatment as well as after a three month delay. A map of Earth shape movements in the experimental group is provided as shown (Fig. 6.1; see also Table 6.11 and Appendix VII for a delayed overview). Interestingly, initial routes and pathways (pre- to post-) revealed 15 'non-movers' (original ideas retained – horizontal links) and 16 'risers' (original ideas progressed – positive gradient links). Later routes and pathways (post- to delayed) revealed 22 'non-movers', 4 'risers' and 5 'fallers' (negative gradient links), three of whom had made progress initially. It is important to notice that most of the changes which appear to have taken place did so within the one mental model (the Earth is spherical), a feature of the linguistic variation described and weak restructuring. Interestingly, in those areas of children's ideas about the Earth which received most attention earlier (E1, E2, E4, E10 and E11), observed differences in median scores between second and third interviews (post-experimental treatment and delayed), including the shape of the Earth, were not significant indicating a high degree of retention and recall.

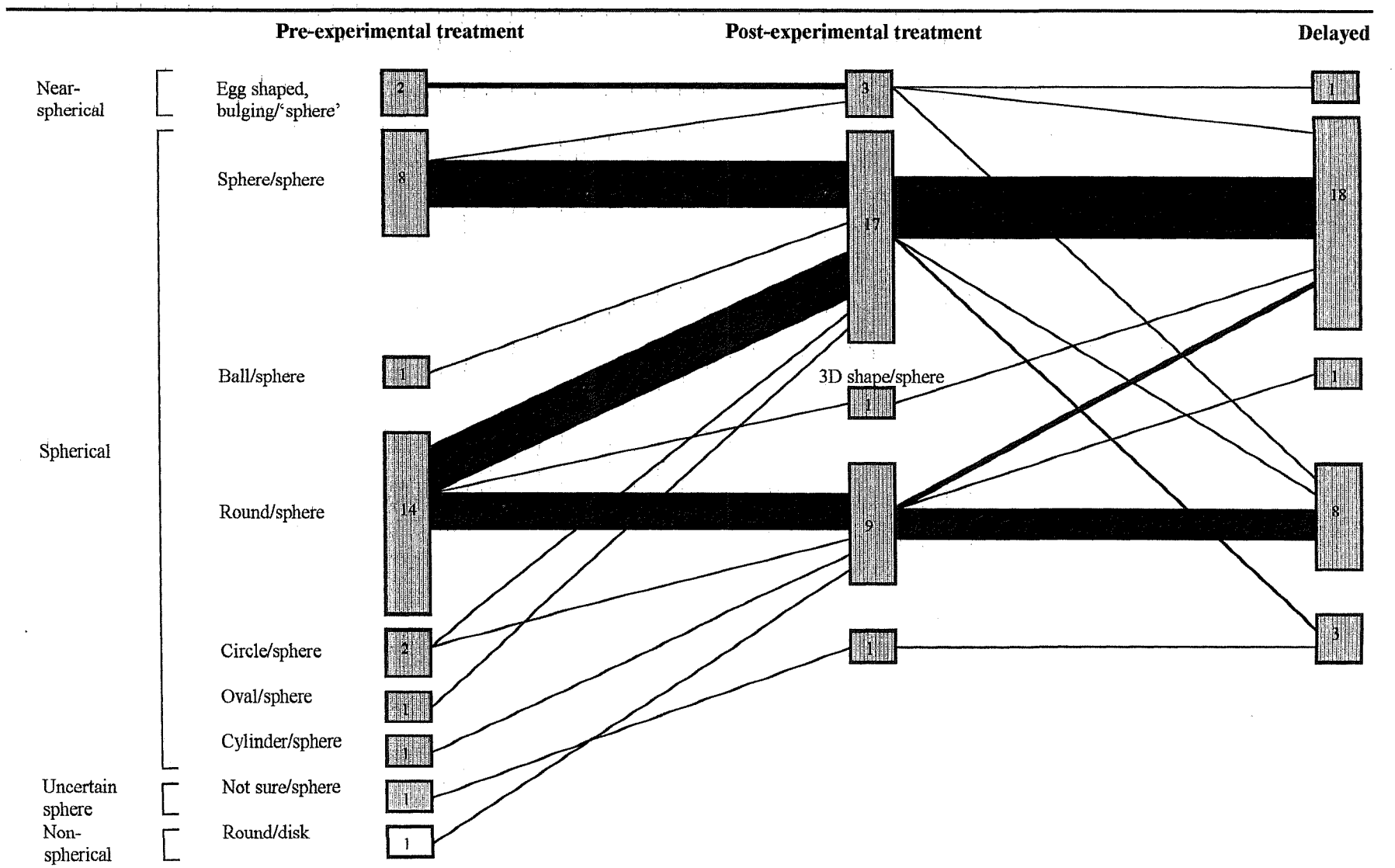


Fig.6.1 Knowledge acquisition and concept learning: mapped changes in children's response categories and mental models of the Earth's shape

6.5 The Sun

The Sun is a star, a spherical or near-spherical body of hot, glowing gases, and the largest object in the Solar System. In this section, children's ideas about the shape of the Sun, how it looks from space and its nature as a star, including its source of heat and light, are of particular interest. Like the Earth, while relative size is included as a scored item, relative size is dealt with separately in Section 6.7.

6.5.1 First interview: pre-experimental treatment

Overviews of Sun responses, mental models, score frequency profiles and summated scores from children in the experimental group and control group at first interview (pre-experimental treatment) can be found in Appendix VII.

(a) Correctness

The overall correctness of response in each of the twelve Sun items considered is summarized as shown (Table 6.12). For most items, the general pattern of responses obtained from both groups, though mixed, appears broadly similar. Particularly high frequencies were recorded in S2 (shape selection), S5 (colour), S6 ('life') and S12 (picture recognition). Particularly low frequencies were recorded in S1 (shape verbal), and S8 (source of heat/light). None of the children were aware of the Sun's temperature (S7) or its absolute size (S9).

	Experimental group			Control group		
Sun item	Boys	Girls	Total	Boys	Girls	Total
S1: Shape (verbal)	8 (47.1)	1 (7.1)	9 (29.0)	5 (29.4)	4 (28.6)	9 (29.0)
S2: Shape (selection)	17 (100.0)	9 (64.3)	26 (83.8)	14 (82.4)	9 (64.3)	23 (74.2)
S3: Interp. of evidence	11 (64.7)	2 (14.3)	13 (41.9)	8 (47.1)	5 (35.7)	13 (41.9)
S4: Drawing	11 (64.7)	7 (50.0)	18 (58.1)	10 (58.8)	8 (57.1)	18 (58.1)
S5: Colour	17 (100.0)	14 (100.0)	31 (100.0)	17 (100.0)	14 (100.0)	31 (100.0)
S6: 'Life'	16 (94.1)	11 (78.6)	27 (87.1)	16 (94.1)	12 (85.7)	28 (90.3)
S7: Temperature	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
S8: Source of heat/light	4 (23.5)	0 (0.0)	4 (12.9)	3 (17.6)	1 (7.1)	4 (12.9)
S9: Absolute size	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
S10: Relative size	9 (52.9)	5 (35.7)	14 (45.2)	7 (41.2)	7 (50.0)	14 (45.2)
S11: Nature	6 (35.3)	4 (28.6)	10 (32.3)	10 (58.8)	6 (42.9)	16 (51.6)
S12: Picture recognition	17 (100.0)	13 (92.9)	30 (96.8)	17 (100.0)	14 (100.0)	31 (100.0)

Table 6.12 Sun correctness by item (frequency and percentage)

(b) The shape of the Sun

Combined response categories for items S1 (shape verbal) and S2 (shape selection) are summarized as shown (Table 6.13). The general pattern of combined responses from both groups appears broadly similar. The most common description of the shape of the Sun in both groups was *'round'* and the most common choice of shape most like the Sun in both groups was a sphere. With some support from other items, notably S3 (interpretation of evidence) and S4 (drawing), these combined response categories were used to examine children's ideas about the shape of the Sun further.

	Experimental group			Control group		
Response (verbal/choice)	Boys	Girls	Total	Boys	Girls	Total
No real shape/'sphere'	0 (0.0)	1 (7.1)	1 (3.2)	1 (5.9)	2 (14.3)	3 (9.7)
Ball/'sphere'	1 (5.9)	0 (0.0)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
Sphere/sphere	4 (23.5)	0 (0.0)	4 (12.9)	2 (11.8)	0 (0.0)	2 (6.5)
Ball/sphere	3 (17.6)	0 (0.0)	3 (9.7)	1 (5.9)	2 (14.3)	3 (9.7)
Round/sphere	6 (35.3)	5 (35.7)	11 (35.5)	9 (52.9)	4 (28.6)	13 (41.9)
Circle/sphere	1 (5.9)	3 (21.4)	4 (12.9)	1 (5.9)	1 (7.1)	2 (6.5)
Oval/sphere	1 (5.9)	0 (0.0)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
Not sure/sphere	1 (5.9)	0 (0.0)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
Various/hemisphere	0 (0.0)	1 (7.1)	1 (3.2)	1 (5.9)	1 (7.1)	2 (6.5)
Round/cylinder	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	0 (0.0)	1 (3.2)
Circle/disk	0 (0.0)	1 (7.1)	1 (3.2)	0 (0.0)	1 (7.1)	1 (3.2)
Circle, round/various	0 (0.0)	3 (21.4)	3 (9.7)	1 (5.9)	0 (0.0)	1 (3.2)
Not sure/ hemisphere	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	2 (14.3)	2 (6.5)
Not sure/not sure	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (7.1)	1 (3.2)

Table 6.13 Sun shape response categories (frequency and percentage)

Five mental models were identified. The children in the experimental group presented ideas consistent with Models 1, 2, 3 and 4, the children in the control group Models 1, 2, 4 and 5.

- Model 1: the Sun is nearly spherical (2 children in the experimental group; 3 children in the control group). The children assigned to this model described the Sun as having *'no real shape'* or as *'a ball'* but with reference to *'fire coming out of it'*. While all selected a sphere as most like the Sun from the different shapes provided, this choice was often described as only *'kind of spherical'*.

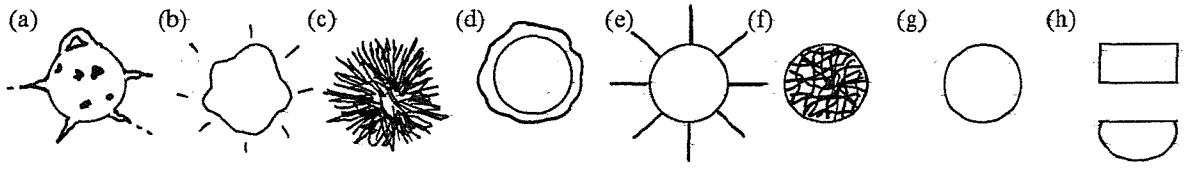
- Model 2: the Sun is spherical (23 children in the experimental group; 20 children in the control group). The children assigned to this model described the Sun as *'a sphere'* or *'spherical'*, *'ball shaped'* or *'round like a ball'*, *'round'*, *'a circle'* or *'circular'* and *'oval'*. All verbal responses were followed by the selection of a sphere as most like the Sun from the different shapes provided. Each of the five verbal responses provided indicate linguistic variation within the spherical model. 'Oval' was considered an acceptable deviation given the choice of shape and supporting responses from the other items.
- Model 3: uncertain sphere (1 child in the experimental group; 0 children in the control group). The one child assigned to this model was unable to describe the shape of the Sun verbally but selected a sphere as most like the Sun from the different shapes provided. Responses to other items suggested that this child may indeed have held a spherical Sun model or Model 2.
- Model 4: the Sun is non-spherical (5 children in the experimental group; 5 children in the control group). The children assigned to this model failed to provide an adequate verbal response or to select a sphere as most like the Sun from the different shapes provided. Responses to other items were also either inconsistent or inconclusive. Variation was extensive. Response combinations suggested that the Sun was perhaps thought hemispherical, cylindrical or disk shaped. In some cases, children considered the possibility of all three as perhaps they sought to account for the shape of the Sun's visible disk.
- Model 5: uncertain non-spherical (0 children in the experimental group; 2 children in the control group). The two children assigned to this model were also unable to describe the shape of the Sun verbally or to select a sphere as most like the Sun from the different shapes provided. The 'not sure/hemisphere' combinations suggested that the Sun in both cases was perhaps thought hemispherical or that the children involved also sought to account for the shape of the Sun's visible disk.

One child in the control group could not be assigned to any model (*'not sure'/'not sure'*). Where provided, children's evidence for the shape of the Sun in both groups came mostly from reference to Earth or space-based technologies (e.g. *'telescopes'* and *'satellites'*), books, television, logic (e.g. *'the Earth's going round it'*), comparing the properties of other shapes,

what they could see for themselves, and being told. Where provided, the interpretation of evidence did not always support the model held.

(c) Sun drawings and descriptions

Response categories for item S4 (drawing) are summarized as shown (Table 6.14). The general pattern of responses from both groups appears broadly similar. The most common type of drawing produced from both groups was a blank circle (g). Together with support from items S5 (colour), S6 ('life'), S7 (temperature), S8 (source of heat/light) and S12 (picture recognition), these response categories were used to examine children's ideas about how the Sun looks from space further.



Response	Experimental group			Control group		
	Boys	Girls	Total	Boys	Girls	Total
(a) Featured	1 (5.9)	2 (14.3)	3 (9.7)	2 (11.8)	0 (0.0)	2 (6.5)
(b) Irregular	2 (11.8)	1 (7.1)	3 (9.7)	1 (5.9)	1 (7.1)	2 (6.5)
(c) Fuzzy	1 (5.9)	0 (0.0)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
(d) Halo	3 (17.6)	0 (0.0)	3 (9.7)	2 (11.8)	2 (14.3)	4 (12.9)
(e) Sunbeam	3 (17.6)	4 (28.6)	7 (22.6)	5 (29.4)	4 (28.6)	9 (29.0)
(f) Internal	1 (5.9)	0 (0.0)	1 (3.2)	0 (0.0)	1 (7.1)	1 (3.2)
(g) Blank	6 (35.3)	7 (50.0)	13 (41.9)	7 (41.2)	5 (35.7)	12 (38.7)
(h) Semicircle/rectangle	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (7.1)	1 (3.2)

Table 6.14 Drawings of the Sun from space (frequency and percentage)

Three mental models were identified. The children in the experimental group presented ideas consistent with Models 1 and 2, the children in the control group Models 1, 2 and 3.

- Model 1: the Sun is an astronomical body of some considerable size with the depiction of surface features, heat and light taking many different forms (18 children in the experimental group; 19 children in the control group). Like the Earth, while each of the drawing types provided appear to indicate stylistic variation along a continuum (a-f),

differing only in the attention to detail represented and the descriptive information provided, the notion of each as a discrete model in its own right cannot be entirely discounted. Within the single model adopted here, the lack of recognizable sunspots and solar flares or prominences found only in (a) was considered an acceptable deviation.

- Model 2: the Sun is an astronomical body of some considerable size with surface features, heat and light not represented (13 children in the experimental group; 12 children in the control group). The children assigned to this model were unable or unwilling to complete their drawing (g) though surface features, heat and light were often described.
- Model 3: the Sun is a particularly hot astronomical body of some considerable size and unusual shape (0 children in the experimental group; 1 child in the control group). The one child assigned to this model drew two pictures of the Sun, one semi-circular and the other rectangular. This supported their view of the shape of the Sun in response to S1 (shape verbal) and S2 (shape selection).

While descriptions of the colour of the Sun varied, all of the children in both groups considered it either *'orange'*, *'yellow'*, *'red'* or *'fiery'* or two or more of these colours in combination. With the exception of a few children who were *'not sure'*, almost all considered the Sun *'too hot'* to support life (other than minor reference to aliens), though the absolute temperature of the Sun remained unknown. While *'burning gas'* was occasionally given as the source of the Sun's heat and light, *'lava'* and other references to volcanic activity also featured prominently. Almost all of the children in the experimental group and all of the children in the control group identified the Sun from pictures of other Solar System objects.

(d) Nature of the Sun

Response categories for item S11 (nature) are summarized as shown (Table 6.15). The general pattern of responses from both groups appears different. Most children in the experimental group considered the Sun to be a *'planet'* or a *'planet on fire'* while most children in the control group considered the Sun to be *'a star'*, *'a ball of fire'* or *'burning gas'*. With limited support from other items, this category was used to examine children's ideas about the nature of the Sun further.

Response	Experimental group			Control group		
	Boys	Girls	Total	Boys	Girls	Total
Star (ball of fire/burning gas)	4 (23.5)	2 (14.3)	6 (19.4)	5 (29.4)	4 (28.6)	9 (29.0)
Star	2 (11.8)	2 (14.3)	4 (12.9)	5 (29.4)	2 (14.3)	7 (22.6)
Light/heat/fire	2 (11.8)	4 (28.6)	6 (19.4)	1 (5.9)	2 (14.3)	3 (9.7)
Planet	9 (52.9)	4 (28.6)	13 (41.9)	3 (17.6)	3 (21.4)	6 (19.4)
Not sure	0 (0.0)	2 (14.3)	2 (6.5)	3 (17.6)	3 (21.4)	6 (19.4)

Table 6.15 The nature of the Sun (frequency and percentage)

Three mental models were identified. The children in the experimental group and the control group presented ideas consistent with all three.

- Model 1: the Sun exists in space as a star (10 children in the experimental group; 16 children in the control group). Two descriptive variations were indicated. In the first, the Sun was known to be a star with a star described as a *'ball of fire'* or a *'ball of burning gas'*; in the second, the Sun was know to be a star but the nature of stellar objects remained uncertain. The second variation was considered an acceptable deviation. Many children revealed further uncertainty in the nature of the Sun by extending their responses to indicate that the Sun is *'a big star'* or *'a daytime star'* with reference to their knowledge and understanding of stars as a whole.
- Model 2: the Sun is light, heat or fire (6 children in the experimental group; 3 children in the control group). Children assigned to this model seemed unaware that the Sun is a star, resorting instead to describing it in terms of its most obvious physical attributes.
- Model 3: the Sun exists in space as a planet or a planet on fire (13 children in the experimental group; 6 children in the control group). Children assigned to this model considered the Sun in the same category of objects as the Earth.

Two children in the experimental group and six children in the control group could not be assigned to any model (*'not sure'*).

6.5.2 Second interview: post-experimental treatment

Overviews of Sun responses, mental models, score frequency profiles and summated scores from children in the experimental group and control group at second interview (post-experimental treatment) can be found in Appendix VII.

(a) Correctness

The overall correctness of responses in each of the twelve Sun items is summarized as shown (Table 6.16). Increases in correctness in the experimental group were observed in ten Sun items (S1 to 4, 6 to 8 and 10 to 12) with no change in two (S5 and 9). Among the many differences, frequencies associated with items S1 (shape verbal), S4 (drawing), S8 (source of heat/light), S10 (relative size) and S11 (nature) in the experimental group were notably greater relative to changes in the control group (up between 23 and 48 percentage points for S1 and S11 respectively). Despite a slight increase in the frequency of correct responses from the experimental group, children's knowledge and understanding of the temperature of the Sun and its absolute size remained poor.

	Experimental group			**Control group**		
Sun item	Boys	Girls	Total	Boys	Girls	Total
S1: Shape (verbal)	13 (76.5)	5 (35.7)	18 (58.1)	6 (35.3)	5 (35.7)	11 (35.5)
S2: Shape (selection)	17 (100.0)	11 (78.6)	28 (90.3)	15 (88.2)	11 (78.6)	26 (83.9)
S3: Interp. of evidence	13 (76.5)	4 (28.6)	17 (54.8)	5 (29.4)	7 (50.0)	12 (38.7)
S4: Drawing	17 (100.0)	10 (71.4)	27 (87.1)	12 (70.6)	8 (57.1)	20 (64.5)
S5: Colour	17 (100.0)	14 (100.0)	31 (100.0)	17 (100.0)	14 (100.0)	31 (100.0)
S6: 'Life'	17 (100.0)	14 (100.0)	31 (100.0)	17 (100.0)	14 (100.0)	31 (100.0)
S7: Temperature	3 (17.6)	1 (7.1)	4 (12.9)	0 (0.0)	0 (0.0)	0 (0.0)
S8: Source of heat/light	9 (52.9)	5 (35.7)	14 (45.2)	3 (17.6)	0 (0.0)	3 (9.7)
S9: Absolute size	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
S10: Relative size	15 (88.2)	10 (71.4)	25 (80.6)	9 (52.9)	8 (57.1)	17 (54.8)
S11: Nature	16 (94.1)	13 (92.9)	29 (93.5)	12 (70.6)	8 (57.1)	20 (64.5)
S12: Picture recognition	17 (100.0)	14 (100.0)	31 (100.0)	17 (100.0)	14 (100.0)	31 (100.0)

Table 6.16 Sun correctness by item (frequency and percentage)

(b) The shape of the Sun

Combined response categories for items S1 (shape verbal) and S2 (shape selection) are summarized as shown (Table 6.17). The general pattern of combined responses observed between groups was no longer similar. In the experimental group, the most common description of the shape of the Sun was *'a sphere'* or *'spherical'* (previously *'round'*). The most common choice of shape most like the Sun remained a sphere.

Response (verbal/choice)	Experimental group			Control group		
	Boys	Girls	Total	Boys	Girls	Total
No real shape/sphere	3 (17.6)	0 (0.0)	3 (9.7)	0 (0.0)	0 (0.0)	0 (0.0)
Ball, sphere/'sphere'	2 (11.8)	0 (0.0)	2 (6.5)	0 (0.0)	0 (0.0)	0 (0.0)
Sphere/sphere	8 (47.1)	5 (35.7)	13 (41.9)	4 (23.5)	2 (14.3)	6 (19.4)
Ball/sphere	0 (0.0)	0 (0.0)	0 (0.0)	2 (11.8)	2 (14.3)	4 (12.9)
Round/sphere	2 (11.8)	6 (42.9)	8 (25.8)	8 (47.1)	7 (50.0)	15 (48.4)
Circle/sphere	2 (11.8)	0 (0.0)	2 (6.5)	1 (5.9)	0 (0.0)	1 (3.2)
Sort of ... /hemisphere	0 (0.0)	1 (7.1)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
Round, ball/cylinder	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	1 (7.1)	2 (6.5)
Circle, round/disk	0 (0.0)	1 (7.1)	1 (3.2)	1 (5.9)	0 (0.0)	1 (3.2)
Round/not sure	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (7.1)	1 (3.2)
Not sure/disk	0 (0.0)	1 (7.1)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
Not sure/not sure	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (7.1)	1 (3.2)

Table 6.17 Sun shape response categories (frequency and percentage)

Only four of the original five mental models were identified. The children in the experimental group presented ideas consistent with all four.

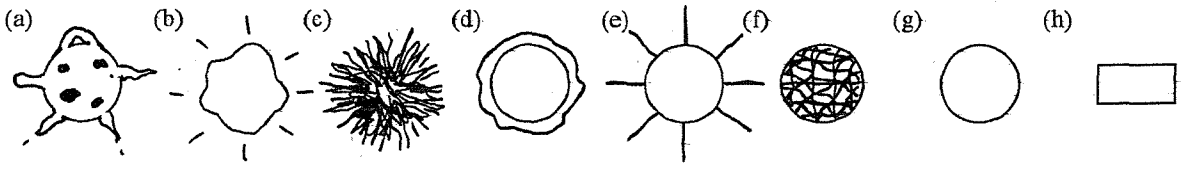
- Model 1: the Sun is nearly spherical (5 children in the experimental group; 0 children in the control group). The children in the experimental group assigned to this model described the Sun as having *'no real shape'* or *'a ball'* and *'a sphere'*, the latter two with reference to *'fire coming out of it'*. Having selected a sphere as most like the Sun from the different shapes provided, accompanying descriptions often included *'only kind of spherical'*.
- Model 2: the Sun is spherical (23 children in the experimental group; 26 children in the control group). Within the experimental group, the five original linguistic variations of spherical Sun were reduced to three with the loss of *'ball shaped'* or *'round like a ball'* and *'oval'*. The increase in frequency of descriptions of the Sun as *'a sphere'* or *'spherical'* (up 16 percentage points relative to changes in the control group) and the reduced frequency of descriptions of the Earth as *'round'* (down 16 percentage points relative to changes in the control group) were particularly notable.
- Model 3: The Sun is non-spherical (2 children in the experimental group; 3 children in the control group). Variation within the experimental group was less extensive. Response combinations suggested that the Sun was perhaps thought hemispherical or disk shaped. Three of the five children in the experimental group assigned to this model initially now provided responses consistent with Model 2.

- Model 4: uncertain non-spherical (1 child in the experimental group; 0 children in the control group). The one child in the experimental group assigned to this model provided initial responses consistent with Model 2. Response combinations suggested that the Sun was perhaps thought disk shaped.

The one child in the experimental group presenting uncertain spherical ideas initially now provided responses consistent with Model 1. Two children in the control group could not be assigned to any model (*'not sure'/'not sure'* and *'round'/'not sure'*). Where provided, children's evidence for the shape of the Sun came from the same sources mentioned earlier. Within the experimental group, however, there was a notable increase in reference to Earth or space-based technologies (e.g. *'astronomers have taken photographs of it through telescopes'*, *'they've most probably had satellites go out to look at it'*). Where provided, the interpretation of evidence supported the models held in most cases.

(c) Sun drawings and descriptions

Response categories for item S4 (drawing) are summarized as shown (Table 6.18). The general pattern of responses observed between groups was no longer similar. Previously a blank circle (g), the most common drawings produced by the experimental group were featured (a).



Response	Experimental group			Control group		
	Boys	Girls	Total	Boys	Girls	Total
(a) Featured	12 (70.6)	5 (35.7)	17 (54.8)	2 (11.8)	1 (7.1)	3 (9.7)
(b) Irregular	2 (11.8)	0 (0.0)	2 (6.5)	2 (11.8)	0 (0.0)	2 (6.5)
(c) Fuzzy	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
(d) Halo	2 (11.8)	2 (14.3)	4 (12.9)	3 (17.6)	1 (7.1)	4 (12.9)
(e) Sunbeam	1 (5.9)	3 (21.4)	4 (12.9)	4 (23.5)	6 (42.9)	10 (32.3)
(f) Internal	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	0 (0.0)	1 (3.2)
(g) Blank	0 (0.0)	4 (28.6)	4 (12.9)	5 (29.4)	5 (35.7)	10 (32.3)
(h) Semicircle/rectangle	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.0)	1 (3.2)

Table 6.18 Drawings of the Sun from space (frequency and percentage)

All three of the original mental models were identified. The children in the experimental group continued to present ideas consistent with Models 1 and 2 only.

- Model 1: the Sun is an astronomical body of some considerable size with the depiction of surface features, heat and light taking many different forms (27 children in the experimental group; 20 children in the control group). Within the experimental group, the six original stylistic variations of this model were reduced to four (a, b, d and e). The increased frequency of featured drawings (a), with the depiction of sunspots, flares and prominences clearly visible and described, was particularly notable (up 42 percentage points relative to changes in the control group).
- Model 2: the Sun is an astronomical body of some considerable size with surface features, heat and light not represented (4 children in the experimental group; 10 children in the control group). Within the experimental group, the reduced frequency of the Sun drawn as blank circles (g) was particularly notable (down 23 percentage points relative to changes in the control group). Ten of the thirteen children in the experimental group assigned to this model initially now provided responses consistent with Model 1.
- Model 3: the Sun is a particularly hot astronomical body of some considerable size and unusual shape (0 children in the experimental group; 1 child in the control group). No children in the experimental group were assigned to this model initially.

While descriptions of the colour of the Sun still varied, and included *'orange'*, *'yellow'*, *'red'* and *'fiery'* or two or more of these colours in combination, *'black'* was also mentioned regularly for *'sunspots'* or *'cool areas of gas'*. Sunspots were variously described as *'black spots'*, *'cool spots'* and *'black holes'*. In featured drawings (a), prominences and flares were mentioned by name and described as *'flames'*, *'pillars of fire'* and *'bits exploding off'*. While all of the children considered the Sun *'too hot'* to support life, its absolute temperature was only provided by four individuals (e.g. *'15 million degrees in the centre'*, *'5000 degrees at the surface'*). About half of the children suggested that the source of the Sun's heat and light came from *'gas burning'* with occasional reference to *'hydrogen and helium like in bombs'* and *'it's like nuclear fusion isn't it?'*. Other references included *'it uses up a lot of energy like hydrogen and neutrogen'* and *'the hydrogen burns and the helium helps it ... it's like oil'*.

All of the children in the experimental group identified the Sun from pictures of other Solar System objects.

(d) Nature of the Sun

Response categories for item S11 (nature) are summarized as shown (Table 6.19). The general pattern of responses observed between groups appears broadly more similar than before. The most common response from the experimental group was *'a star'*, *'a ball of fire'* or *'burning gas'* (previously *'a planet'* or *'a planet on fire'*).

	Experimental group			Control group		
Response	Boys	Girls	Total	Boys	Girls	Total
Star (ball of fire/burning gas)	9 (52.9)	7 (50.0)	16 (51.6)	4 (23.5)	1 (7.1)	5 (16.1)
Star	7 (41.2)	6 (42.9)	13 (41.9)	8 (47.1)	7 (50.0)	15 (48.4)
Light/heat/fire	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (7.1)	1 (3.2)
Planet	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	3 (21.4)	4 (12.9)
Not sure	1 (5.9)	1 (7.1)	2 (6.5)	4 (23.5)	2 (14.3)	6 (19.4)

Table 6.19 The nature of the Sun (frequency and percentage)

The three original mental models were identified. The children in the experimental group presented ideas consistent with Model 1 only.

- Model 1: the Sun exists in space as a star (29 children in the experimental group; 20 children in the control group). Within the experimental group, while the two original variations remained, the increased frequencies of the Sun as a star (a ball of fire/burning gas) and simply a star were particularly notable (the former up 19 percentage points relative to changes in the control group, the latter, despite a substantial increase, up only 3 percentage points relative to changes in the control group). Reference to the Sun as *'a big star'* or *'a daytime star'*, often mentioned earlier, were rare.
- Model 2: the Sun is light, heat or fire (0 children in the experimental group; 1 child in the control group). The six children in the experimental group assigned to this model initially now provided responses consistent with Model 1.
- Model 3: the Sun exists in space as a planet or a planet on fire (0 children in the experimental group; 4 children in the control group). Notably, all but two of the thirteen

children in the experimental group assigned to this model initially now provided responses consistent with Model 1 (down 35 percentage points relative to changes in the control group).

Two children in the experimental group and six children in the control group could not be assigned to any model (*'not sure'*).

6.5.3 Summary of inferential analyses

For a full treatment of the quantitative data see Appendix VIII.

(i) Pre-experimental treatment

At first interview, overall scores in the experimental group ranged from 9 to 22 with a mean of 15.4 (SD 3.17). Score profile percentages included 25.0% 0s, 26.1% 1s, 44.6% 2s and 4.3% 3s. 1 child scored between 0 and 11 (3%) and 30 children between 12 and 23 (97%). Overall scores in the control group ranged from 10 to 23 with a mean of 15.5 (SD 3.82). Score profile percentages included 28.5% 0s, 21.2% 1s, 43.0% 2s and 7.3% 3s. 4 children scored between 0 and 11 (13%) and 27 children between 12 and 23 (87%). The observed differences between the experimental group and control group in overall mean scores, score profile percentages and median scores in items of particular interest (S1, S2, S4, S8 and S11) at first interview were not significant.

Boys in the experimental group appeared to score more highly than the girls overall and the observed difference in their mean scores, 16.5 and 14.0 (SDs 3.11 and 2.75), was significant ($t=2.38$, $df=29$, $p=0.024$; normality for boys $D_{xb}=0.109$, $p>0.15$; normality for girls $D_{xg}=0.072$, $p>0.15$; F-ratio=1.28) as were the observed differences in score profile percentages by gender (test statistic $D_{xbg}=0.176$, critical value $K_D=0.170$ for $\alpha=0.01$). In those items of particular interest (S1, S2, S4, S8 and S11), observed differences in median scores between boys and girls were significant in S2 (shape selection: $W_{xb}=310.5$, $W_{xg}=185.5$, $p=0.039$). No significant gender differences were observed in the control group.

(ii) Post-experimental treatment

At second interview, overall scores in the experimental group ranged from 11 to 29 with a mean of 20.1 (SD 4.31), a significant change from before (matched t=-8.28, p=0.000, normality of differences in experimental scores D_{dx}=0.134, p>0.15; F-ratio=1.85 which is just significant at α=0.05). Score profile percentages included 20.4% 0s, 11.0% 1s, 49.5% 2s and 19.1% 3s, again a significant change from before (test statistic D_x=0.196, critical value K_D=0.120 for α=0.01). 1 child scored between 0 and 11 (3%), 22 children between 12 and 23 (71%) and 8 children between 24 and 36 (26%). Overall scores in the control group ranged from 11 to 23 with a mean of 15.4 (SD 3.03). Score profile percentages included 29.6% 0s, 16.1% 1s, 50.5% 2s and 3.8% 3s. 1 child scored between 0 and 11 (3%) and 30 children between 12 and 23 (97%). None of the changes observed between interviews were significant. More importantly, however, the mean gain in individual scores from children in the experimental group (O_3-O_1) and control group (O_4-O_2), +4.7 and –0.1 (SDs 3.15 and 2.76), was significant (t=6.31, df=60 p=0.000; D_{dx}=0.134, D_{dc}=0.059, p>0.15; F-ratio=1.30) as was the post-experimental treatment analysis of the score profile percentages (test statistic D_{xc}=0.153, critical value K_D=0.120 for α=0.01). In those items of particular interest (S1, S2, S4, S8 and S11), observed differences in median scores between the experimental group and control group were significant for S4 (drawing: W_{x2}=1214.5, W_{c2}=738.5, p=0.000), S8 (source of heat and light: W_{x2}=1178.0, W_{c2}=775.0, p=0.001) and S11 (nature: W_{x2}=1198.5, W_{c2}=754.5, p=0.001). Within the experimental group, multiple linear regression analysis using age, intellectual maturity and science curiosity as independent predictor variables was significant (R^2=0.294, F=3.75, p=0.022, df=3), but with only age contributing to the differences in summated scores between individuals.

Boys in the experimental group continued to significantly outscore the girls (mean scores 22.1 and 17.6, SDs 3.91 and 3.52 respectively; t=3.27, df=29, p=0.003; normality for boys D_{xb}=0.057, p>0.15; normality for girls D_{xg}=0.144, p>0.15; F-ratio=1.23) and again this was reflected in score profile percentages by gender (test statistic D_{xbg}=0.154, critical value K_D=0.142 for α=0.05). Observed differences in median scores between boys and girls were significant in items S1 (shape verbal: W_{xb}=330.0, W_{xg}=166.0, p=0.012), S2 (shape selection:

W_{xb}=308.5, W_{xg}=187.5, p=0.026) and S4 (drawing: W_{xb}=323.5, W_{xg}=172.5, p=0.024). No significant differences were observed in the control group.

6.5.4 Knowledge acquisition and concept learning

Within the experimental group at first interview, and before the experimental treatment, children's declared knowledge and understanding as probed suggested that their concept of the Sun was in a variable state of development. In terms of the Sun's shape, how it looks from space and its nature, scientific as well as non-scientific models (intuitive and transitional) were evident (Table 6.20). As with the Earth, almost all of the scientific models identified contained acceptable deviations in the form of linguistic, stylistic and descriptive variation to a greater or lesser degree.

	Pre-experimental Total	+/-	Post-experimental Total	+/-	Delayed Total
Shape	25 (80.6)	+3	28 (90.3)	+1	29 (93.5)
Drawing	18 (58.1)	+9	27 (87.1)	-3	24 (77.4)
Nature	10 (32.3)	+19	29 (93.5)	-1	28 (90.3)
Shape + drawing	13 (41.9)	+13	26 (83.9)	-2	24 (77.4)
Shape + drawing + nature	7 (22.6)	+17	24 (77.4)	0	24 (77.4)

Table 6.20 Summary of scientific mental models of the Sun (frequency and percentage)

At second interview, and after the experimental treatment, increases in the frequencies of scientific models and combinations of models as a whole revealed considerable improvements particularly in drawings and the nature of the Sun (Table 6.20). Features associated with knowledge acquisition and concept learning in the experimental group relative to the control group are summarized as follows:

- descriptions of the Sun's shape revealed a slight reduction in linguistic variation with a corresponding and moderate improvement in the correct use of scientific vocabulary;
- drawings of the Sun from space revealed a significant improvement in style featuring the presentation and description of flares, prominences and sunspots;
- accounts of the nature of the Sun revealed a significant improvement in descriptions of the Sun as a star, a ball of fire or burning gas;

- unlike the Earth, the experimental treatment appeared to widen the gap in the differences observed between boys and girls (correctness, response categories, median scores in several items of particular interest and mean score);
- the number of children with summated scores in the 24 to 36 range, reflecting more 2s and 3s, increased notably with a corresponding and significant increase in score profile percentages, overall mean score and mean gain;
- only the predictor variable age contributed significantly to the differences in summated scores between individuals.

Interestingly, the experimental treatment did little to improve knowledge and understanding of the Sun's absolute size or its temperature. Similarly, while the source of the Sun's heat and light was significantly better known, this only included about half of the children involved.

Knowledge acquisition and concept learning in the experimental group are perhaps best accounted for in terms of both weak (accretion and tuning) and radical restructuring. Like the Earth, the relationship between response categories, mental models, knowledge acquisition and concept learning is particularly well illustrated in the mapped movements or routes and pathways in children's ideas about the Sun's shape (Fig. 6.2; see also Table 6.20 and Appendix VII for a delayed overview). Interestingly, initial routes and pathways (pre-to post-) revealed 11 'non-movers' (original ideas retained – horizontal links), 15 'risers' (original ideas progressed – positive gradient links) and 5 'fallers' (original ideas regressed – negative gradient links). Later routes and pathways (post- to delayed) revealed 16 'non-movers', 6 'risers' and 9 'fallers', five of whom made progress initially. It is important to notice that while many of the changes which appear to have taken place did so within one mental model (the Sun is spherical), a feature of the linguistic variation described and weak restructuring, many other changes also took place between other models. In the case of non-spherical to spherical Suns, for example, this represented radical restructuring. The complex pattern of change in linguistic variation observed perhaps indicates that learning about the shape of the Sun was slightly more difficult than learning about the shape of the Earth. In those areas of children's ideas about the Sun which received most attention earlier (S1, S2, S4, S8 and S11), observed differences in median scores between second and third interviews

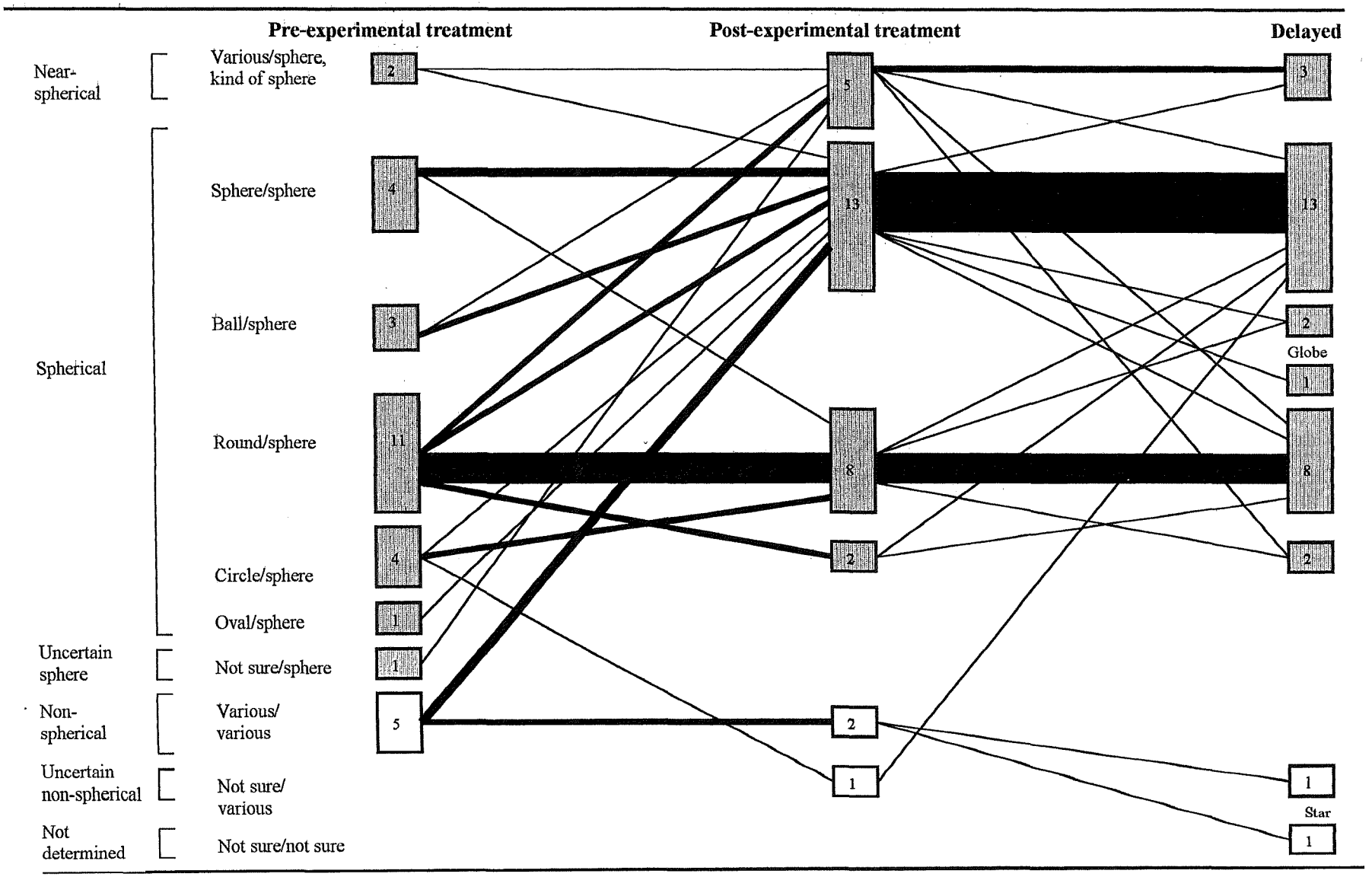


Fig.6.2 Knowledge acquisition and concept learning: mapped changes in children's response categories and mental models of the Sun's shape

(post-experimental treatment and delayed) were not significant indicating a high degree of retention and recall.

6.6 The Moon

The Moon is the Earth's only natural satellite, a lifeless ball of rock visited between 1969 and 1972 by American astronauts during the Apollo space missions. In this section, children's ideas about the shape of the Moon, how it looks from space and its nature as a satellite are of particular interest. Like the Earth and the Sun, while relative size is included as a scored item, relative size is dealt with in Section 6.7.

6.6.1 First interview: pre-experimental treatment

Overviews of Moon responses, mental models, score frequency profiles and summated scores from children in the experimental group and control group at first interview (pre-experimental treatment) can be found in Appendix VII.

(a) Correctness

The overall correctness of response in each of the twelve Moon items considered is summarized as shown (Table 6.21). Like the Sun, the general pattern of responses obtained from both groups for most items, though mixed, appears broadly similar. Particularly high frequencies were recorded in M2 (shape selection), M4 (drawing) and, in the control group, M12 (picture recognition). Particularly low frequencies were recorded in M5 (colour), M6 ('life'), M7 (phases), M8 (cycle) and M11 (nature). None of the children were aware of the Moon's absolute size (M9).

Moon item	Experimental group			Control group		
	Boys	Girls	Total	Boys	Girls	Total
M1: Shape (verbal)	7 (41.2)	1 (7.1)	8 (25.8)	3 (17.6)	2 (14.3)	5 (16.1)
M2: Shape (selection)	14 (82.4)	6 (42.9)	20 (64.5)	14 (82.4)	10 (71.4)	24 (77.4)
M3: Interp. of evidence	10 (58.8)	4 (28.6)	14 (45.1)	9 (52.9)	9 (64.3)	18 (58.1)
M4: Drawing	14 (82.4)	9 (64.3)	23 (74.2)	13 (76.5)	10 (71.4)	23 (74.2)
M5: Colour	5 (29.4)	3 (21.4)	8 (25.8)	5 (29.4)	3 (21.4)	8 (25.8)
M6: 'Life'	5 (29.4)	1 (7.1)	6 (19.4)	4 (23.5)	0 (0.0)	4 (12.9)
M7: Phases	1 (5.9)	0 (0.0)	1 (3.2)	4 (23.5)	3 (21.4)	7 (22.6)
M8: Cycle	7 (41.2)	3 (21.4)	10 (32.3)	3 (17.6)	1 (7.1)	4 (12.9)
M9: Absolute size	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
M10: Relative size	9 (52.9)	5 (35.7)	14 (45.2)	7 (41.2)	7 (50.0)	14 (45.2)
M11: Nature	3 (17.6)	1 (7.1)	4 (12.9)	4 (23.5)	3 (21.4)	7 (22.6)
M12: Picture recognition	7 (41.2)	7 (50.0)	14 (45.2)	12 (70.6)	8 (57.1)	20 (64.5)

Table 6.21 Moon correctness by item (frequency and percentage)

(b) The shape of the Moon

Combined response categories for items M1 (shape verbal) and M2 (shape selection) are summarized as shown (Table 6.22). The general pattern of combined responses from both groups appears broadly similar. The most common description of the shape of the Moon in both groups was *'round'* and the most common choice of shape most like the Moon in both groups was a sphere. With some support from other items, notably M3 (interpretation of evidence) and M4 (drawing), these combined response categories were used to examine children's ideas about the shape of the Moon further.

Response (verbal/choice)	Experimental group			Control group		
	Boys	Girls	Total	Boys	Girls	Total
Sphere/sphere	4 (23.5)	1 (7.1)	5 (16.1)	2 (11.8)	2 (14.3)	4 (12.9)
Ball/sphere	3 (17.5)	0 (0.0)	3 (9.7)	1 (5.9)	0 (0.0)	1 (3.2)
Bumpy/sphere	1 (5.9)	0 (0.0)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
Round/sphere	4 (23.5)	5 (35.7)	9 (29.0)	8 (47.1)	5 (35.7)	13 (41.9)
Circle/sphere	2 (11.8)	0 (0.0)	2 (6.5)	3 (17.6)	3 (21.4)	6 (19.4)
Round, circle/hemisphere, various	1 (5.9)	2 (14.3)	3 (9.7)	1 (5.9)	1 (7.1)	2 (6.5)
Round, circle/disk	1 (5.9)	0 (0.0)	1 (3.2)	0 (0.0)	1 (7.1)	1 (3.2)
Round, half/semicircle	0 (0.0)	1 (7.1)	1 (3.2)	0 (0.0)	1 (7.1)	1 (3.2)
Not sure/semicircle, various	0 (0.0)	2 (14.3)	2 (6.5)	2 (11.8)	0 (0.0)	2 (6.5)
Round, banana/not sure	1 (5.9)	3 (21.4)	4 (12.9)	0 (0.0)	0 (0.0)	0 (0.0)
Not sure/not sure	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (7.1)	1 (3.2)

Table 6.22 Moon shape response categories (frequency and percentage)

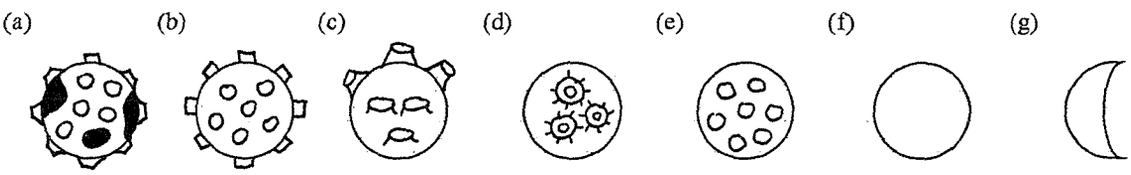
Three mental models were identified. The children in the experimental group and the control group presented ideas consistent with all three.

- Model 1: the Moon is spherical (20 children in the experimental group; 24 children in the control group). The children assigned to this model described the Moon as *'a sphere'* or *'spherical'*, *'ball shaped'* or *'round like a ball'*, *'bumpy'*, *'round'* and *'a circle'* or *'circular'*. All verbal responses were followed by the selection of a sphere as most like the Moon from the different shapes provided. Each of the five verbal responses provided indicate linguistic variation within the spherical model.
- Model 2: the Moon is non-spherical (5 children in the experimental group; 4 children in the control group). The children assigned to this model failed to provide an adequate verbal response or to select a sphere as most like the Moon from the different shapes provided. Responses to other items were also either inconsistent or inconclusive. Variation was extensive. Response combinations suggested that the Moon was thought hemispherical, disk shaped or a range of different shapes all clearly influenced by the appearance of the Moon's phases.
- Model 3: uncertain non-spherical (6 children in the experimental group; 2 children in the control group). The children assigned to this model were unable to describe the shape of the Moon verbally or to select a sphere as most like the Moon from the different shapes provided. Variation was extensive. Response combinations suggested that the Moon was perhaps thought a whole range of different shapes, including *'like a banana'*, also clearly influenced by the appearance of the Moon's phases.

One child in the control group could not be assigned to any model (*'not sure'*/*'not sure'*). Where provided, children's evidence for the shape of the Moon in both groups came mostly from reference to Earth or space-based technologies (e.g. *'telescopes'* and *'satellites'*), books, posters, television, comparing the properties of other shapes, what they could see for themselves, and being told. Only a small number of children in both groups made reference to *'men'* having visited the Moon or travelled around it. Where provided, the interpretation of evidence did not always support the model held.

(c) Moon drawings and descriptions

Response categories for item M4 (drawing) are summarized as shown (Table 6.23). The general pattern of responses from both groups appears broadly similar. The most common type of drawing produced from both groups was a simple circle annotated with *'craters'* and *'holes'* or *'places where meteorites had hit it'* (e). Together with support from items M5 (colour), M6 ('life') and M12 (picture recognition), these response categories were used to examine children's ideas about how the Moon looks from space further.



Response	Experimental group			Control group		
	Boys	Girls	Total	Boys	Girls	Total
(a) Featured	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (7.1)	1 (3.2)
(b) Cratered I	1 (5.9)	1 (7.1)	2 (6.5)	2 (11.8)	1 (7.1)	3 (9.7)
(c) Cratered II	3 (17.6)	0 (0.0)	3 (9.7)	2 (11.8)	2 (14.3)	4 (12.9)
(d) Cratered III	2 (11.8)	0 (0.0)	2 (6.5)	1 (5.9)	0 (0.0)	1 (3.2)
(e) Cratered IV	8 (47.1)	8 (57.1)	16 (51.6)	8 (47.1)	6 (42.9)	14 (45.2)
(f) Blank	2 (11.8)	2 (14.3)	4 (12.9)	2 (11.8)	3 (21.4)	5 (16.1)
(g) Crescent	1 (5.9)	3 (21.4)	4 (12.9)	2 (11.8)	1 (7.1)	3 (9.7)

Table 6.23 Drawings of the Moon from space (frequency and percentage)

Three mental models were identified. The children in the experimental group and the control group presented ideas consistent with all three.

- Model 1: the Moon is an astronomical body with a cratered surface (23 children in the experimental group; 23 children in the control group). Like the Earth and the Sun, while each of the drawing types provided appear to indicate stylistic variation along a continuum (a-e), differing only in the attention to detail represented and the descriptive information provided, the notion of each as a discrete model in its own right cannot be entirely discounted. Depiction of the Moon's *'seas'* appeared on only one occasion from one child in the control group (a). Within the single model adopted here, the lack of 'seas' found only in (a) was considered an acceptable deviation.

- Model 2: the Moon is an astronomical body with surface features not represented (4 children in the experimental group; 5 children in the control group). The children assigned to this model were unable or unwilling to complete their drawing (f) though *'craters'* were described.
- Model 3: the Moon is an astronomical body of unusual shape (4 children in the experimental group; 3 children in the control group). The children assigned to this model drew the Moon in the shape of a crescent. In all cases, drawings matched models of shape provided earlier (non-spherical, uncertain non-spherical or not sure).

While descriptions of the colour of the Moon varied, most of the children in both groups considered it 'white' or 'grey' or a combination of the two. Others included *'brown'*, *'misty'*, *'light blue or green'* and *'yellow(-ish)'*. Most of the children in both groups recalled having observed up to three different phases of the Moon (usually full, crescent and quarter phases) but fewer were aware that these phases and others formed part of the Moon's regular cycle of apparent change. While many children were aware that the Moon supported no known life (other than minor reference to aliens), reasons varied (e.g. *'too hot'*, *'too cold'*, *'no air (or oxygen)'*, *'no gravity'*, *'no trees'*, *'nothing to see or do'*, *'too dusty'*, *'too dark'*). Several children in both groups mentioned that *'astronauts had been there and found none'*. One child in the experimental group referred to the possibility of *'bacteria'*, claims for bacteria in Martian meteorites having recently been reported by NASA in popular media. Only a little under half of the children in the experimental group and a little over half of the children in the control group identified the Moon from pictures of other Solar System objects.

(d) Nature of the Moon

Response categories for item M11 (nature) are summarized as shown (Table 6.24). The general pattern of responses from both groups appears broadly similar. Most children in both groups considered the Moon to be *'a planet'*. With limited support from other items, this category was used to examine children's ideas about the Moon further.

Response	Experimental group			Control group		
	Boys	Girls	Total	Boys	Girls	Total
Ball of rock/dust	3 (17.6)	1 (7.1)	4 (12.9)	4 (23.5)	3 (21.4)	7 (22.6)
Planet	9 (52.9)	2 (14.3)	11 (35.5)	8 (47.1)	4 (28.6)	12 (38.7)
Star	0 (0.0)	2 (14.3)	2 (6.5)	0 (0.0)	0 (0.0)	0 (0.0)
'between a star/planet'	2 (11.8)	0 (0.0)	2 (6.5)	0 (0.0)	0 (0.0)	0 (0.0)
'Moon is the Moon'	1 (5.9)	0 (0.0)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
'soft stuff'	0 (0.0)	1 (7.1)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
'comes out/shines at night'	1 (5.9)	4 (28.6)	5 (16.3)	0 (0.0)	1 (7.1)	1 (3.2)
Not sure	1 (5.9)	4 (28.6)	5 (16.3)	5 (29.4)	6 (42.9)	11 (35.5)

Table 6.24 The nature of the Moon (frequency and percentage)

Four mental models were identified. The children in the experimental group presented ideas consistent with Models 1, 2, 3 and 4, the children in the control group Models 1, 2 and 4.

- Model 1: the Moon is a ball of rock and/or dust (4 children in the experimental group; 7 children in the control group). Children assigned to this model considered the Moon in terms of its composition rather than as the Earth's only natural satellite.
- Model 2: the Moon is a planet (11 children in the experimental group; 12 children in the control group). Children assigned to this model considered the Moon in the same category of objects as the Earth.
- Model 3: the Moon is a star (2 children in the experimental group; 0 children in the control group). Children assigned to this model considered the Moon in the same category of objects as the Sun.
- Model 4: mixed nature (9 children in the experimental group; 1 children in the control group). Variations included *'between a star and a planet'*, *'the Moon is the Moon'*, *'soft stuff'* and the Moon is something which *'comes out'* or *'shines at night'*.

Five children in the experimental group and eleven children in the control group could not be assigned to any model (*'not sure'*).

6.6.2 Second interview: post-experimental treatment

Overviews of Moon responses, mental models, score frequency profiles and summated scores from children in the experimental group and control group at second interview (post-experimental treatment) can be found in Appendix VII.

(a) Correctness

The overall correctness of response in each of the twelve Moon items considered is summarized as shown (Table 6.25). Increases in correctness in the experimental group were observed in all twelve Moon items. Among the many differences, frequencies associated with all items other than M9 (absolute size), which remained poor, were notably greater relative to changes in the control group (up to 61 percentage points in the case of M7: phases).

	Experimental group			Control group		
Moon item	Boys	Girls	Total	Boys	Girls	Total
M1: Shape (verbal)	8 (47.1)	7 (50.0)	15 (48.4)	2 (11.8)	2 (14.3)	4 (12.9)
M2: Shape (selection)	16 (94.1)	11 (78.6)	27 (87.1)	14 (82.4)	10 (71.4)	24 (77.4)
M3: Interp. of evidence	13 (76.5)	9 (64.3)	22 (71.0)	9 (52.9)	6 (42.9)	15 (48.4)
M4: Drawing	15 (88.2)	13 (92.9)	28 (90.3)	10 (58.8)	9 (64.3)	19 (61.3)
M5: Colour	13 (76.5)	10 (71.4)	23 (74.2)	7 (41.2)	1 (7.1)	8 (25.8)
M6: 'Life'	14 (82.4)	5 (35.7)	19 (61.3)	3 (17.6)	0 (0.0)	3 (9.7)
M7: Phases	14 (82.4)	6 (42.9)	20 (64.5)	4 (23.5)	3 (21.4)	7 (22.6)
M8: Cycle	10 (58.8)	4 (28.6)	14 (45.2)	2 (11.8)	2 (14.3)	4 (12.9)
M9: Absolute size	1 (5.9)	0 (0.0)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
M10: Relative size	15 (88.2)	10 (71.4)	25 (80.6)	9 (52.9)	8 (57.1)	17 (54.8)
M11: Nature	11 (64.7)	5 (35.7)	16 (51.6)	2 (11.8)	1 (7.1)	3 (9.7)
M12: Picture recognition	14 (82.4)	10 (71.4)	24 (77.4)	13 (76.5)	9 (64.3)	22 (71.0)

Table 6.25 Moon correctness by item (frequency and percentage)

(b) The shape of the Moon

Combined response categories for items M1 (shape verbal) and M2 (shape selection) are summarized as shown (Table 6.26). The general pattern of responses observed between groups was no longer similar. In the experimental group, the most common description of the shape of the Moon was *'a sphere'* or *'spherical'* (previously *'round'*). The most common choice of shape most like the Moon remained a sphere.

Response (verbal/choice)	Experimental group			Control group		
	Boys	Girls	Total	Boys	Girls	Total
Sphere/sphere	8 (47.1)	7 (50.0)	15 (48.4)	2 (11.8)	2 (14.3)	4 (12.9)
Round/sphere	7 (41.2)	4 (28.6)	11 (35.5)	11 (64.7)	7 (50.0)	18 (58.1)
Circle/sphere	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	1 (7.1)	2 (6.5)
Not sure/sphere	1 (5.9)	0 (0.0)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
Depends/sphere and disk	0 (0.0)	1 (7.1)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
Round, circle/hemisphere, various	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	3 (21.4)	4 (12.9)
Round/disk	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (7.1)	1 (3.2)
Depends/disk and semicircle	0 (0.0)	1 (7.1)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
Not sure/hemisphere, semicircle	1 (5.9)	1 (7.1)	2 (6.5)	2 (11.8)	0 (0.0)	2 (6.5)

Table 6.26 Moon shape response categories (frequency and percentage)

In addition to the three original mental models, the responses provided by the children in the experimental group indicated the presence of a fourth not previously identified.

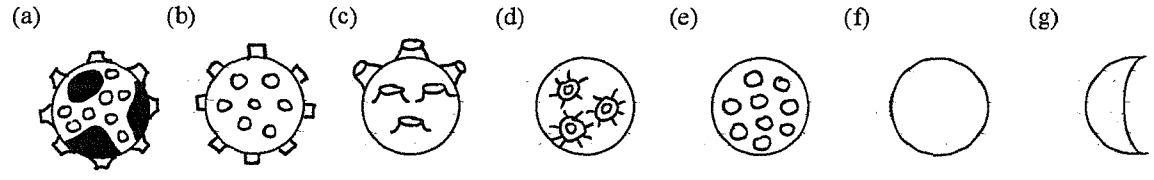
- Model 1: the Moon is spherical (26 children in the experimental group; 24 children in the control group). Within the experimental group, the five original linguistic variations of spherical Moon were reduced to two with the loss of all but *'a sphere'* or *'spherical'* and *'round'*. The increase in frequency of descriptions of the Moon as *'a sphere'* or *'spherical'* was particularly notable (up 32 percentage points relative to changes in the control group).
- Model 2: uncertain sphere (1 child in the experimental group; 0 children in the control group). Not previously identified. The one child in the experimental group assigned to this model was unable to describe the shape of the Moon verbally but selected a sphere as most like the Moon from the different shapes provided. This child initially provided responses consistent with Model 1.
- Model 3: the Moon is non-spherical (2 children in the experimental group; 5 children in the control group). Variation within the experimental group was less extensive. Response combinations suggested that distractions associated with the Moon's phases continued to influence some ideas (shape *'depends'* with selection of spheres, disks and semicircles). Four of the five children in the experimental group assigned to this model initially now provided responses consistent with Model 1.
- Model 4: uncertain non-spherical (2 children in the experimental group; 2 children in the control group). Variation within the experimental group was less extensive. Response combinations suggested that distractions associated with the Moon's phases continued to

influence some ideas. Four of the six children in the experimental group assigned to this model initially now provided responses consistent with Model 1.

Where provided, children's evidence for the shape of the Moon came from the same sources mentioned earlier. Within the experimental group, however, there was a notable increase in reference to Earth or space-based technologies (e.g. *'people have looked at it through telescopes'*) and the Moon landings (e.g. *'astronauts have landed on it and they've photographed it from the shuttle and the landing module'*). One child commented, with reference to the Earth-shine effect, that *'if you're really careful if it's a quarter you can see the full Moon in the shadow'*. Where provided, the interpretation of evidence supported the models held in many cases.

(c) Moon drawings and descriptions

Response categories for item M4 (drawing) are summarized as shown (Table 6.27). The general pattern of responses observed between groups was no longer similar. In the experimental group, while the most common drawing of the Moon remained a simple circle annotated with *'craters'*, where *'meteorites and asteroids had hit it'*, and *'mountains'* (e), this was closely followed by more featured drawings showing both *'craters'* and *'seas of lava'* (a). In one case, the *'sea of Tranquillity where Neil Armstrong had been'* was mentioned.



Response	Experimental group			Control group		
	Boys	Girls	Total	Boys	Girls	Total
(a) Featured	7 (41.2)	2 (14.3)	9 (29.0)	2 (11.8)	1 (7.1)	3 (9.7)
(b) Cratered I	2 (11.8)	0 (0.0)	2 (6.5)	2 (11.8)	2 (14.3)	4 (12.9)
(c) Cratered II	2 (11.8)	0 (0.0)	2 (6.5)	2 (11.8)	0 (0.0)	2 (6.5)
(d) Cratered III	1 (5.9)	1 (7.1)	2 (6.5)	1 (5.9)	1 (7.1)	2 (6.5)
(e) Cratered IV	3 (17.6)	10 (71.4)	13 (41.9)	3 (17.6)	5 (35.7)	8 (25.8)
(f) Blank	1 (5.9)	1 (7.1)	2 (6.5)	4 (23.5)	4 (28.6)	8 (25.8)
(g) Crescent	1 (5.9)	0 (0.0)	1 (3.2)	3 (17.6)	1 (7.1)	4 (12.9)

Table 6.27 Drawings of the Moon from space (frequency and percentage)

All three of the original mental models were identified. The children in the experimental group continued to present ideas consistent with all three.

- Model 1: the Moon is an astronomical body with a cratered surface (28 children in the experimental group; 19 children in the control group). Within the experimental group, the five original stylistic variations of this model remained (a-e). The increase in frequency of more featured drawings of the Moon (a) was particularly notable (up 23 percentage points relative to changes in the control group).
- Model 2: the Moon is an astronomical body with surface features not represented (2 children in the experimental group; 8 children in the control group). Within the experimental group, the reduced frequency of the Moon drawn as blank circles (f) was particularly notable (down 16 percentage points relative to changes in the control group). Three of the four children assigned to this model initially now presented views consistent with Model 1.
- Model 3: the Moon is an astronomical body of unusual shape (1 child in the experimental group; 4 children in the control group). Within the experimental group, the reduced frequency of the Moon drawn as a crescent (g) was particularly notable (down 13 percentage points relative to changes in the control group). Three of the four children assigned to this model initially now presented views consistent with Model 1.

While descriptions of the colour of the Moon still varied, mentions of *'grey'*, *'brown'*, *'dusty'* and *'like rock'* were more common. A wider range of Moon phases were recalled and almost half of the children in the experimental group were now aware of their monthly cycle. Over half of the children in the experimental group indicated more clearly that the Moon supported no known life because it had *'no air'* or *'no atmosphere'*. Mentions of *'too hot'*, *'too cold'* and *'no gravity'* also remained common. One child commented that *'we'd know because lots of people have been up there'*. About three-quarters of the children in the experimental group identified the Moon from pictures of other Solar System objects.

(d) Nature of the Moon

Response categories for item M11 (nature) are summarized as shown (Table 6.28). The general pattern of responses observed between groups was no longer similar. The most common response from the experimental group was *'a ball of rock'* or *'dust'* (previously *'a planet'*).

Response	Experimental group			Control group		
	Boys	Girls	Total	Boys	Girls	Total
Earth satellite	3 (17.6)	0 (0.0)	3 (9.7)	0 (0.0)	0 (0.0)	0 (0.0)
Ball of rock/dust	8 (47.1)	5 (35.7)	13 (41.9)	2 (11.8)	1 (7.1)	3 (9.7)
Planet	4 (23.5)	1 (7.1)	5 (16.1)	8 (47.1)	9 (64.3)	17 (54.8)
Star	1 (5.9)	1 (7.1)	2 (6.5)	0 (0.0)	1 (7.1)	1 (3.2)
Asteroid	0 (0.0)	0 (0.0)	0 (0.0)	2 (11.8)	0 (0.0)	2 (6.5)
'Moon is the Moon'	0 (0.0)	3 (21.4)	3 (9.7)	0 (0.0)	0 (0.0)	0 (0.0)
Not sure	1 (5.9)	4 (28.6)	5 (16.1)	5 (29.4)	3 (21.4)	8 (25.8)

Table 6.28 The nature of the Moon (frequency and percentage)

In addition to the four original models, the responses provided by children in the experimental group and the control group indicated the presence of two others not previously identified.

- Model 1: the Moon is a natural satellite of the Earth (3 children in the experimental group; 0 children in the control group). Not previously identified. The three children in the experimental group assigned to this model provided initial responses consistent with Models 3 and 6.
- Model 2: the Moon is a ball of rock and/or dust (13 children in the experimental group; 3 children in the control group). Within the experimental group, the increase in frequency of children assigned to this model was particularly notable (up 42 percentage points relative to changes in the control group).
- Model 3: the Moon is a planet (5 children in the experimental group; 17 children in the control group). Two of the eleven children in the experimental group assigned to this model initially now provided responses consistent with Model 1 while five provided responses consistent with Model 2. The decrease in frequency of children in the

experimental group assigned to this model was particularly notable (down 35 percentage points relative to changes in the control group).

- Model 4: the Moon is a star (2 children in the experimental group; 1 child in the control group). One of the two children in the experimental group assigned to this model initially now provided responses consistent with Model 2.
- Model 5: the Moon is an asteroid (0 children in the experimental group; 2 children in the control group). Not previously identified.
- Model 6: mixed nature (3 children in the experimental group; 0 children in the control group). One of the nine children in the experimental group assigned to this model initially now provided responses consistent with Model 1 while four provided responses consistent with Model 2. The four original variations were reduced to one (*'the Moon is the Moon'*).

Five children in the experimental group and eight children in the control group could not be assigned to any model (*'not sure'*).

6.6.3 Summary of inferential analyses

For a full treatment of the quantitative data see Appendix VIII.

(i) Pre-experimental treatment

At first interview, overall scores in the experimental group ranged from 6 to 21 with a mean of 13.3 (SD 4.10). Score profile percentages included 24.7% 0s, 42.5% 1s, 30.4% 2s and 2.4% 3s. 10 children scored between 0 and 11 (32%) and 21 children between 12 and 23 (68%). Overall scores in the control group ranged from 6 to 19 with a mean of 14.1 (3.92). Score profile percentages included 22.0% 0s, 41.9% 1s, 32.3% 2s and 3.8% 3s. 9 children scored between 0 and 11 (29%) and 22 children between 12 and 23 (71%). The observed differences between the experimental group and control group in overall mean scores, score profile percentages and median scores in items of particular interest (M1, M2, M4 and M11) at first interview were not significant.

Boys in the experimental group appeared to score more highly than the girls overall and the observed difference in their mean scores, 14.6 and 11.6 (SDs 4.05 and 3.61), was significant (t=2.21, df=29, p=0.035; normality for boys D_{xb}=0.113, p>0.15; normality for girls D_{xg}=0.168, p>0.15; F-ratio=1.26) as were the observed differences in score profile percentages by gender (test statistic D_{xbg}=0.164, critical value K_D=0.142 for α=0.05). In those items of particular interest (M1, M2, M4 and M11), observed differences in median scores between boys and girls were significant in M1 (shape verbal: W_{xb}=322.5, W_{xg}=173.5, p=0.016) and M2 (shape selection: W_{xb}=319.5, W_{xg}=176.5, p=0.028). No significant gender differences were observed in the control group.

(ii) Post-experimental treatment

At second interview, overall scores in the experimental group ranged from 6 to 27 with a mean of 19.1 (SD 4.87), a significant change from before (matched t=-9.60, p=0.000, normality of differences in experimental scores D_{dx}=0.085, p>0.15; F-ratio=1.41). Score profile percentages included 17.2% 0s, 19.9% 1s, 49.2% 2s and 13.7% 3s, again a significant change from before (test statistic D_x=0.301, critical value K_D=0.120 for α=0.01). 2 children scored between 0 and 11 (7%), 25 children between 12 and 23 (81%) and 4 children between 24 and 36 (13%). Overall scores in the control group ranged from 8 to 20 with a mean of 13.9 (SD 3.54). Score profile percentages included 21.2% 0s, 44.9% 1s, 30.4% 2s and 3.5% 3s. 10 children scored between 0 and 11 (32%) and 21 children between 12 and 23 (68%). None of the changes observed between interviews were significant. More importantly, however, the mean gain in individual scores from children in the experimental group (O_3-O_1) and control group (O_4-O_2), +5.9 and –0.2 (SDs 3.40 and 2.92), was significant (t=7.54, df=60, p=0.000; normalities D_{dx}=0.085, D_{dc}=0.074, p>0.15; F-ratio=1.36) as was the post-experimental treatment analysis of the score profile percentages (test statistic D_{xc}=0.290, critical value K_D=0.120 for α=0.01). In those items of particular interest (M1, M2, M4 and M11), observed differences in median scores between the experimental group and control group were significant in M1 (shape verbal: W_{x2}=1122.5, W_{c2}=830.5, p=0.017), M4 (drawing: W_{x2}=1159.5, W_{c2}=793.5, p=0.004) and M11 (nature: W_{x2}=1172.5, W_{c2}=780.5, p=0.003). Within the experimental group, multiple linear regression analysis using age, intellectual maturity and science curiosity as independent predictor variables was significant (R^2=0.367,

F=5.21, p=0.006, df=3), but with only age and intellectual maturity contributing to the differences in summated scores between individuals.

Boys in the experimental group continued to significantly outscore the girls overall (means 20.8 and 17.1, SDs 4.23 and 4.94 respectively; t=2.28, df=29, p=0.030; normality for boys D_{xb}=0.129, p>0.15; normality for girls D_{xg}=0.146, p>0.15; F-ratio=1.36) and again this was reflected in an analysis of the score profile percentages by gender (test statistic D_{xbg}=0.170, critical value K_D=0.170 for α=0.01). Observed differences in median scores between boys and girls were significant but only in item M11 (nature: W_{xb}=321.5, W_{xg}=174.5, p=0.039). No significant gender differences were observed in the control group.

6.6.4 Knowledge acquisition and concept learning

Within the experimental groups at first interview, and before the experimental treatment, children's declared knowledge and understanding as probed suggested that that their concept of the Moon was in a variable state of development. In terms of the Moon's shape, how it looks from space and its nature, scientific as well as non-scientific models (intuitive and transitional) were evident (Table 6.29). As with the Earth and the Sun, almost all of the scientific models identified contained acceptable deviations in the form of linguistic, stylistic and descriptive variation to a greater or lesser degree.

	Pre-experimental Total	+/-	Post-experimental Total	+/-	Delayed Total
Shape	20 (64.5)	+6	26 (83.9)	+1	27 (87.1)
Drawing	23 (74.2)	+5	28 (90.3)	-3	25 (80.6)
Nature	4 (12.9)	+12	16 (51.6)	-4	12 (38.7)
Shape + drawing	18 (58.1)	+6	24 (77.4)	-1	23 (74.2)
Shape + drawing + nature	4 (12.9)	+11	15 (48.4)	-4	11 (35.5)

Table 6.29 Summary of scientific mental models of the Moon (frequency and percentage)

At second interview, and after the experimental treatment, increases in the frequencies of scientific models and combinations of models as a whole revealed considerable improvements particularly in the case of the nature of the Moon (Table 6.29). Features associated with knowledge acquisition and concept learning in the experimental group relative to the control group are summarized as follows:

- descriptions of the Moon's shape revealed a reduction in linguistic variation with a corresponding and moderate improvement in the correct use of scientific vocabulary and significant improvement in the choice of shape;
- drawings of the Moon from space revealed a significant improvement in style featuring the presentation and description of craters and 'seas';
- accounts of the nature of the Moon revealed a significant improvement in descriptions of the Moon as the Earth's satellite or a ball of rock or dust;
- unlike the Earth, the experimental treatment appeared to have had little effect on the gap in the differences observed between boys and girls;
- the number of children with summated scores in the 24 to 36 range, reflecting more 2s and 3s, increased slightly but with a corresponding and significant increase in score profile percentages, overall mean score and mean gain;
- only the predictor variables age and intellectual maturity contributed significantly to the differences in summated scores between individuals.

Interestingly, the experimental treatment did little to improve knowledge and understanding of the Moon's absolute size. Knowledge acquisition and concept learning in the experimental group are perhaps best accounted for in terms of both weak (accretion and tuning) and radical restructuring. Like the Earth and Sun, the relationship between response categories, mental models, knowledge acquisition and concept learning is particularly well illustrated in the mapped movements or routes and pathways in children's ideas about the Moon's shape (Fig. 6.3; see also Table 6.29 and Appendix VII for a delayed overview). Interestingly, initial routes and pathways (pre-to post-) revealed 13 'non-movers' (original ideas retained – horizontal links), 14 'risers' (original ideas progressed – positive gradient links) and 4 'fallers' (original ideas regressed – negative gradient links). Later routes and pathways (post-to delayed) revealed 19 'non-movers', 5 'risers' and 7 'fallers', all seven of whom had made progress initially. It is important to notice that while many of the changes which appear to have taken place did so within one mental model (the Moon is spherical), a feature of the linguistic variation described and weak restructuring, many other changes also took place between other models. In the case of non-spherical to spherical Moons, for example, this represented radical restructuring. The more complex pattern of change observed perhaps indicates that learning about the shape of the Moon was slightly more difficult than learning

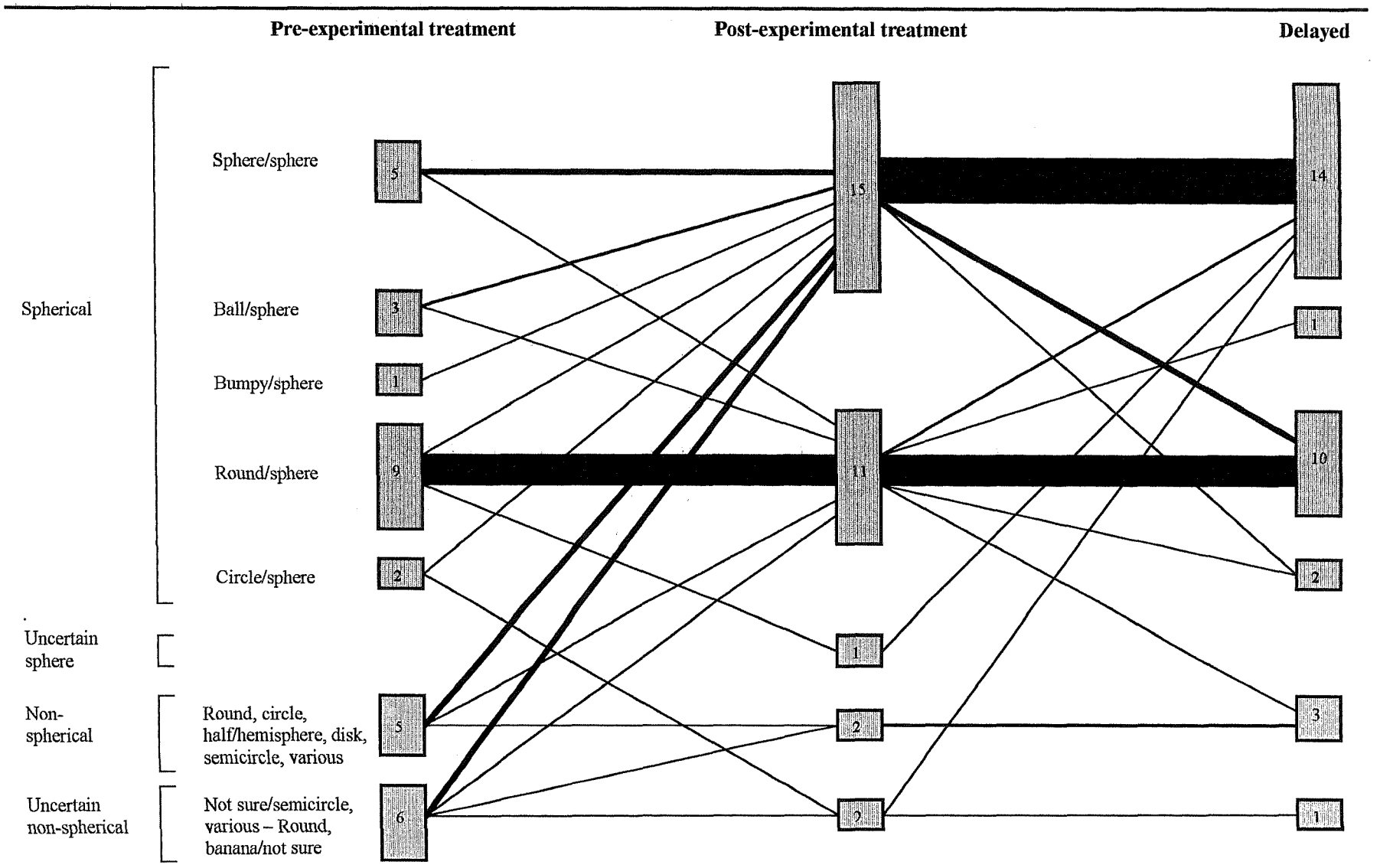


Fig.6.3 Knowledge acquisition and concept learning: mapped changes in children's response categories and mental models of the Moon's shape

about the shape of the Earth and the Sun. Interestingly, in those areas of children's ideas about the Moon which received most attention earlier (M1, M2, M4 and M11), observed differences in median scores between second and third interviews (post-experimental treatment and delayed) were not significant indicating a high degree of retention and recall.

6.7 Relative size

Contrary to how it might appear, the Earth is not the largest object in the Solar System. As already established, the Sun is about one hundred times the size of the Earth which is, in turn, about four times the size of the Moon (diameters).

6.7.1 First interview: pre-experimental treatment

Overviews of relative size responses and mental models from children in the experimental group and control group at first interview (pre-experimental treatment) can be found with the Earth, the Sun and the Moon in Appendix VII.

(a) Correctness

The overall correctness of response associated with relative size (scored items E9, S10 and M10) is given as follows:

- 9 boys (52.9%) and 5 girls (35.7%) or 14 (45.2%) in total for the experimental group;
- 7 boys (41.2%) and 7 girls (50.0%) or 14 (45.2%) in total for the control group.

(b) Earth, Sun and Moon

Response categories for items E9, S10 and M10 are summarized as shown (Table 6.30). The general pattern of responses from both groups appears broadly similar. The most common description provided by both groups indicated that the Sun is greater in size than the Earth and that the Earth is greater in size than the Moon (S>E>M).

	Experimental group			Control group		
Response	Boys	Girls	Total	Boys	Girls	Total
S>E>M	9 (52.9)	5 (35.7)	14 (45.2)	7 (41.2)	7 (50.0)	14 (45.2)
S>M>E	3 (17.6)	0 (0.0)	3 (9.7)	1 (5.9)	0 (0.0)	1 (3.2)
S>M=E	0 (0.0)	1 (7.1)	1 (3.2)	1 (5.9)	0 (0.0)	1 (3.2)
M>S>E	1 (5.9)	1 (7.1)	2 (6.5)	1 (5.9)	0 (0.0)	1 (3.2)
M>E>S	0 (0.0)	1 (7.1)	1 (3.2)	0 (0.0)	1 (7.1)	1 (3.2)
E>S>M	0 (0.0)	2 (14.3)	2 (6.5)	1 (5.9)	0 (0.0)	1 (3.2)
E>M>S	1 (5.9)	0 (0.0)	1 (3.2)	1 (5.9)	0 (0.0)	1 (3.2)
E>S=M	1 (5.9)	1 (7.1)	2 (6.5)	4 (23.5)	2 (14.3)	6 (19.4)
S=E=M	0 (0.0)	3 (21.4)	3 (9.7)	1 (5.9)	2 (14.3)	3 (9.7)
Not sure	2 (11.8)	0 (0.0)	2 (6.5)	0 (0.0)	2 (14.3)	2 (6.5)

Table 6.30 Relative size response categories (frequency and percentage)

Five mental models were identified. The children in the experimental and control groups presented ideas consistent with all five.

- Model 1: the Sun is greater in size than the Earth which is greater in size than the Moon (14 children in the experimental group; 14 children in the control group). While this was the commonest response obtained from both groups, none of the children were aware of the proportions involved. Typical responses included: *'the Sun is bigger than all the planets and a star ... the Moon is half the size of the Earth'* and *'when I look in the morning, I can see the Sun and I know the Sun is bigger than the Earth, when I see the Moon, I know the Moon's smaller than the Earth'*.
- Model 2: Sun largest (4 children in the experimental group; 2 children in the control group). Two variations were indicated. In the first, the Sun was considered bigger than the Moon which was bigger than the Earth. In the second, the Sun was considered bigger than the Moon which was about the same size as the Earth.
- Model 3: Moon largest (3 children in the experimental group; 2 children in the control group). Two variations were indicated. In the first, the Moon was considered bigger than the Sun which was bigger than the Earth. In the second, the Moon was considered bigger than the Earth which was bigger than the Sun.
- Model 4: the Earth, the Sun and the Moon are the same size (3 children in the experimental group; 3 children in the control group). Children assigned to this model considered the Sun, the Earth and the Moon to be equal in size.
- Model 5: Earth largest (5 children in the experimental group; 8 children in the control group). Three variations were indicated. In the first, the Earth was considered bigger

than the Sun which was bigger than the Moon. In the second, the Earth was considered bigger than the Moon which was bigger than the Sun. In the third, the Earth was considered bigger than the Sun which was the same size as the Moon.

Two children in the experimental group and two children in the control group could not be assigned to any model (*'not sure'*). Most responses were based on what the children in both groups could remember having read about in books or, in the most intuitive case (Earth largest), what they could see for themselves. In one particular comment of interest it was suggested that *'the Moon's quite big but we've got lots of Moons which we can't see so it must be smaller than the Earth'*.

6.7.2 Second interview: post-experimental treatment

Overviews of relative size responses and mental models from children in the experimental group and control group at second interview (post-experimental treatment) can be found with the Earth, the Sun and the Moon in Appendix VII.

(a) Correctness

The overall correctness of response associated with relative size (scored items E9, S10 and M10) is given as follows:

- 15 boys (88.2%) and 10 girls (71.4%) or 25 (80.6%) in total for the experimental group;
- 9 boys (52.9%) and 8 girls (57.1%) or 17 (54.8%) in total for the control group.

(b) Earth, Sun and Moon

Response categories for items E9, S10 and M10 are summarized as shown (Table 6.31). The general pattern of responses observed between groups remained somewhat similar. The most common description of relative size given by the experimental group increased in frequency but had not changed (S>E>M).

Response	Experimental group			Control group		
	Boys	Girls	Total	Boys	Girls	Total
S>E>M (prop.)	4 (23.5)	1 (7.1)	5 (16.1)	0 (0.0)	0 (0.0)	0 (0.0)
S>E>M	11 (64.7)	9 (64.3)	20 (64.5)	9 (52.9)	8 (57.1)	17 (54.8)
S>M>E	1 (5.9)	0 (0.0)	1 (3.2)	3 (17.6)	0 (0.0)	3 (9.7)
M>S>E	0 (0.0)	1 (7.1)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
E>S>M	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	1 (7.1)	2 (6.5)
E>S=M	1 (5.9)	1 (7.1)	2 (6.5)	2 (11.8)	2 (14.3)	4 (12.9)
S=E=M	0 (0.0)	2 (14.3)	2 (6.5)	1 (5.9)	0 (0.0)	1 (3.2)
Not sure	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	3 (21.4)	4 (12.9)

Table 6.31 Relative size response categories (frequency and percentage)

Despite a reduction in the number of response categories obtained, all five of the original mental models were identified. The children in the experimental group continued to present ideas consistent with all five.

- Model 1: the Sun is greater in size than the Earth which is greater in size than the Moon (25 children in the experimental group; 17 children in the control group). Within the experimental group, two variations were indicated. In the first, the Sun was correctly considered about one hundred times the size of the Earth, the Earth itself about four times the size of the Moon. Occasionally, other references to size or scale were provided: *'I think you could fit 10 000 Earth's into the Sun'* and *'the Sun's one hundred times the size of the Earth, the Moon's about a quarter the size of the Earth ... Betelgeuse is probably a million times bigger than the Sun or something'*. In the second, the proportions were either not known or stated incorrectly. The increased frequency of responses in the experimental group was particularly notable (up 26 percentage points relative to the control group - 16 percentage points of which are attributed to the more accurate variation).
- Model 2: Sun largest (1 child in the experimental group; 3 children in the control group). The two original variations were reduced to one in both groups (S>M>E). Within the experimental group, the reduced frequency of responses was particularly notable (down 13 percentage points relative to changes in the control group). All four of the children in the experimental group assigned to this model initially now provided responses consistent with Model 1.
- Model 3: Moon largest (1 child in the experimental group; 0 children in the control group). Within the experimental group, the two original variations were reduced to one

(M>S>E). All three of the children in the experimental group assigned to this model initially now provided responses consistent with Model 1.

- Model 4: the Earth, the Sun and the Moon are the same size (2 children in the experimental group; 1 child in the control group). Two of the three children in the experimental group assigned to this model initially now provided responses consistent with Model 1.
- Model 5: Earth largest (2 children in the experimental group; 6 children in the control group). Within the experimental group, the three original variations were reduced to only one (E>S=M). Two of the five children in the experimental group assigned to this model initially now provided responses consistent with Model 1.

Four children in the control group could not be assigned to any model (*'not sure'*).

6.7.3 Summary of inferential analyses

While appearing as a single scored item within data for the Earth, the Sun and the Moon, an inferential analysis of relative size is still presented here. For a full treatment of the quantitative data see Appendix VIII.

(i) Pre-experimental treatment

At first interview, overall score profile percentages for relative size alone in the experimental group and control group were identical, 6.5% 0s, 48.4% 1s and 45.2% 2s (test statistic D_{xc}=0.000, critical value K_D=0.345 for α=0.05). The same was true in median score. Analyses of score profile percentages and median score by gender revealed no significant differences in either group.

(ii) Post-experimental treatment

At second interview, overall score profile percentages for relative size alone in the experimental group included 0.0% 0s, 19.4% 1s, 83.9% 2s and 16.1% 3s, a significant change from before (test statistic D_x=0.354, critical value K_D=0.345 for α=0.05). Overall score profile percentages in the control group included 12.9% 0s, 32.3% 1s and 54.8% 2s.

Observed changes were not significant. Interestingly, while analysis of the score profile percentages of the experimental group and the control group at second interview suggested that the observed differences were not significant (test statistic D_{xc}=0.258, critical value K_D=0.345 for α=0.05), observed differences in median scores were (W_x=1155.0, W_c=798.0, p=0.004). Analyses of score profile percentages and median score by gender again revealed no significant differences in either group.

6.7.4 Knowledge acquisition and concept learning

Within the experimental group at first interview, and before the experimental treatment, children's declared knowledge and understanding as probed suggested that their concept of relative size was moderately well developed in a little under half of those interviewed. At second interview, and after the experimental treatment, the increase in frequency of scientific models of relative size observed was significant. The effect of scientific and non-scientific mental models (intuitive and transitional) of relative size on overall models of the Earth, the Sun and the Moon using different combinations of attributes is demonstrated as shown (Table 6.32). With the exception of the Moon, an extended model of the Earth and the Sun was observed in over 70% of those involved at second interview and three months later.

	Pre-experimental Total	+/-	Post-experimental Total	+/-	Delayed Total
Earth (shape+drawing+nature)	25 (80.6)	+5	30 (96.8)	-3	27 (87.1)
Earth (shape+drawing+nature+rel. size)	13 (41.9)	+12	25 (80.6)	-2	23 (74.2)
Sun (shape+drawing+nature)	7 (22.6)	+17	24 (77.4)	0	24 (77.4)
Sun (shape+drawing+nature+rel. size)	5 (16.1)	+17	22 (71.0)	0	22 (71.0)
Moon (shape+drawing+nature)	4 (12.9)	+11	15 (48.4)	-4	11 (35.5)
Moon (shape+drawing+nature+rel. size)	4 (12.9)	+10	14 (45.2)	-4	10 (32.3)

Table 6.32 Summary of Earth, Sun and Moon mental models including relative size (frequency and percentage)

Knowledge acquisition and concept learning in the experimental group is perhaps best accounted for in terms of both weak (accretion and tuning) and radical restructuring. Like the Earth, the Sun and the Moon, the relationship between response categories, mental models, knowledge acquisition and concept learning is particularly well illustrated in the mapped movements or routes and pathways in children's ideas (Fig. 6.4; see also Table 6.32 and Appendix VII for delayed overviews). Interestingly, initial routes and pathways

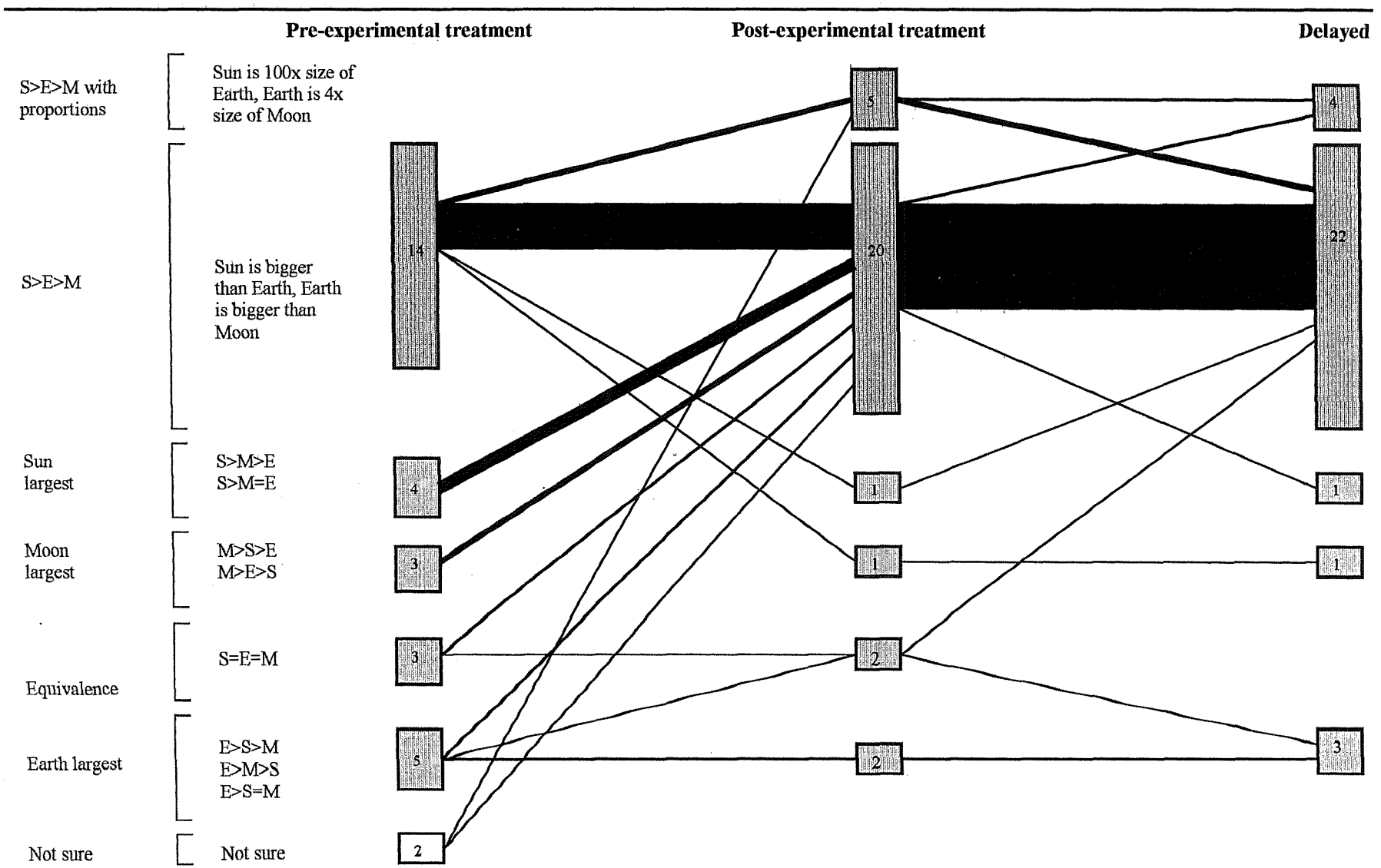


Fig.6.4 Knowledge acquisition and concept learning: mapped changes in children's response categories and mental models of relative size

(pre-to post-) revealed 11 'non-movers' (original ideas retained – horizontal links), 17 'risers' (original ideas progressed – positive gradient links) and 3 'fallers' (original ideas regressed – negative gradient links). Later routes and pathways (post- to delayed) revealed 22 'non-movers', 4 'risers' and 5 'fallers', all of whom made progress initially. It is important to notice that, in the case of relative size, many of the changes which appear to have taken place did so between rather than within mental models (radical restructuring). Weak restructuring was perhaps most evident in the appearance of new variation within Model 1 (S>E>M) and in children clarifying their ideas in Model 2 (Sun largest). Radical restructuring was most evident in almost all other changes. The apparent ease with which change took place perhaps indicates that learning about relative size was, like the Earth, relatively straight forward. Observed differences in median scores between the experimental group at second (post-experimental treatment) and third interviews (delayed) were not significant indicating a high degree of retention and recall.

6.8 The day and night cycle

The day and night cycle is caused by the rotation of the Earth about its axis once every 24 hours. In this section, children's ideas about what causes the day and night cycle in terms of their verbal descriptions, their ability to manipulate props, and their drawings are of particular interest.

6.8.1 First interview: pre-experimental treatment

Overviews of mental models, score frequency profiles and summated scores of the day and night cycle from children in the experimental group and control group at first interview (pre-experimental treatment) can be found in Appendix VII.

(a) Correctness

The overall correctness of response in each of the six day and night items considered is summarized as shown (Table 6.33). The general pattern of responses obtained from both groups appears broadly similar. Particularly high frequencies were recorded in item DN5 (day length). Low frequencies were recorded in DN3 (drawing), and DN6 (variation).

Item	Experimental group			Control group		
	Boys	Girls	Total	Boys	Girls	Total
DN1: Verbal	12 (70.6)	5 (35.7)	17 (54.8)	9 (52.9)	6 (42.9)	15 (48.4)
DN2: Use of props	10 (58.8)	5 (35.7)	15 (48.4)	9 (52.9)	6 (42.9)	15 (48.4)
DN3: Drawing	6 (35.3)	3 (21.4)	9 (29.0)	5 (29.4)	4 (28.6)	9 (29.0)
DN4: Period	6 (35.3)	5 (35.7)	11 (35.5)	8 (47.1)	5 (35.7)	13 (41.9)
DN5: Day length	17 (100.0)	13 (92.9)	30 (96.8)	16 (94.1)	12 (85.7)	28 (90.3)
DN6: Variation	6 (35.3)	3 (21.4)	9 (29.0)	5 (29.4)	3 (21.4)	8 (25.8)

Table 6.33 Day and night correctness by item (frequency and percentage)

(b) What causes day and night?

Combined response categories for items DN1, 2 and 3 were used in order to determine the range of mental models of what causes the day and night cycle. These are presented as shown (Table 6.34). Children were assigned to models on the basis of presenting consistent responses from two out of the three items considered. That the Earth rotates once every 24 hours was the most common model of the day and night cycle in both groups.

Models	Experimental group			Control group		
	Boys	Girls	Total	Boys	Girls	Total
1. Earth rotates every 24 hours	6 (35.3)	5 (35.7)	11 (35.5)	8 (47.1)	5 (35.7)	13 (41.9)
2. Earth rotates (variable period)	4 (23.5)	0 (0.0)	4 (12.9)	1 (5.9)	1 (7.1)	2 (6.5)
3. Sun and Moon orbit the Earth	3 (17.6)	4 (28.6)	7 (22.6)	3 (17.6)	4 (28.6)	7 (22.6)
4. Earth orbits the Moon	1 (5.9)	0 (0.0)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
5. Earth orbits the Sun	1 (5.9)	0 (0.0)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
6. Sun orbits Moon	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	0 (0.0)	1 (3.2)
7. Moon orbits Earth	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (7.1)	1 (3.2)
8. Mixed verbal	0 (0.0)	1 (7.1)	1 (3.2)	1 (5.9)	1 (7.1)	2 (6.5)

Table 6.34 Mental models of the day and night cycle (frequency and percentage)

Overall, eight mental models were identified. The children in the experimental group presented ideas consistent with Models 1, 2, 3, 4, 5 and 8, the children in the control group Models 1, 2, 3, 6, 7 and 8.

- Model 1: the Earth rotates once every 24 hours (11 children in the experimental group; 13 children in the control group). The children assigned to this model described the rotation

of the Earth in many different ways: *'the Earth moving around'*, *'the Earth turns around very slowly'*, *'we're not always facing the Sun'*, *'the Earth spins'*, *'the Earth spins and while the Earth spins it goes around the Sun and the Moon goes around the Earth'*, *'the Earth rotates slowly on an axis'*. In all cases, the period of rotation was given as 24 hours. The involvement of the Earth's axis often caused confusion (e.g. *'it spins on an axle'*) and in many cases its presence was not indicated at all (verbally, props, drawings). Variations included the day and night cycle presented as a complete Earth-Sun-Moon System with all objects moving correctly, a linear Earth-Sun-Moon System with only the Earth rotating between a stationary Sun and Moon, and a Moon free system with only the involvement of the Sun and a rotating Earth. These were considered acceptable deviations.

- Model 2: the Earth rotates over a variable period of time (4 children in the experimental group; 2 children in the control group). The children assigned to this model described the rotation of the Earth similarly to the children assigned to Model 1 (e.g. *'when we turn away from the Sun we get night-time'*) but were either unaware of the period of Earth rotation or provided an incorrect response (e.g. *'a month'*, *'64 hours'*). In one case, the period of rotation was given as *'8 to 24 hours'* which was used to account for the differences in daylight hours observed throughout the year.
- Model 3: the Sun and the Moon orbit the Earth (7 children in the experimental group; 7 children in the control group). The children assigned to this model considered day and night to be caused by the action of an orbiting Sun and Moon (e.g. *'the Sun goes around the Earth'*). Variations included only an orbiting Sun or a mixed model with an orbiting Sun and a rotating Earth. Where provided, the orbital period of the Sun and Moon was often given as 24 hours.
- Model 4: the Earth orbits the Moon (1 child in the experimental group; 0 children in the control group). The one child in the experimental group assigned to this model considered day and night to be caused by the Earth orbiting the Moon once every 24 hours with the Moon blocking out the Sun's light as the Earth passed behind it. The Earth was also considered to *'turn around very slowly'* at the same time.
- Model 5: the Earth orbits the Sun (1 child in the experimental group; 0 children in the control group). The one child in the experimental group assigned to this model considered day and night to be caused by a non-rotating Earth orbiting the Sun once every 24 hours.

- Model 6: the Sun orbits the Moon (0 children in the experimental group; 1 child in the control group). The one child in the control group assigned to this model considered day and night to be caused by the *'Sun getting in the way of the Moon'* once every 24 hours.
- Model 7: the Moon orbits the Earth (0 children in the experimental group; 1 child in the control group). The one child in the control group assigned to this model considered day and night to be caused by the Moon blocking out light from the Sun as it passed in front of the Earth.
- Model 8: mixed verbal models (1 child in the experimental group; 2 children in the control group). The children providing verbal models were unable or unwilling to further demonstrate their ideas in other ways. Variations in this model included day and night occurring *'so people can sleep'*, because of *'God'* or because *'the Sun goes down when it's tired'*.

Six children in the experimental group and five children in the control group could not be assigned to any model (*'not sure'*, insufficient detail). Regardless of model type and any rotational or other movements involved, almost all of the children in both groups knew that 'a day' lasts *'24 hours'*. Variations in the length of daylight hours were known to occur at high latitudes by fewer than half of the children in both groups (e.g. *'Canada'*, *'Russia ... my gran comes from the Ukraine'*, *'Finland 'cause they're right at the top ... we had two students from Finland'*, *'the Arctic and Antarctica'*, *'the north and south pole'*, *'somewhere near the top and bottom where it hasn't got the Sun or the Moon shining on it'*) but with a number of different causal factors involved (e.g. *'the weather'*, *'in summer the Earth takes less time to turn round'*, *'the clocks go back one hour'*, *'it's too cold in the winter for longer days'*). A selection of drawings of what causes the day and night cycle from children in the experimental group at first interview is provided as shown (Fig. 6.5).

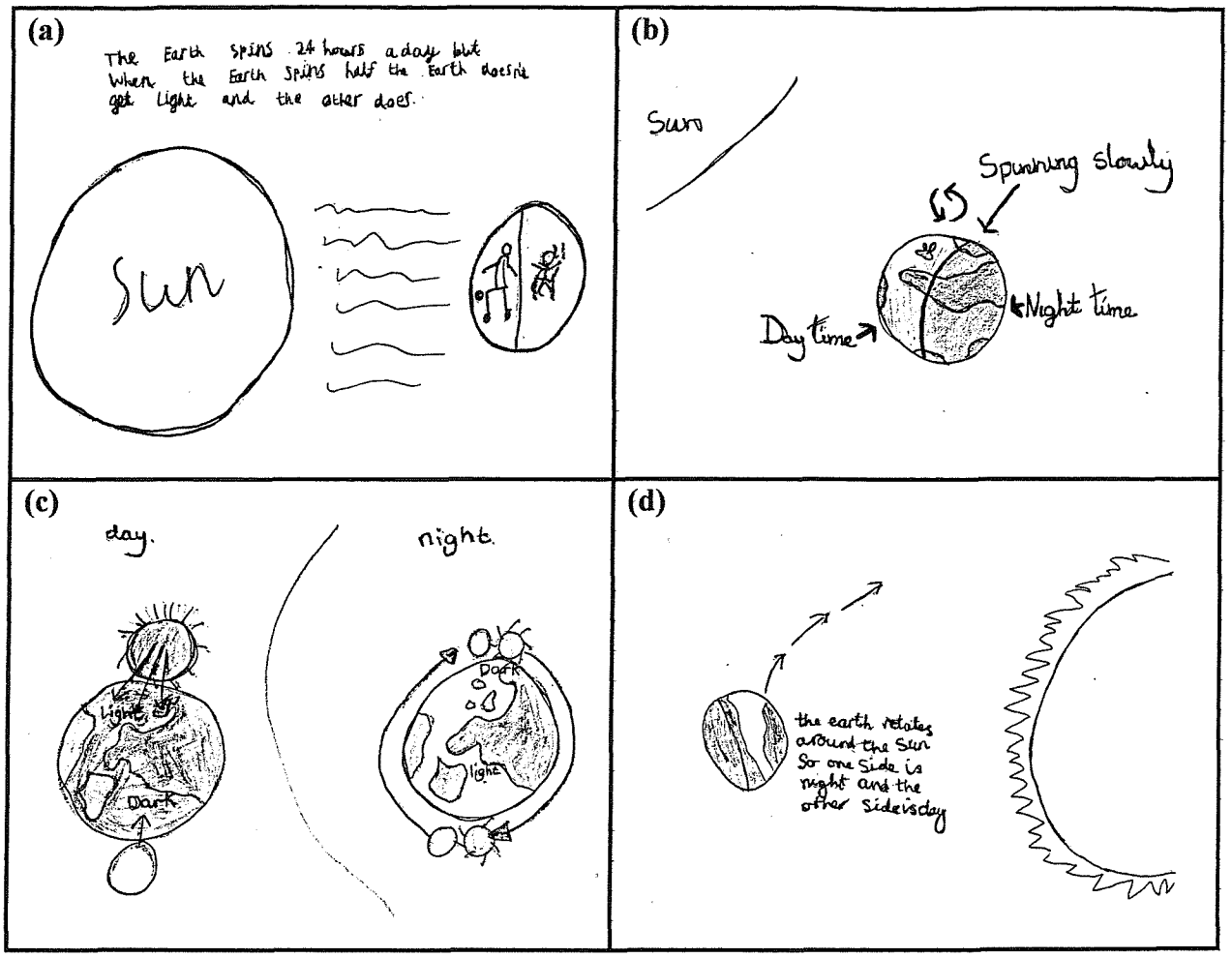


Fig. 6.5 Children's drawings of what causes day and night (pre-experimental treatment)

(a) Model 1: the Earth rotates once every 24 hours
(b) Model 2: the Earth rotates over a variable period of time
(c) Model 3: the Sun and Moon orbit the Earth
(d) Model 5: the Earth orbits the Sun

6.8.2 Second interview: post-experimental treatment

Overviews of mental models, score frequency profiles and summated scores of the day and night cycle from children in the experimental group and control group at second interview (post-experimental treatment) can be found in Appendix VII.

(a) Correctness

The overall correctness of response in each of the six day and night items is summarized as shown (Table 6.35). Increases in correctness in the experimental group were observed in five day and night items (DN1, 2, 3, 4 and 6) with a decrease in one (DN5). Among the many differences, frequencies associated with items DN2 (use of props), DN4 (period) and DN6 (variation) in the experimental group were notably greater relative to changes in the control group (up 32, 39 and 26 percentage points respectively).

	Experimental group			Control group		
Item	Boys	Girls	Total	Boys	Girls	Total
DN1: Verbal	15 (88.2)	11 (78.6)	26 (83.9)	10 (58.8)	8 (57.1)	18 (58.1)
DN2: Use of props	15 (88.2)	12 (85.7)	27 (87.1)	10 (58.8)	7 (50.0)	17 (54.8)
DN3: Drawing	10 (58.8)	8 (57.1)	18 (58.1)	7 (41.2)	6 (42.9)	13 (41.9)
DN4: Period	13 (76.5)	9 (64.3)	22 (71.0)	9 (52.9)	3 (21.4)	12 (38.7)
DN5: Day length	16 (94.1)	13 (92.9)	29 (93.5)	15 (88.2)	13 (92.9)	28 (90.3)
DN6: Variation	12 (70.6)	3 (21.4)	15 (48.4)	4 (23.5)	2 (14.3)	6 (19.4)

Table 6.35 Day and night correctness by item (frequency and percentage)

(b) What causes day and night?

The general pattern of models observed between groups was no longer similar (Table 6.36). Despite this, Earth rotation once every 24 hours remained the most common model of the day and night cycle in the experimental group.

	Experimental group			Control group		
Models	Boys	Girls	Total	Boys	Girls	Total
1. Earth rotates every 24 hours	14 (82.4)	10 (71.4)	24 (77.4)	9 (52.9)	2 (14.3)	11 (35.5)
2. Earth rotates (variable period)	0 (0.0)	1 (7.1)	1 (3.2)	2 (11.8)	5 (35.7)	7 (22.6)
3. Sun and Moon orbit the Earth	1 (5.9)	0 (0.0)	1 (3.2)	3 (17.6)	4 (28.6)	7 (22.6)
4. Earth orbits the Sun	1 (5.9)	0 (0.0)	1 (3.2)	1 (5.9)	0 (0.0)	1 (3.2)
5. Sun rotates	0 (0.0)	1 (7.1)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
6. Satellites	0 (0.0)	1 (7.1)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)

Table 6.36 Mental models of the day and night cycle (frequency and percentage)

With the loss of Earth orbits the Moon, Sun orbits the Moon, Moon orbits the Earth and mixed verbal responses, only four of the original eight mental models were identified. The

responses provided by the children in the experimental group indicated the presence of two others. The children in the experimental group presented ideas consistent with all six.

- Model 1: the Earth rotates once every 24 hours (24 children in the experimental group; 11 children in the control group). Descriptions of the involvement of the Earth's axis and the effects of Earth rotation showed improvement often with clearer evidence of the Earth's axial tilt (verbally, in the use of props and in drawings): *'the Earth spins on its axis ... we come round in the morning, then it's midday, then gradually night'*, *'the Earth spins on its axis ... it takes 24 hours to go round ... if England's in the Sun it means Australia's in darkness'*, *'the Earth's tilted and we're going around the Sun spinning on our own axis ... because it's spinning around, the Sun's shining on different parts'*. Accounts of the day and night cycle involving a complete Earth-Sun-Moon System with all objects moving correctly were also more common. The increased frequency of children in the experimental group assigned to this model was particularly notable (up 48 percentage points relative to changes in the control group).
- Model 2: the Earth rotates over a variable period of time (1 child in the experimental group; 7 children in the control group). All of the four children in the experimental group assigned to this model initially now provided responses consistent with Model 1. The reduced frequency of children assigned to this model was particularly notable (down 26 percentage points relative to changes in the control group).
- Model 3: the Sun and the Moon orbit the Earth (1 child in the experimental group; 7 children in the control group). Six of the seven children in the experimental group assigned to this model initially now provided responses consistent with Model 1. The reduced frequency of children holding this model was also particularly notable (down 19 percentage points relative to changes in the control group).
- Model 4: the Earth orbits the Sun (1 child in the experimental group; 1 child in the control group). The one child in the experimental group assigned to this model initially now provided responses consistent with Model 1.
- Model 5: the Sun rotates (1 child in the experimental group; 0 children in the control group). Not previously identified. The one child in the experimental group assigned to this model provided an initial response of *'not sure'*. The day and night cycle was now thought caused by the Sun, which possessed its own *'dark side'*, rotating once every 24 hours.

- Model 6: satellites (1 child in the experimental group; 0 children in the control group). Not previously identified. The one child in the experimental group assigned to this model provided an initial response of *'not sure'*. The day and night cycle was now thought caused by the Earth rotating once every 24 hours but with the rotation of the Earth brought about by *'a satellite which keeps making the Earth go round'*. The nature of the satellite (the Moon, other) remained uncertain.

Two children in the experimental group and five children in the control group could not be assigned to any model (*'not sure'*, insufficient detail). Again, regardless of model type and any rotational or other movements involved, almost all of the children in the experimental group knew that 'a day' lasts 24 hours. Variations in the length of daylight hours were still known to occur at high latitudes but this time by about half of the children in the experimental group. Responses were often more focused and accurate (e.g. *'the North Pole in summer gets most light 'cause the axis points towards the Sun, the South Pole gets a lot of light sometimes too'*) though at times some confusion remained (e.g. *'the South pole gets the least light all of the time, the North Pole gets most 'cause it's on top'*). A typical example of an acceptable scientific drawing of what causes the day and night cycle from one child in the experimental group at second interview is provided as shown (Fig. 6.6).

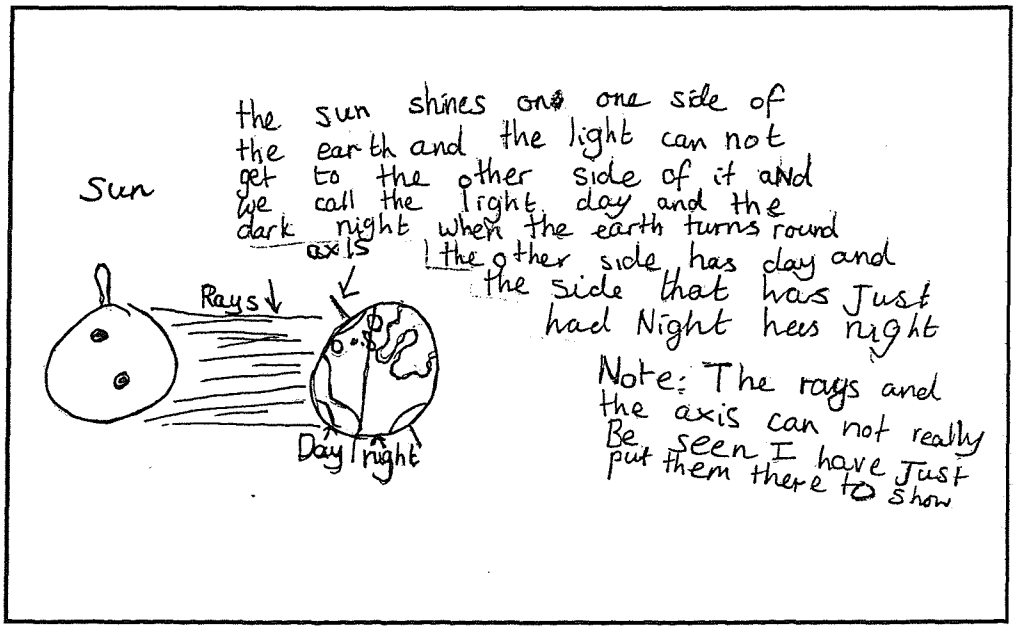


Fig. 6.6 Child's drawing of what causes day and night (post-experimental treatment)

6.8.3 Summary of inferential analyses

For a full treatment of the quantitative data see Appendix VIII.

(i) Pre-experimental treatment

At first interview, overall scores in the experimental group ranged from 2 to 13 with a mean of 7.3 (SD 3.70). Score profile percentages included 30.6% 0s, 20.4% 1s, 46.2% 2s and 2.7% 3s. 11 children scored between 0 and 5 (35%), 15 children between 6 and 11 (48%) and 5 children between 12 and 18 (16%). Overall scores in the control group ranged from 2 to 14 with a mean of 7.3. Score profile percentages included 31.2% 0s, 21.5% 1s, 41.4% 2s and 5.9% 3s. 11 children scored between 0 and 5 (35%), 13 children between 6 and 11 (42%) and 7 children between 12 and 18 (23%). The observed differences between the experimental group and control group in overall mean scores, score profile percentages and median scores in items of particular interest (DN1, DN2, DN3 and DN6) at first interview were not significant.

No significant gender differences were observed in either group.

(i) Post-experimental treatment

At second interview, overall scores in the experimental group ranged from 1 to 15 with a mean of 10.4 (SD 3.29), a significant change from before (matched t=-5.95, p=0.000, normality of differences in experimental scores D_{dx}=0.112, p>0.15; F-ratio=1.26). Score profile percentages included 12.4% 0s, 14.0% 1s, 61.3% 2s and 12.4% 3s, again a significant change from before (test statistic D_x=0.248, critical value K_D=0.169 for α=0.01). 2 children scored between 0 and 5 (6%), 14 children between 6 and 11 (45%) and 15 children between 12 and 18 (48%). Overall scores in the control group ranged from 0 to 13 with a mean of 7.2 (SD 3.12). Score profile percentages included 31.2% 0s, 18.3% 1s, 49.5% 2s and 1.1% 3s. 6 children scored between 0 and 5 (19%), 22 children between 6 and 11 (71%) and 3 children between 12 and 18 (10%). None of the changes observed were significant. More importantly, however, the mean gain in individual scores from children in the experimental group (O_3-O_1) and control group (O_4-O_2), +3.2 and –0.1 (SDs 2.96 and 3.03), was significant

(t=4.29, df=60, p=0.000; normalities D_{dx}=0.112, D_{dc}=0.069, p>0.15; F-ratio=1.05) as was the post-experimental treatment analysis of the score profile percentages (test statistic D_{xc}=0.232, critical value K_D=0.169 for α=0.01). In those items of particular interest (DN1, DN2, DN3 and DN6), observed differences in median scores between the experimental group and control group were significant in DN1 (verbal: W_{x2}=1141.0, W_{c2}=812.0, p=0.009), DN2 (use of props: W_{x2}=1151.0, W_{c2}=802.0, p=0.004), DN3 (drawing: W_{x2}=1179.0, W_{c2}=774.0, p=0.003) and DN6 (variation: W_{x2}=1145.5, W_{c2}=807.5, p=0.006). Within the experimental group, multiple linear regression analysis using age, intellectual maturity and science curiosity as independent predictor variables was significant (R^2=0.326, F=4.35, p=0.013, df=3), but with only age contributing to the differences in summated scores between individuals.

No significant gender differences were observed in mean score and score profile percentages in either group. An observed difference in median scores favouring boys in the experimental group was significant in item DN6 (variation: W_{xb}=339.5, W_{xg}=156.5, p=0.04).

6.8.4 Knowledge acquisition and concept learning

Within the experimental group at first interview, and before the experimental treatment, children's declared knowledge and understanding as probed suggested that their concept of what causes the day and night cycle was in a variable state of development. Scientific as well as non-scientific (intuitive and transitional) models were evident. Almost all of the scientific models identified contained acceptable deviations (verbally, props, drawings) to a greater or lesser degree. At second interview, and after the experimental treatment, the observed increase in the frequency of a basic scientific model was significant. A summary of the numbers of children within the experimental group presenting a scientific model of what causes the day and night cycle is provided as follows:

- 11 (35.5%) pre-experimental treatment;
- 24 (77.4%) post-experimental treatment;
- 23 (74.2%) delayed.

Features associated with knowledge acquisition and concept learning in the experimental group relative to the control group are summarized as follows:

- accounts of the day and night cycle provided verbally, through the use of props and in drawings improved significantly;
- descriptions of variations associated with daylight hours from place to place throughout the world improved significantly;
- gender differences within models of the day and night cycle were not observed (DN6:variation was a minor exception);
- the number of children with summated scores in the 12 to 18 range, reflecting more 2s and 3s, increased notably with a corresponding and significant increase in score profile percentages, overall mean score and mean gain;
- only the predictor variable age contributed significantly to the differences in summated scores between individuals.

Knowledge acquisition and concept learning in the experimental group are perhaps best accounted for in terms of weak (accretion and tuning) and radical restructuring. Radical restructuring is particularly well illustrated in the mapped movements or routes and pathways between children's ideas and models themselves (Fig. 6.7; see also Appendix VII for a delayed overview). Interestingly, initial routes and pathways (pre- to post-) revealed 11 'non-movers' (original ideas retained – horizontal links), 18 'risers' (original ideas progressed – positive gradient links) and 2 'fallers' (original ideas regressed – negative gradient links). Later routes and pathways (post- to delayed) revealed 21 'non-movers', 5 'risers' and 5 'fallers', all of whom had made progress initially. Weak restructuring was particularly evident within the basic scientific model of what causes the day and night cycle itself and the improved clarity and accuracy of accounts (verbally, props, drawings). Interestingly, in those areas of the day and night cycle which received most attention earlier (DN1, DN2, DN3 and DN6), observed differences in median scores between second and third interviews (post-experimental treatment and delayed) were significant for DN3 (drawing: W_{x2}=1188.5, W_D=764.5, p=0.002). Despite this, the retention and recall of ideas were good.

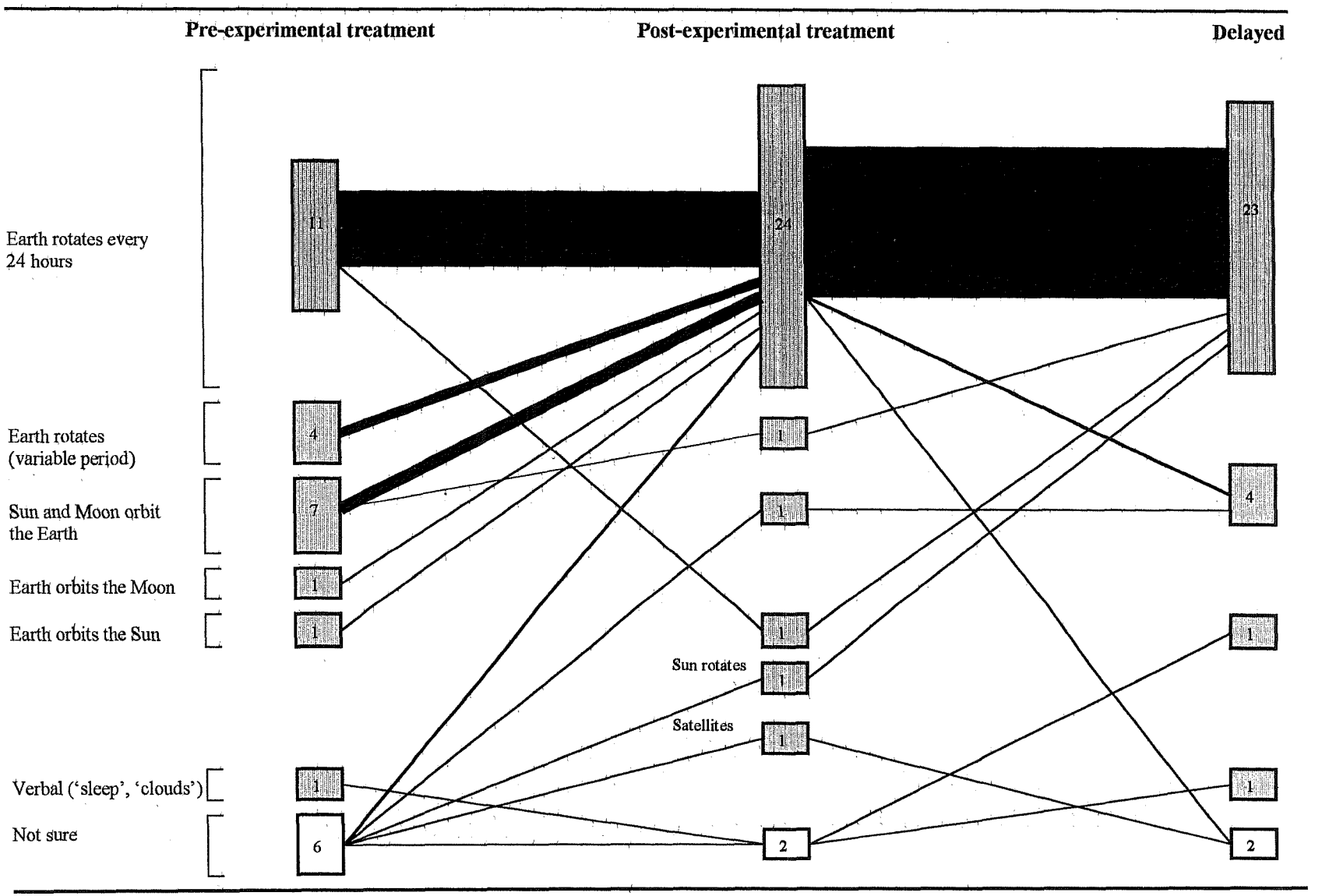


Fig.6.7 Knowledge acquisition and concept learning: mapped changes in children's mental models of the day and night cycle

6.9 Seasonal change

The annual cycle of seasonal change is caused by the constant tilt and orientation of the Earth's axis relative to the plane of the Earth's orbit around the Sun which, in turn, affects the amount of solar energy received at the Earth's surface and troposphere. In this section, children's ideas about what causes seasonal change in terms of their verbal descriptions, their ability to manipulate props, and their drawings are of particular interest.

6.9.1 First interview: pre-experimental treatment

Overviews of mental models, score frequency profiles and summated scores of seasonal change from children in the experimental group and control group at first interview (pre-experimental treatment) can be found in Appendix VII.

(a) Correctness

The overall correctness of response in each of the six seasonal change items considered is summarized as shown (Table 6.37). The general pattern of responses obtained from both groups appears broadly similar. Particularly high frequencies were recorded with item SC5 (year length) with particularly low frequencies recorded elsewhere. None of the children in the experimental group and only two of the children in the control group provided anything approaching a correct scientific model of seasonal change.

	Experimental group			Control group		
Item	Boys	Girls	Total	Boys	Girls	Total
SC1: Verbal	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	1 (7.1)	2 (6.5)
SC2: Use of props	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	1 (7.1)	2 (6.5)
SC3: Drawing	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	1 (7.1)	2 (6.5)
SC4: Period	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	0 (0.0)	1 (3.2)
SC5: Year length	11 (64.7)	6 (42.9)	17 (54.8)	12 (70.6)	8 (57.1)	20 (64.5)
SC6: Variation	6 (35.3)	2 (14.3)	8 (25.8)	5 (29.4)	6 (42.9)	11 (35.5)

Table 6.37 Seasonal change correctness by item (frequency and percentage)

(b) What causes the seasons to change?

Combined response categories for items SC1, 2 and 3 were used in order to determine the range of mental models of what causes seasonal change. These are presented as shown (Table 6.38). Like day and night, children were assigned to models on the basis of presenting consistent responses from two out of the three items considered. No single model emerged as clearly the most common in either group.

Models	Experimental group			Control group		
	Boys	Girls	Total	Boys	Girls	Total
1. Tilt of Earth's axis/orbits Sun	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	1 (7.1)	2 (6.5)
2. Earth orbits Sun (various)	2 (11.8)	0 (0.0)	2 (6.5)	2 (11.8)	0 (0.0)	2 (6.5)
3. Sun orbits Earth (various)	2 (11.8)	2 (14.3)	4 (12.9)	0 (0.0)	0 (0.0)	0 (0.0)
4. Sun heats up and cools down	1 (5.9)	0 (0.0)	1 (3.2)	0 (0.0)	2 (14.3)	2 (6.5)
5. Rotation of the Earth	2 (11.8)	0 (0.0)	2 (6.5)	1 (5.9)	1 (7.1)	2 (6.5)
6. Earth and Sun move closer/apart	2 (11.8)	1 (7.1)	3 (9.7)	1 (5.9)	0 (0.0)	1 (3.2)
7. Moon gets in the way	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	0 (0.0)	1 (3.2)
8. Mixed verbal	0 (0.0)	2 (14.3)	2 (6.5)	1 (5.9)	3 (21.4)	4 (12.9)

Table 6.38 Mental models of seasonal change (frequency and percentage)

Overall, eight mental models were identified. The children in the experimental group presented ideas consistent with Models 2, 3, 4, 5, 6 and 8, the children in the control group Models 1, 2, 4, 5, 6, 7 and 8.

- Model 1: the tilt of the Earth's axis as the Earth orbits the Sun once a year (0 children in the experimental group; 2 children in the control group). The children assigned to this model described seasonal change in terms of *'the Earth at an angle'* and being *'different every quarter of the way around'* while correctly demonstrating the orientation of the Earth's axis with respect to the Earth orbiting the Sun using props. The Earth's orbital period was given in only one case as *'12 months'*. Drawings were less detailed but nevertheless supported the other responses provided. Solar energy was not mentioned.
- Model 2: the Earth orbits the Sun (2 children in the experimental group; 2 children in the control group). The children assigned to this model recognized that seasonal change involved the Earth orbiting the Sun but were unaware of the involvement of the tilt of the Earth's axis and its effect on received solar energy. Variations included the Earth moving

at *'different speeds'* often *'stopping in one place for longer'* (often for a reason e.g. *'to allow flowers to grow in spring'*), *'some parts of the Earth being closer to the Sun than others'* (e.g. the equator by virtue of the Earth's shape), and because by orbiting the Sun *'the Sun shines lower and lower'* (reference to the changing altitude of the Sun in the sky throughout the year). Where provided, orbital periods were given as *'12 months'* or *'365 days'*.

- Model 3: the Sun orbits the Earth (4 children in the experimental group; 0 children in the control group). The children assigned to this model described seasonal change in terms of the Sun orbiting the Earth *'at different speeds'* or *'stopping at times'*. The time taken for the Sun to orbit the Earth was not known.
- Model 4: the Sun heats up and cools down (1 child in the experimental group; 2 children in the control group). The children assigned to this model described seasonal change in terms of some physical attribute assigned to the Sun or its perceived effect (e.g. *'sometimes in summer the Sun gets really hot ... as days go by it gets cooler'*, *'the Sun shines brighter'*). In drawings, summer Suns and winter Suns were different in size. No orbital movements were involved.
- Model 5: rotation of the Earth (2 children in the experimental group; 2 children in the control group). The children assigned to this model appeared to mix or confuse seasonal change with day and night. Often entire Earth-Sun-Moon Systems were involved. As the Earth rotated, it was indicated that *'in the summer we face the Sun, it's cold when we face the Moon'*, *'as it* [the Earth] *spins, the Sun's not shining on it'* and *'in the day it's summer, at night it's winter'*. Where provided, orbital periods and rotational periods were given as *'12 months'* and *'365 days'*.
- Model 6: the Earth and Sun move closer together and further apart (3 children in the experimental group; 1 child in the control group). The children assigned to this model described seasonal change in terms of the changing linear distance between the two bodies involved. Variations included the Earth approaching the Sun in summer and vice versa (e.g. *'at certain times it* [the Earth] *moves to the Sun for six months'*). No orbital movements were involved.
- Model 7: the Moon gets in the way (0 children in the experimental group; 1 child in the control group). The one child assigned to this model considered seasonal change in terms of the Moon orbiting the Earth once every *'12 months'* and blocking out the Sun's heat and light at certain times of the year.

- Model 8: mixed verbal models (2 children in the experimental group; 4 children in the control group). Variations in this model included seasonal change occurring in order for flowers to *'grow and die'* or because of something *'to do with the Moon'*, *'leaves falling'* or *'cold air'* coming. Like day and night, the children providing verbal models were unable or unwilling to further demonstrate their ideas in other ways.

Seventeen children in the experimental group and seventeen children in the control group could not be assigned to any model (*'not sure'*, insufficient detail). Regardless of the model type and any orbital or other movements involved, over half of the children in both groups knew that a year lasts *'12 months'*, *'52 weeks'* or *'365 days'*. Incorrect responses included *'55 weeks'*, *'10 weeks'* and *'165 days'* (many were *'not sure'*). While some of the children in both groups were aware that not all countries experienced the same seasons at the same time, only a few provided appropriate detail (e.g. *'when it's summer in the northern hemisphere it's winter in the southern hemisphere'*, *'when we're in summer, Australia is in winter'*, *'it's different around the equator'*). A selection of drawings of what causes seasonal change from children in the experimental group at first interview is provided as shown (Fig. 6.8).

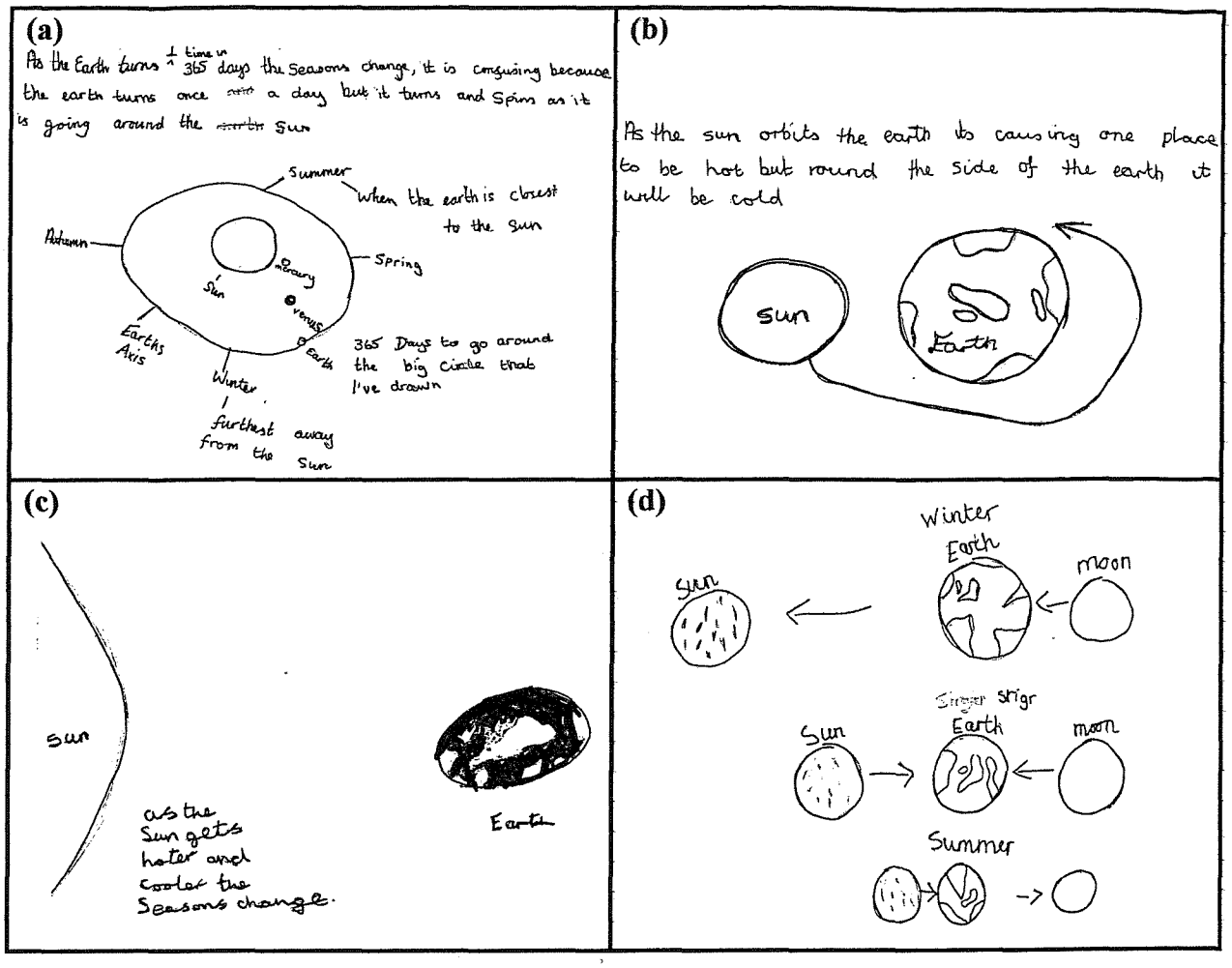


Fig. 6.8 Children's drawings of what causes seasonal change (pre-experimental treatment)

(a) Model 2: the Earth orbits the Sun
(b) Model 3: the Sun orbits the Earth
(c) Model 4: the Sun heats up and cools down
(d) Model 6: the Earth and Sun move closer together and further apart

6.9.2 Second interview: post-experimental treatment

Overviews of mental models, score frequency profiles and summated scores of seasonal change from children in the experimental group and control group at second interview (post-experimental treatment) can be found in Appendix VII.

(a) Correctness

The overall correctness of response in each of the six seasonal change items is summarized as shown (Table 6.39). Increases in correctness in the experimental group were observed in all

six seasonal change items (SC1-6). All frequencies in the experimental group were notably greater relative to changes in the control group (up to 45 percentage points in the cases of SC1: verbal and SC2: use of props).

	Experimental group			Control group		
Item	Boys	Girls	Total	Boys	Girls	Total
SC1: Verbal	11 (64.7)	4 (28.6)	15 (48.4)	2 (11.8)	1 (7.1)	3 (9.7)
SC2: Use of props	11 (64.7)	5 (35.7)	16 (51.6)	2 (11.8)	2 (14.3)	4 (12.9)
SC3: Drawing	9 (52.9)	4 (28.6)	13 (41.9)	2 (11.8)	1 (7.1)	3 (9.7)
SC4: Period	11 (64.7)	5 (35.7)	16 (51.6)	2 (11.8)	2 (14.3)	4 (12.9)
SC5: Year length	13 (76.5)	10 (71.4)	23 (74.2)	11 (64.7)	8 (57.1)	19 (61.3)
SC6: Variation	10 (58.8)	6 (42.9)	16 (51.6)	6 (35.3)	4 (28.6)	10 (32.3)

Table 6.39 Seasonal change correctness by item (frequency and percentage)

(b) What causes the seasons to change?

The general pattern of models observed between groups was no longer similar (Table 6.40). In the experimental group, a single model of what causes seasonal change involving the tilt of the Earth's axis as the Earth orbits the Sun once a year clearly emerged as the most common (none previously).

	Experimental group			Control group		
Models	Boys	Girls	Total	Boys	Girls	Total
1. Tilt of Earth's axis/orbits Sun	11 (64.7)	4 (28.6)	15 (48.4)	2 (11.8)	1 (7.1)	3 (9.7)
2. Earth orbits Sun (various)	1 (5.9)	4 (28.6)	5 (16.1)	0 (0.0)	1 (7.1)	1 (3.2)
3. Sun orbits Earth (various)	1 (5.9)	1 (7.1)	2 (6.5)	0 (0.0)	0 (0.0)	0 (0.0)
4. Sun heats up and cools down	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	0 (0.0)	1 (3.2)
5. Rotation of the Earth	0 (0.0)	1 (7.1)	1 (3.2)	1 (5.9)	0 (0.0)	1 (3.2)
6. Earth and Sun move closer/apart	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	0 (0.0)	1 (3.2)
7. Sun moves up and down	1 (5.9)	0 (0.0)	1 (3.2)	2 (11.8)	0 (0.0)	2 (6.5)
8. Sun's dark side	0 (0.0)	1 (7.1)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
9. Mixed verbal	0 (0.0)	0 (0.0)	0 (0.0)	2 (11.8)	3 (21.4)	5 (16.1)

Table 6.40 Mental models of seasonal change (frequency and percentage)

With the loss of the Moon getting in the way, only seven of the original eight mental models were identified. The responses provided by the children in the experimental group and control group indicated the presence of two others not previously identified. The children in

the experimental group continued to present ideas consistent with only six. This time, these included Models 1, 2, 3, 5, 7 and 8.

- Model 1: the tilt of the Earth's axis as the Earth orbits the Sun once a year (15 children in the experimental group; 3 children in the control group). Accounts of what causes seasonal change in terms of the Earth's axis and its orbit round the Sun improved verbally (e.g. *' 'cause the Earth's tipped towards it in summer, it turns around in winter, we're not facing it', 'when the Earth spins it's tilted and points to the Sun ... in winter it's tilted away', 'the Earth's tilted at 20 to 25 degrees and it spins around the Sun ... when Britain points to the Sun it's northern hemisphere summer, as Australia points to the Sun it's southern hemisphere summer'*). The use of props included more complete Earth-Sun-Moon Systems and drawings often illustrated different seasons with reference to the Earth's tilted axis at four appropriate points in the Earth's orbit around the Sun. The increased frequency of children in the experimental group assigned to this model, though less than half the group itself, was particularly notable (up 45 percentage points relative to changes in the control group). Where provided, reference to the tilt of the Earth's axis and its effect on the amount of solar energy received remained implicit or was provided in the form of *'it gets more* [or less] *Sun'*.
- Model 2: the Earth orbits the Sun (5 children in the experimental group; 1 child in the control group). The two children in the experimental group assigned to this model initially now provided responses consistent with Model 1.
- Model 3: the Sun orbits the Earth (2 children in the experimental group; 0 children in the control group). The four children in the experimental group assigned to this model initially now provided responses consistent with Model 1.
- Model 4: the Sun heats up and cools down (0 child in the experimental group; 1 child in the control group). The one child in the experimental group assigned to this model initially now provided responses consistent with Model 1.
- Model 5: rotation of the Earth (1 child in the experimental group; 1 child in the control group). One of the two children in the experimental group assigned to this model initially now provided responses consistent with Model 1.
- Model 6: the Earth and Sun move closer together and further apart (0 children in the experimental group; 1 child in the control group). One of the three children in the

experimental group assigned to this model initially now provided responses consistent with Model 1.

- Model 7: the Sun moves up and down (1 child in the experimental group; 2 children in the control group). Not previously identified. The one child in the experimental group assigned to this model provided initial responses consistent with Model 6. Seasonal change was now thought caused by the Sun itself moving *'up'* and *'down'* relative to a *'tilted'* but stationary Earth (possible reference to day and night or the changing altitude of the Sun in the sky throughout the year).
- Model 8: the Sun's dark side (1 child in the experimental group; 0 children in the control group). Not previously identified. The one child in the experimental group assigned to this model provided an initial response of *'not sure'*. Seasonal change was now thought caused by the Earth orbiting the Sun and while *'on the dark side of the Sun it's winter and autumn'*.
- Model 9: mixed verbal models (0 children in the experimental group; 5 children in the control group). One of the two children in the experimental group assigned here initially now provided responses consistent with Model 2.

Six children in the experimental group and seventeen children in the control group could not be assigned to any model (*'not sure'*, insufficient detail). Again, regardless of model type and any orbital or other movements involved, about three-quarters of the children in the experimental group knew that a year lasts *'12 months'*, *'52 weeks'* or *'365 days'* with some indicating *'365¼'* or *'365.25'* days. While more of the children in the experimental group were aware that not all countries experienced the same seasons at the same time, the nature of the responses provided were similar to those received earlier. A typical example of an acceptable scientific drawing of what causes seasonal change from one child in the experimental group at second interview is provided as shown (Fig. 6.9).

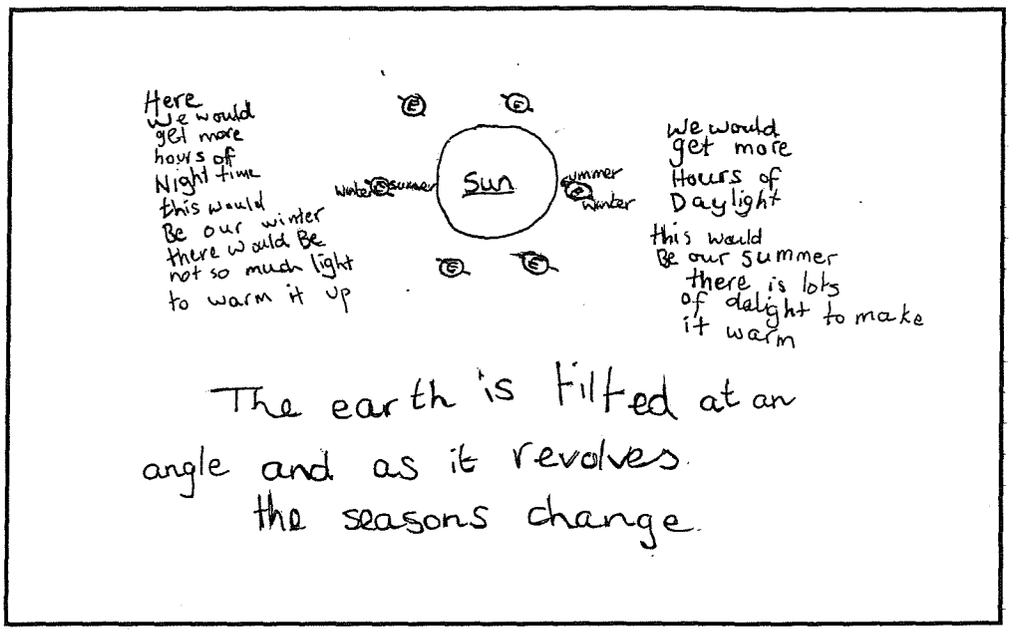


Fig. 6.9 Child's drawing of what causes seasonal change (post-experimental treatment)

6.9.3 Summary of inferential analyses

For a full treatment of the quantitative data see Appendix VIII.

(i) Pre-experimental treatment

At first interview, overall scores in the experimental group ranged from 0 to 7 with a mean of 3.3 (SD 1.83). Score profile percentages included 59.1% 0s, 27.4% 1s, 13.4% 2s and 0.0% 3s. 27 children scored between 0 and 5 (87%) and 4 children between 6 and 11 (13%). Overall scores in the control group ranged from 0 to 10 with a mean of 3.8 (SD 2.42). Score profile percentages included 58.1% 0s, 21.5% 1s, 19.9% 2s and 0.5% 3s. 25 children scored between 0 and 5 (81%) and 6 children between 6 and 11 (19%). The observed differences between the experimental group and control group in overall mean scores, score profile percentages and median scores in items of particular interest (SC1, SC2, SC3 and SC6) at first interview were not significant.

Boys in the experimental group appeared to score more highly than the girls overall and the observed difference in their mean scores, 3.9 and 2.4 (SDs 1.78 and 1.56), was significant

(t=2.49, df=29, p=0.019; normality for boys D_{xb}=0.083, p>0.15; normality for girls D_{xg}=0.094, p>0.15; F-ratio=1.30) though this was not reflected in an analysis of the score profile percentages by gender. In those items of particular interest (SC1, SC2, SC3 and SC6) no significant gender differences were observed. No gender differences were observed in the control group.

(i) Post-experimental treatment

At second interview, overall scores in the experimental group ranged from 0 to 16 with a mean of 9.0 (SD 5.10), a significant change from before (matched t=-7.53, p=0.000, normality of differences in experimental scores D_{dx}=0.113, p>0.15; F-ratio=7.77 which is significant at α=0.01). Score profile percentages included 22.6% 0s, 24.2% 1s, 33.3% 2s and 19.9% 3s, again a significant change from before (test statistic D_x=0.398, critical value K_D=0.169 for α=0.01). 10 children scored between 0 and 5 (32%), 8 children between 6 and 11 (26%) and 13 children between 12 and 18 (42%). Overall scores in the control group ranged from 0 to 14 with a mean of 4.0 (SD 3.49). Score profile percentages included 58.1% 0s, 18.8% 1s, 22.0% 2s and 1.1% 3s. 23 children scored between 0 and 5 (74%), 7 children between 6 and 11 (23%) and 1 child between 12 and 18 (3%). None of the changes observed between interviews were significant. More importantly, however, the mean gain in individual scores from children in the experimental group (O_3-O_1) and control group (O_4-O_2), +5.8 and +0.2 (SDs 4.27 and 1.96), was significant (t=6.61, df=42, p=0.000; normalities D_{dx}=0.113, D_{dc}=0.064, p>0.15; F-ratio=4.75 which is significant at α=0.01) as was the post-experimental treatment analysis of the score profile percentages (test statistic D_{xc}=0.355, critical value K_D=0.169 for α=0.01). In those items of particular interest (SC1, SC2, SC3 and SC6), observed differences in median scores between the experimental group and control group were significant in SC1 (verbal: W_{x2}=1208.0, W_{c2}=745.0, p=0.001), SC2 (use of props: W_{x2}=1261.0, W_{c2}=692.0, p=0.000) and SC3 (drawing: W_{x2}=1294.0, W_{c2}=659.0, p=0.000). Within the experimental group, multiple linear regression analysis using age, intellectual maturity and science curiosity as independent predictor variables was not significant.

No significant gender differences were observed in mean score and median score in either group. However, this was not the case in an analysis of the score profile percentages by

gender in the experimental group which favoured boys were significant (test statistic D_{xbg}=0.232, critical value K_D=0.200 for α=0.05).

6.9.4 Knowledge acquisition and concept learning

Within the experimental group at first interview, and before the experimental treatment, children's declared knowledge and understanding as probed suggested that their concept of what causes seasonal change was in a variable state of development with no acceptable scientific models evident at all (only two in the control group). More than half of the children involved indicated that they were either *'not sure'* or provided insufficient detail for any consistent model assignment to take place. At second interview, and after the experimental treatment, a substantial and significant increase in the frequency of a basic scientific model was evident, if only in about half of those involved. A summary of the numbers of children within the experimental group presenting a scientific mental model of what causes seasonal change is presented as follows:

- 0 (0.0%) pre-experimental treatment;
- 15 (48.4%) post-experimental treatment;
- 9 (29.0%) delayed.

Features associated with knowledge acquisition and concept learning in the experimental group relative to the control group are summarized as follows:

- accounts of seasonal change provided verbally, through the use of props and in drawings improved significantly;
- the number of children indicating *'not sure'* initially decreased substantially;
- descriptions of seasonal variations observed from place to place throughout the world improved significantly;
- the experimental treatment appeared to close the gap in the differences observed between boys and girls (mean score);
- the number of children with summated scores in the 12 to 18 range, reflecting more 2s and 3s, increased dramatically with a corresponding and significant increase in score profile percentages, overall mean score and mean gain.

Knowledge acquisition and concept learning in the experimental group are perhaps best accounted for in terms of mostly radical restructuring, a feature particularly well illustrated in the mapped movements or routes and pathways in children's ideas themselves (Fig. 6.10; see

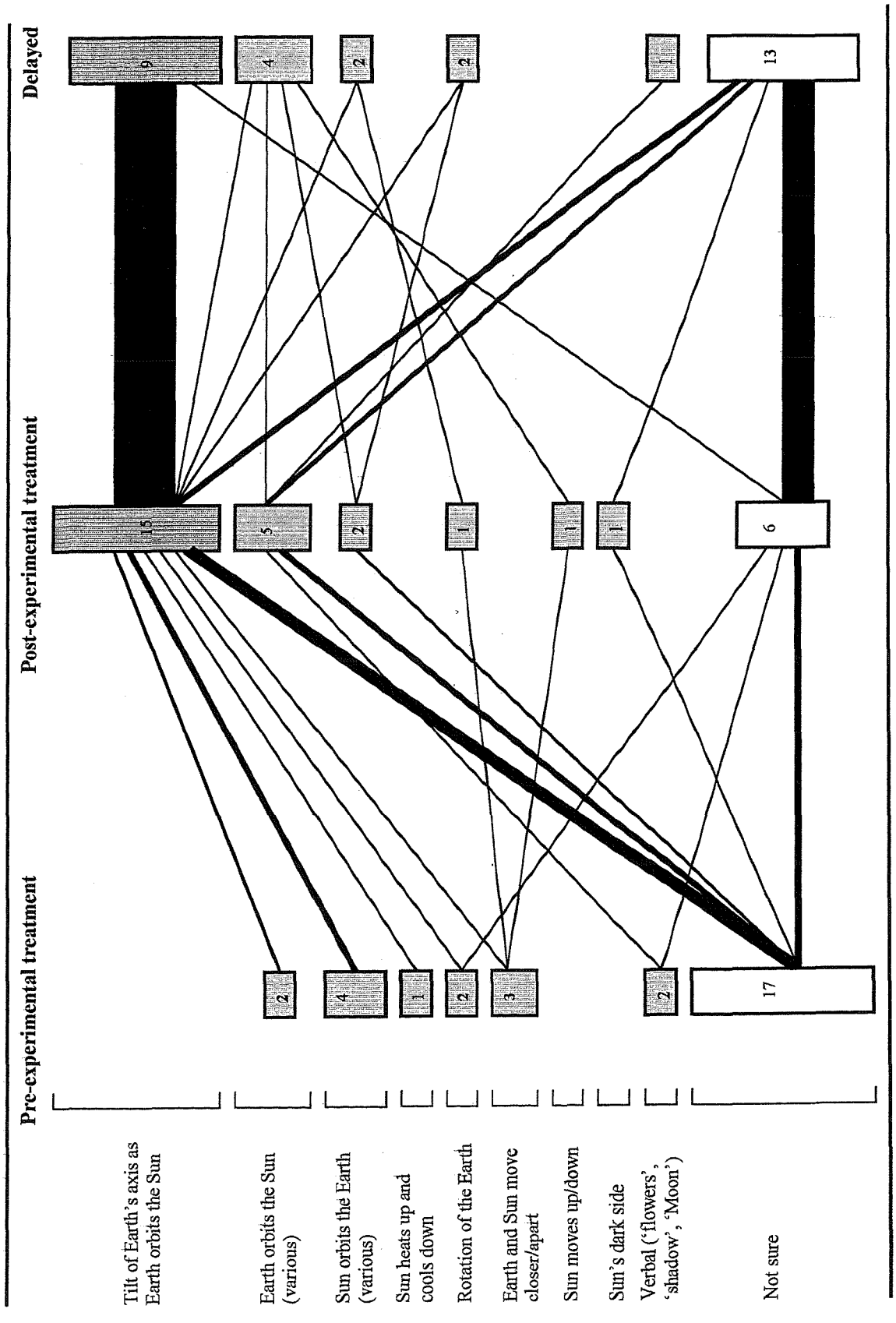


Fig.6.10 Knowledge acquisition and concept learning: mapped changes in children's mental models of seasonal change

also Appendix VII for a delayed overview). Interestingly, initial routes and pathways (pre- to post-) revealed 4 'non-movers' (original ideas retained – horizontal links), 24 'risers' (original ideas progressed – positive gradient links) and 3 'fallers' (original ideas regressed – negative gradient links). Later routes and pathways (post- to delayed) revealed 14 'non-movers', 4 'risers' and 13 'fallers', all of whom had made progress initially. It is important to notice that almost all of the changes observed at second interview did so between models, a feature characteristic of radical restructuring. Interestingly, in those areas of seasonal change which received most attention earlier (SC1, SC2, SC3 and SC6), observed differences in median scores between second and third interviews (post-experimental treatment and delayed) were significant for SC1 (verbal: W_{x2}=1125.5, W_D=827.5, p=0.023), SC2 (use of props: W_{x2}=1157.0, W_D=796.0, p=0.009) and SC3 (drawing: W_{x2}=1265.0, W_D=688.0, p=0.000). Retention and recall were particularly poor with many children reverting to often previously held non-scientific (intuitive and transitional) ideas and models.

6.10 Phases of the Moon

The phases of the Moon are caused by the amount of the Moon's lit side visible as it orbits the Earth. In this section, children's ideas about what causes the phases of the Moon in terms of their verbal descriptions, their ability to manipulate props, and their drawings are of particular interest.

6.10.1 First interview: pre-experimental treatment

Overviews of mental models, score frequency profiles and summated scores of what causes the phases of the Moon from children in the experimental group and control group at first interview (pre-experimental treatment) can be found in Appendix VII.

(a) Correctness

The overall correctness of response in each of the six Moon phase items considered is summarized as shown (Table 6.41). The general pattern of responses observed from both groups appears broadly similar. Particularly high frequencies were recorded with item MP5 (length of month) with particularly low frequencies recorded elsewhere. None of the children

in the experimental group and only one of the children in the control group provided anything approaching a correct scientific model.

Item	Experimental group			Control group		
	Boys	Girls	Total	Boys	Girls	Total
MP1: Verbal	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
MP2: Use of props	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	0 (0.0)	1 (3.2)
MP3: Drawing	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	0 (0.0)	1 (3.2)
MP4: Period	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	0 (0.0)	1 (3.2)
MP5: Length month	13 (76.5)	9 (64.3)	22 (71.0)	12 (70.6)	12 (85.7)	24 (77.4)
MP6: Eclipse	4 (23.5)	2 (14.3)	6 (19.4)	3 (17.6)	2 (14.3)	5 (16.1)

Table 6.41 Moon phases correctness by item (frequency and percentage)

(b) What causes the Moon's phases to change?

Combined response categories for items MP1, 2 and 3 were used in order to determine the range of mental models of what causes the phases of the Moon. These are presented as shown (Table 6.42). Like day and night and seasonal change, children were assigned to models on the basis of presenting consistent responses from two out of the three items considered. The most common single model of what causes the phases of the Moon to emerge from both groups involved clouds (mixed verbal models contained a variety of often unrelated responses).

Models	Experimental group			Control group		
	Boys	Girls	Total	Boys	Girls	Total
1. Lit side seen as Moon orbits Earth	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	0 (0.0)	1 (3.2)
2. Earth shadow (eclipse)	3 (17.6)	0 (0.0)	3 (9.7)	3 (17.6)	1 (7.1)	4 (12.9)
3. Lit side seen as Earth rotates	1 (5.9)	0 (0.0)	1 (3.2)	3 (17.6)	1 (7.1)	4 (12.9)
4. Planets get in the way	2 (11.8)	0 (0.0)	2 (6.5)	1 (5.9)	0 (0.0)	1 (3.2)
5. Clouds	3 (17.6)	3 (21.4)	6 (19.4)	1 (5.9)	4 (28.6)	5 (16.1)
6. Moon goes behind Sun	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	0 (0.0)	1 (3.2)
7. Mixed verbal	5 (29.4)	2 (14.3)	7 (22.6)	1 (5.9)	5 (35.7)	6 (19.4)

Table 6.42 Mental models of what causes the Moon's phases (frequency and percentage)

Overall, seven mental models were identified. The children in the experimental group presented ideas consistent with Models 2, 3, 4, 5 and 7, the children in the control group all seven.

- Model 1: the lit side of the Moon seen as it orbits the Earth (0 children in the experimental group; 1 child in the control group). The one child assigned to this model indicated clearly that *'the Moon doesn't actually change shape, it only looks like it does'*. The Moon's phases were described and represented more accurately, though not completely, using props and in the child's drawing. The Moon was considered to orbit the Earth in a period of *'4 weeks'*, the time it took the phases to complete one cycle.
- Model 2: Earth shadow (3 children in the experimental group; 4 children in the control group). The children assigned to this model considered the Moon's phases to be caused by the Earth blocking light from the Sun and some certainly confused the Moon's phases with eclipse phenomena. Descriptions varied but included *'the Earth gets in the way'*, *'it gets eclipsed'*, *'I think it's because when the Sun reflects the light, the Earth blocks out half the Moon ... when there's no Moon the Earth blocks out all the light'* and *'some of it doesn't reflect because it's in the Earth's shadow'*.
- Model 3: the lit side of the Moon seen as the Earth rotates (1 child in the experimental group; 4 children in the control group). The children assigned to this model considered the Moon's phases to be caused by the rotation of the Earth bringing more of the Moon's lit side into view (e.g. *'you see more of it'*, *'you can see different parts of the Moon from different places'*). Some may have confused a model of the Moon's phases with day and night.
- Model 4: planets get in the way (2 children in the experimental group; 1 child in the control group). The children assigned to this model considered the Moons phases to be caused by other planets (e.g. *'something like a planet gets in the way'*, *'sometimes I reckon a planet gets in the way ... a black planet, it merges with the night'*).
- Model 5: clouds (6 children in the experimental group; 5 children in the control group). The children assigned to this model considered the Moon's phases to be caused by drifting clouds (e.g. *'we can only see half the Moon because of the clouds'*).
- Model 6: the Moon goes behind the Sun (0 children in the experimental group; 1 child in the control group). The one child assigned to this model indicated simply that *'the Moon goes behind the Sun'*. This was supported using props and in the child's drawing.

- Model 7: mixed verbal models (7 children in the experimental group; 6 children in the control group). Variations in this model were extensive but included *'the Moon's got a dark side and it slowly turns around'*, *'it stays its shape but gets covered in darkness'*, *'it's got something to do with the sky'*, *'when it's Hallowe'en it's big'*, *'the seasons ... in the summer it changes'* and *'it gets smaller when the Moon gets cold'*.

Twelve children in the experimental group and nine children in the control group could not be assigned to any model (*'not sure'*, insufficient detail). Regardless of the model type and any orbital or other movements involved (the latter being provided in only one case), about three-quarters of the children in both groups knew that a month lasts *'4 weeks'* or between *'28'* and *'31 days'*. The rest were largely *'not sure'*. Fewer than one-fifth of the children in both groups provided an adequate description of eclipse phenomena when asked specifically. In such cases, responses focused exclusively on solar eclipses (e.g. *'it's when the Moon comes over the Sun'*). Some children remained confused (e.g. *'an eclipse is when the Sun gets in the way of the Moon or the Earth or something'*, *it's when the Sun goes behind clouds in the Middle of the day'*). A selection of drawings of what causes the Moon's phases from children in the experimental group at first interview is provided as shown (Fig. 6.11).

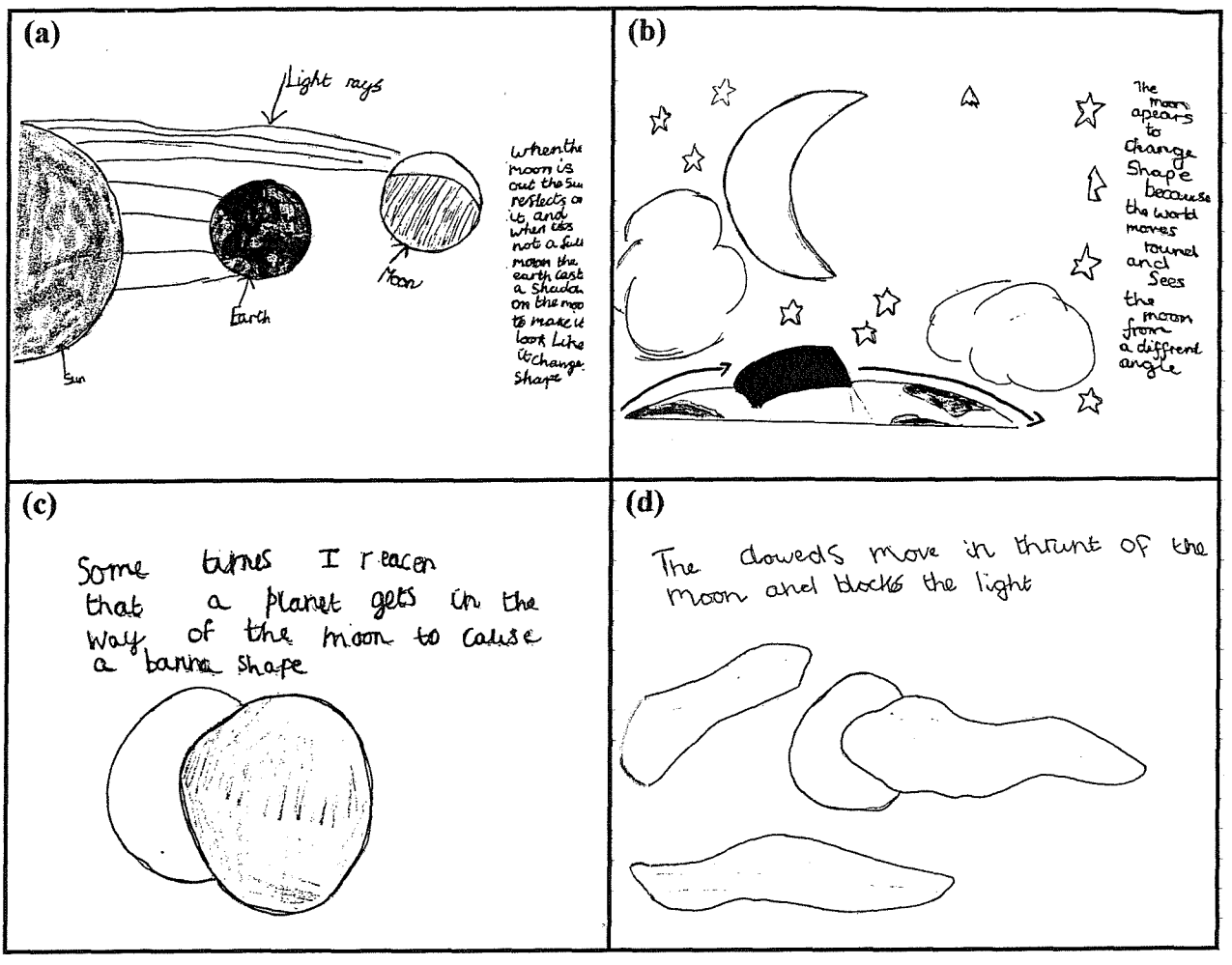


Fig. 6.11 Children's drawings of what causes the Moon's phases (pre-experimental treatment)

(a) Model 2: Earth shadow
(b) Model 3: the lit side of the Moon seen as the Earth rotates
(c) Model 4: planets get in the way
(d) Model 5: clouds

6.10.2 Second interview: post-experimental treatment

Overviews of mental models, score frequency profiles and summated scores of what causes the Moon's phases from children in the experimental group and control group at second interview (post-experimental treatment) can be found in Appendix VII.

(a) Correctness

The overall correctness of response in each of the six Moon phases items is summarized as shown (Table 6.43). Increases in correctness in the experimental group were observed in all six Moon phase items (MP1-6). All frequencies in the experimental group were notably greater relative to changes in the control group (up to 48 percentage points in the cases of MP1: verbal and MP2: use of props).

	Experimental group			Control group		
Item	Boys	Girls	Total	Boys	Girls	Total
MP1: Verbal	9 (52.9)	6 (42.9)	15 (48.4)	0 (0.0)	0 (0.0)	0 (0.0)
MP2: Use of props	11 (64.7)	5 (35.7)	16 (51.6)	2 (11.8)	0 (0.0)	2 (6.5)
MP3: Drawing	4 (23.5)	3 (21.4)	7 (22.6)	2 (11.8)	0 (0.0)	2 (6.5)
MP4: Period	9 (52.9)	3 (21.4)	12 (38.7)	0 (0.0)	0 (0.0)	0 (0.0)
MP5: Month length	15 (88.2)	13 (92.9)	28 (90.3)	11 (64.7)	8 (57.1)	19 (61.3)
MP6: Eclipse	9 (52.9)	3 (21.4)	12 (38.7)	0 (0.0)	0 (0.0)	0 (0.0)

Table 6.43 Moon phases correctness by item (frequency and percentage)

(b) What causes the Moon's phases to change?

The general pattern of models observed between groups was no longer similar (Table 6.44). In the experimental group, the most common model to account for the phases of the Moon involved the amount of lit side seen as the Moon orbits the Earth (previously clouds).

	Experimental group			Control group		
Models	Boys	Girls	Total	Boys	Girls	Total
1. Lit side seen as Moon orbits Earth	10 (58.8)	5 (35.7)	15 (48.4)	2 (11.8)	0 (0.0)	2 (6.5)
2. Earth shadow (eclipse)	3 (17.6)	0 (0.0)	3 (9.7)	1 (5.9)	1 (7.1)	2 (6.5)
3. Lit side seen as Earth rotates	1 (5.9)	0 (0.0)	1 (3.2)	1 (5.9)	2 (14.3)	3 (9.7)
4. Clouds	1 (5.9)	2 (14.3)	3 (9.7)	5 (29.4)	5 (35.7)	10 (32.3)
5. Moon goes behind Sun	0 (0.0)	2 (14.3)	2 (6.5)	4 (23.5)	0 (0.0)	4 (12.9)
6. Mixed verbal	0 (0.0)	1 (7.1)	1 (3.2)	1 (5.9)	2 (14.3)	3 (9.7)

Table 6.44 Mental models of what causes the Moon's phases (frequency and percentage)

With the loss of planets getting in the way, only six of the original seven mental models were identified. The children in the experimental group presented ideas consistent with all six.

- Model 1: the lit side of the Moon seen as it orbits the Earth (15 children in the experimental group; 2 children in the control group). Accounts of what causes the Moon's phases improved verbally (e.g. *'we can't see it all round, it's flat to us ... when it's dark it's where the Sun's not shining ... we can't see the part that's not lit up ... because it orbits the Earth, it depends on where it is compared with the Sun'*). The use of props included more complete Earth-Sun-Moon Systems and drawings were often more inclined to show named phases with the Moon often in its correct position around the Earth (particularly *'full'*, *'new'* and *'half'* Moons). Where provided, and in almost all cases, the Moon's orbital period was given as *'4 weeks'* or *'a month'*. The increased frequency of children in the experimental group assigned to this model, though less than half the group itself, was particularly notable (up 45 percentage points relative to changes in the control group).
- Model 2: Earth shadow (3 children in the experimental group; 2 children in the control group). The three children in the experimental group assigned to this model initially now provided responses consistent with Model 1.
- Model 3: the lit side of the Moon seen as the Earth rotates (1 child in the experimental group; 3 children in the control group). The one child in the experimental group assigned to this model initially now provided responses consistent with Model 1.
- Model 4: clouds (3 children in the experimental group; 10 children in the control group). Three of the six children in the experimental group assigned to this model initially now provided responses consistent with Model 1. The reduced frequency of children in the experimental group assigned to this model was particularly notable (down 26 percentage points relative to changes in the control group).
- Model 5: the Moon goes behind the Sun (2 children in the experimental group; 4 children in the control group). No children from the experimental group were assigned to this model initially. The two children here now provided earlier responses of *'not sure'*.
- Model 6: mixed verbal models (1 child in the experimental group; 3 children in the control group). One of the seven children in the experimental group assigned here initially now provided responses consistent with Model 1.

Six children in the experimental group and seven children in the control group could not be assigned to any model (*'not sure'*, insufficient detail). Again, regardless of model type and any orbital or other movements involved, almost all of the children in the experimental group knew that a month lasts *'4 weeks'* or between *'28'* and *'31 days'*. While more of the children in the experimental group provided adequate descriptions of eclipse phenomena when asked, these still focused exclusively on solar eclipses (e.g. *'when the Sun and the Moon are in the sky at the same time and it* [Moon] *goes in the middle of the Earth and Sun and blocks out all the sunlight'*, *'the Moon blocks the Sun out ... there's one coming in August 1999, it's only like that for a few minutes ... people in Tudor and Victorian times thought the Sun'd been swallowed'*). A typical example of an acceptable scientific drawing of what causes the Moon's phases from one child in the experimental group at second interview is provided as shown (Fig. 6.12).

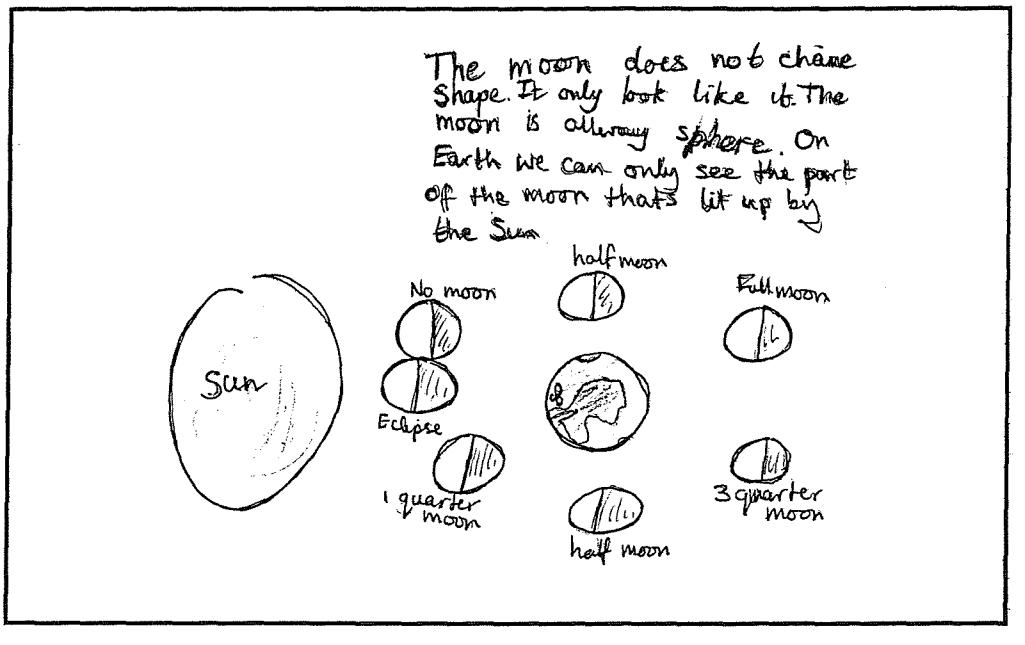


Fig. 6.12 Child's drawing of what causes the Moon's phases (post-experimental treatment)

6.10.3 Summary of inferential analyses

For a full treatment of the quantitative data see Appendix VIII.

(i) Pre-experimental treatment

At first interview, overall scores in the experimental group ranged from 0 to 7 with a mean of 3.5 (SD 1.95). Score profile percentages included 57.0% 0s, 28.0% 1s, 15.1% 2s and 0.0% 3s. 27 children scored between 0 and 5 (87%) and 4 children between 6 and 11 (13%). Overall scores in the control group ranged from 0 to 11 with a mean of 3.9 (SD 2.31). Score profile percentages included 55.4% 0s, 27.4% 1s, 13.4% 2s and 3.8% 3s. 24 children scored between 0 and 5 (77%) and 7 children between 6 and 11 (23%). The observed differences between the experimental group and control group in overall mean scores, scores profile percentages and median scores in items of particular interest (MP1, MP2, MP3 and MP6) at first interview were not significant.

Boys in the experimental group appeared to score more highly than the girls overall and the observed difference in their mean scores, 4.4 and 2.4 (SDs 1.50 and 1.95), was significant ($t=3.11$, $df=29$, $p=0.004$; normality for boys $D_{xb}=0.052$, $p>0.15$; normality for girls $D_{xg}=0.099$, $p>0.15$; F-ratio=1.69) and this was also reflected in an analysis of the score profile percentages by gender (test statistic $D_{xbg}=0.285$, critical value $K_D=0.240$ for $\alpha=0.01$). In those items of particular interest (MP1, MP2, MP3 and MP6), observed differences in median scores between boys and girls were significant in MP1 (verbal: $W_{xb}=327.5$, $W_{xg}=168.5$, $p=0.010$), MP2 (use of props: $W_{xb}=316.5$, $W_{xg}=179.5$, $p=0.041$) and MP3 (drawing: $W_{xb}=316.5$, $W_{xg}=179.5$, $p=0.041$). No significant gender differences were observed in the control group.

(ii) Post-experimental treatment

At second interview, overall scores in the experimental group ranged from 1 to 16 with a mean of 7.7 (SD 4.01), a significant change from before (matched $t=-6.38$, $p=0.000$, normality of differences in experimental scores $D_{dx}=0.068$, $p>0.15$; F-ratio=4.23 which is significant at $\alpha=0.01$). Score profile percentages included 26.3% 0s, 25.3% 1s, 41.4% 2s and 7.0% 3s, again a significant change from before (test statistic $D_x=0.333$, critical value $K_D=0.169$ for $\alpha=0.01$). 11 children scored between 0 and 5 (32%), 15 children between 6 and 11 (48%) and 5 children between 12 and 18 (16%). Overall scores in the control group ranged from 0 to 9 with a mean of 3.2 (SD 2.31). Score profile percentages included 61.8%

0s, 25.8% 1s, 9.1% 2s and 3.2% 3s. 27 children scored between 0 and 5 (87%) and 4 children between 6 and 11 (13%). None of the changes observed between interviews were significant. More importantly, however, the mean gain in individual scores from children in the experimental group (O_3-O_1) and control group (O_4-O_2), +4.3 and –0.7 (SDs 3.72 and 2.10), was significant (t=6.48, df=47, p=0.000; normalities D_{dx}=0.068, D_{dc}=0.060, p>0.15; F-ratio=3.14 which is significant at α=0.01). In those items of particular interest (MP1, MP2, MP3 and MP6), observed differences in median scores between the experimental group and control group were significant in MP1 (verbal: W_{x2}=1172.0, W_{c2}=781.0, p=0.002), MP2 (use of props: W_{x2}=1211.5, W_{c2}=741.5, p=0.000), MP3 (drawing: W_{x2}=1142.5, W_{c2}=810.5, p=0.012) and MP6 (eclipse: W_{x2}=1114.5, W_{c2}=838.5, p=0.029). Within the experimental group, multiple linear regression analysis using age, intellectual maturity and science curiosity as independent predictor variables was significant (R^2=0.480, F=8.29, p=0.000, df=3), but with only age contributing to the differences in summated scores between individuals.

Significant differences in the experimental group favouring boys were only observed in an analysis of the score profile percentages (test statistic D_{xbg}=0.236, critical value K_D=0.200 for α=0.05) and in those areas of particular interest including item MP6 (eclipse: W_{xb}=329.0, W_{xg}=167.0, p=0.016). On this occasion, boys in the control group appeared to score more highly than the girls overall and the observed difference in their mean scores, 4.0 and 2.3 (SDs 2.48 and 1.73), was also significant (t=2.19, df=29, p=0.037; normality for boys D_{cb}=0.088, p>0.15; normality for girls D_{cg}=0.129, p>0.15; F-ratio=2.05) though this was not reflected in an analysis of the score profile percentages by gender. In those items of particular interest (MP1, MP2, MP3 and MP6), observed differences in median scores favouring boys were significant in MP2 (use of props: W_{cb}=327.0, W_{cg}=169.0, p=0.012) and MP3 (drawing: W_{cb}=319.0, W_{cg}=177.0, p=0.038).

6.10.4 Knowledge acquisition and concept learning

Within the experimental group at first interview, and before the experimental treatment, children's declared knowledge and understanding as probed suggested that their concept of what causes the phases of the Moon was in a variable state of development with no acceptable scientific models evident at all (only one in the control group). A little less than

half of the children involved indicated that they were either *'not sure'* or provided insufficient detail for any consistent model assignment to take place. At second interview, and after the experimental treatment, a substantial and significant increase in the frequency of a basic scientific model was evident if only in about half of those involved. A summary of the numbers of children within the experimental group presenting a scientific mental model of what causes the phases of the Moon is presented as follows:

- 0 (0.0%) pre-experimental treatment;
- 15 (48.4%) post-experimental treatment;
- 7 (22.6%) delayed.

Features associated with knowledge acquisition and concept learning in the experimental group relative to the control group are summarized as follows:

- accounts of what causes the phases of the Moon provided verbally, through the use of props and in drawings improved significantly;
- the number of children indicating *'not sure'* initially decreased substantially;
- the experimental treatment appeared to close the gap in the differences observed between boys and girls (mean score, median scores in most items of particular interest);
- the number of children with summated scores in the 12 to 18 range, reflecting more 2s and 3s, increased dramatically with a corresponding and significant increase in score profile percentages, overall mean score and mean gain;
- only the predictor variable age contributed significantly to the differences in summated scores between individuals.

Knowledge acquisition and concept learning in the experimental group are perhaps best accounted for in terms of mostly radical restructuring, a feature particularly well illustrated in the mapped movements or routes and pathways in children's ideas themselves (Fig. 6.13; see also Appendix VII for a delayed overview). Interestingly, initial routes and pathways (pre- to post-) revealed 8 'non-movers' (original ideas retained – horizontal links), 21 'risers' (original ideas progressed – positive gradient links) and 2 'fallers' (original ideas regressed – negative gradient links). Later routes and pathways (post- to delayed) revealed 16 'non-movers', 3 'risers' and 12 'fallers', ten of whom had made progress initially. It is important to notice that almost all of the changes observed at second interview did so between models,

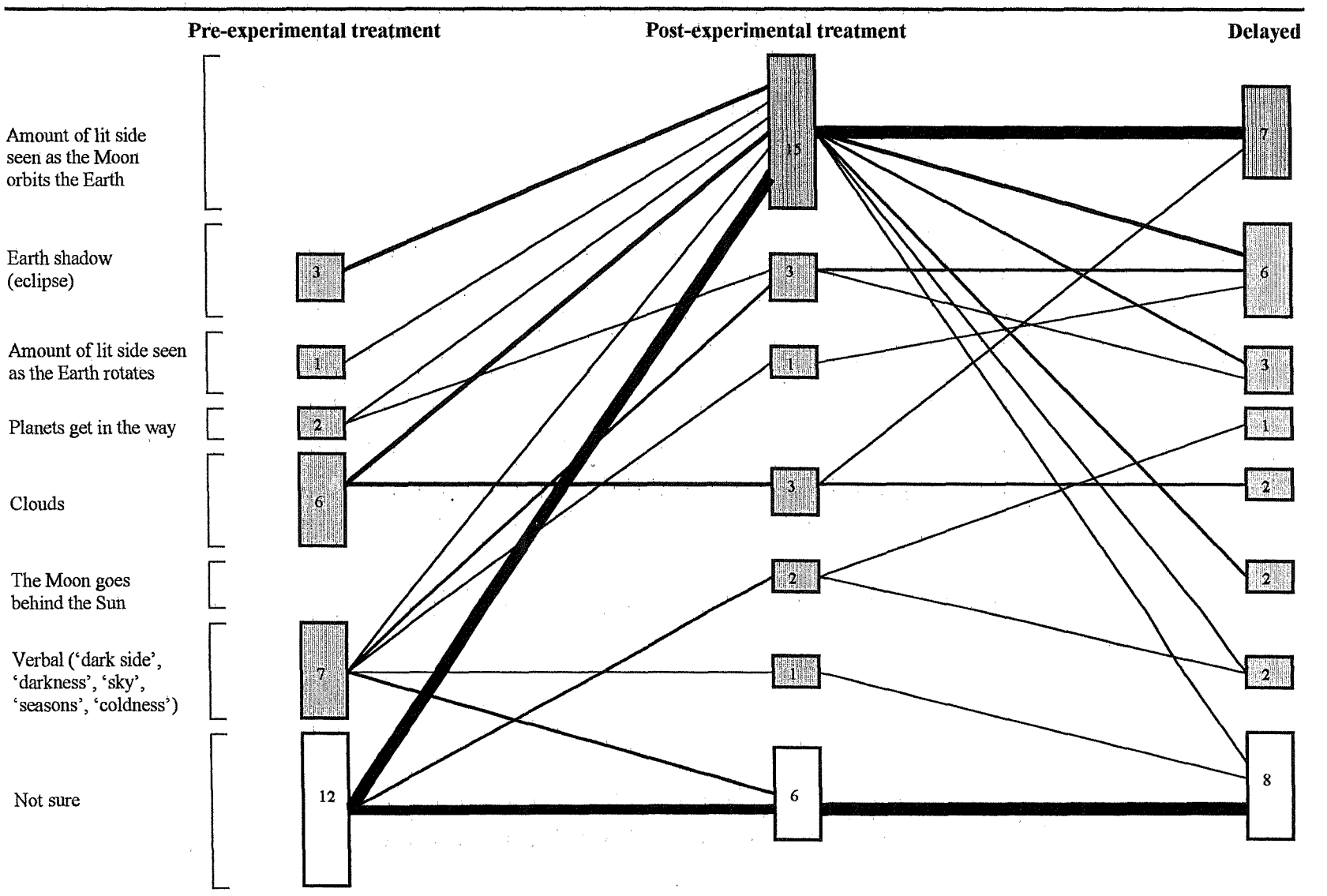


Fig.6.13 Knowledge acquisition and concept learning: mapped changes in children's mental models of the Moon's phases

a feature characteristic of radical restructuring. Interestingly, in those areas of the Moon's phases which received most attention earlier (MP1, MP2, MP3 and MP6), observed differences in median scores between second and third interviews (post-experimental treatment and delayed) were significant for MP3 (drawing: W_{x2}=1201.0, W_D=752.0, p=0.001). Despite this, retention and recall were, like seasonal change, particularly poor with many children reverting to often previously held non-scientific (intuitive and transitional) ideas and models.

6.11 The Solar System and wider Universe

The Solar System, within a wider Universe, is the name given to our nearest star, the Sun, together with its family of nine planets, their moons, and other objects including asteroids, comets and meteoroids. In this section, children's ideas about the Solar System in terms of its contents, structure, dynamics, age and origin are of particular interest.

6.11.1 First interview: pre-experimental treatment

Overviews of mental models, score frequency profiles and summated scores for the Solar System and wider Universe from children in the experimental group and control group at first interview (pre-experimental treatment) can be found in Appendix VII.

(a) Correctness

The overall correctness of response in each of the twelve Solar System items considered is summarized as shown (Table 6.45). The general pattern of responses observed from both groups appears broadly similar. Particularly high frequencies were recorded with item SOL1 (contents), which focused on the mention of planets, with particularly low frequencies recorded elsewhere (including zeros). Only one child in the experimental group was able to draw a basic 'map' of the Solar System.

Item	Experimental group			Control group		
	Boys	Girls	Total	Boys	Girls	Total
SOL 1: Contents	17 (100.0)	13 (92.9)	30 (96.8)	17 (100.0)	14 (100.0)	31 (100.0)
SOL 2: Number of planets	9 (52.9)	5 (35.7)	14 (45.2)	4 (23.5)	3 (21.4)	7 (22.6)
SOL 3: Names of planets	2 (11.8)	0 (0.0)	2 (6.5)	1 (5.9)	0 (0.0)	1 (3.2)
SOL 4: Picture recognition	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
SOL 5: Solar System map	1 (5.9)	0 (0.0)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
SOL 6: Features	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
SOL 7: Relative sizes	7 (41.2)	2 (14.3)	9 (29.0)	3 (17.6)	0 (0.0)	3 (9.7)
SOL 8: Relative distances	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	0 (0.0)	1 (3.2)
SOL 9: Movements of planets	4 (23.5)	0 (0.0)	4 (12.9)	8 (47.1)	0 (0.0)	8 (25.8)
SOL10: Forces	1 (5.9)	0 (0.0)	1 (3.2)	5 (29.4)	0 (0.0)	5 (16.1)
SOL11: Solar System age	0 (0.0)	0 (0.0)	0 (0.0)	2 (11.8)	1 (7.1)	3 (9.7)
SOL12: Origin	4 (23.5)	0 (0.0)	4 (12.9)	2 (11.8)	2 (14.3)	4 (12.9)

Table 6.45 Solar System correctness by item (frequency and percentage)

(b) Mapping the Solar System

Response categories for item SOL5 (Solar System map), together with some support from other items, notably SOL1, 2 and 3, were used in order to determine the range of mental models of the structure and composition of the Solar System. These are presented as shown (Table 6.46). Most of the children in both groups presented a model of the Solar System in which the Sun and an incomplete selection of planets recalled from memory were arranged randomly in space.

Models	Experimental group			Control group		
	Boys	Girls	Total	Boys	Girls	Total
1. Heliocentric (complete/correct)	1 (5.9)	0 (0.0)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
2. Heliocentric (complete/incorrect)	1 (5.9)	0 (0.0)	1 (3.2)	3 (17.6)	0 (0.0)	3 (9.7)
3. Heliocentric (incomplete/incorrect)	6 (35.3)	2 (14.3)	8 (25.8)	5 (29.4)	4 (28.6)	9 (29.0)
4. Geocentric (incomplete/incorrect)	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	0 (0.0)	1 (3.2)
5. Processional (Earth-centred)	2 (11.8)	2 (14.3)	4 (12.9)	0 (0.0)	0 (0.0)	0 (0.0)
6. Random	6 (35.3)	4 (28.6)	10 (32.3)	8 (47.1)	7 (50.0)	15 (48.4)
7. Earth, Sun and Moon	1 (5.9)	2 (6.5)	3 (9.7)	0 (0.0)	3 (21.4)	3 (9.7)

Table 6.46 Mental models of the Solar System (frequency and percentage)

Overall, seven mental models were identified. The children in the experimental group presented ideas consistent with Models 1, 2, 3, 5, 6 and 7, the children in the control group Models 2, 3, 4, 6 and 7.

- Model 1: heliocentric - complete/correct (1 child in the experimental group; 0 children in the control group). The one child assigned to this model drew a Solar System including all nine planets. The planets were arranged linearly, in the correct order from the Sun, and correctly named.
- Model 2: heliocentric – complete/incorrect (1 child in the experimental group; 3 children in the control group). The children assigned to this model drew Solar Systems including all nine planets. The planets were arranged linearly, in the wrong order from the Sun, and correctly named in only two cases.
- Model 3: heliocentric – incomplete/incorrect (8 children in the experimental group; 9 children in the control group). The children assigned to this model drew Solar Systems including a mixed selection of planets. The planets were arranged both linearly (7 cases) and concentrically (1 case) and in the wrong order from the Sun.
- Model 4: geocentric – incomplete/incorrect (0 children in the experimental group; 1 child in the control group). The one child assigned to this model drew a Solar System including a mixed selection of planets. The planets were arranged linearly and in the wrong order from the Earth.
- Model 5: processional – Earth-centred (4 children in the experimental group; 0 children in the control group). The children assigned to this model drew Solar Systems including a mixed selection of planets. The planets were arranged in a single orbit around the Earth.
- Model 6: random (10 children in the experimental group; 15 children in the control group). The children assigned to this model drew Solar Systems including a mixed selection of planets arranged entirely at random.
- Model 7: Earth, Sun and Moon (3 children in the experimental group; 3 children in the control group). The children assigned to this model drew Solar Systems consisting of these three bodies only.

Four children in the experimental group could not be assigned to any model (no drawings produced). In addition to the Sun and planets, *'moons'*, *'comets'*, *'meteorites'* and *'asteroids'* were also mentioned as Solar System objects but much less widely and erratically represented in drawings. While almost all of the children in both groups were aware that planets other than the Earth formed part of the Solar System itself, fewer than half of those involved indicated that there were *'nine'* in total. Where provided, other suggestions included *'three'*, *'seven'*, *'twelve'* and *'thousands'*. Only two children in the experimental group and one child

in the control group could recall all nine names with most giving between four and seven (in order of frequency of mention - Earth, Mars, Pluto, Saturn, Jupiter, Venus, Mercury, Uranus and Neptune). In terms of planetary recognition, only the Earth and Saturn were readily identified from pictures (with Pluto, Jupiter, Uranus, Mars and Neptune less so). Other than the Earth and the Sun, the planets and other Solar System objects depicted in 'maps' were usually drawn without recognizable features. The relative sizes of the Sun and the planets and the relative distances between them were poorly represented. Where considered, planetary movements were described by a small number of children in the experimental group and the control group in terms of *'orbiting the Sun at different times'*. Other indications of movement included planets orbiting the Sun but together at the same time, planets orbiting the Earth in procession and planets moving at random. Many children considered all of the planets to be stationary (e.g. *'if they were still they wouldn't fall as there's no gravity in space'*). The planets were considered to remain in orbit around the Sun because of the *'gravitational pull of the Sun'*, because *'the Sun pushes them around'* or because they *'need light'*. While the age of the Solar System was given occasionally as *'billions of years old'*, other suggestions included *'500 million years old'*, *'50 million years old'*, *'since the Earth was created'*, *'before Christ was born'* and *'2000 years old'*. One child in the control group considered the Solar System to be *'65 million years old'* and to have formed at the same time as the dinosaurs became extinct. In terms of the origin of the Solar System, within the context of the wider Universe, only a few children made correct reference to events stemming from the *'Big Bang'*. One child in the experimental group indicated clearly that *'scientists don't know'*. Other suggestions included *'from pitch black'*, *'from a star'*, *'from a star that got bigger'*, *'from a planet that exploded'* and *'God'*. Features of the wider Universe mentioned included *'stars'*, *'exploding stars'*, *'galaxies'*, *'the Milky Way'*, *'gas and dust'*, *'black holes'*, *'worm holes'*, *'white dwarfs'*, *'quasars'*, *'space junk'*, *'probes'* and *'extra-terrestrials'*. A selection of drawings of the Solar System from children in the experimental group at first interview is provided as shown (Fig. 6.14).

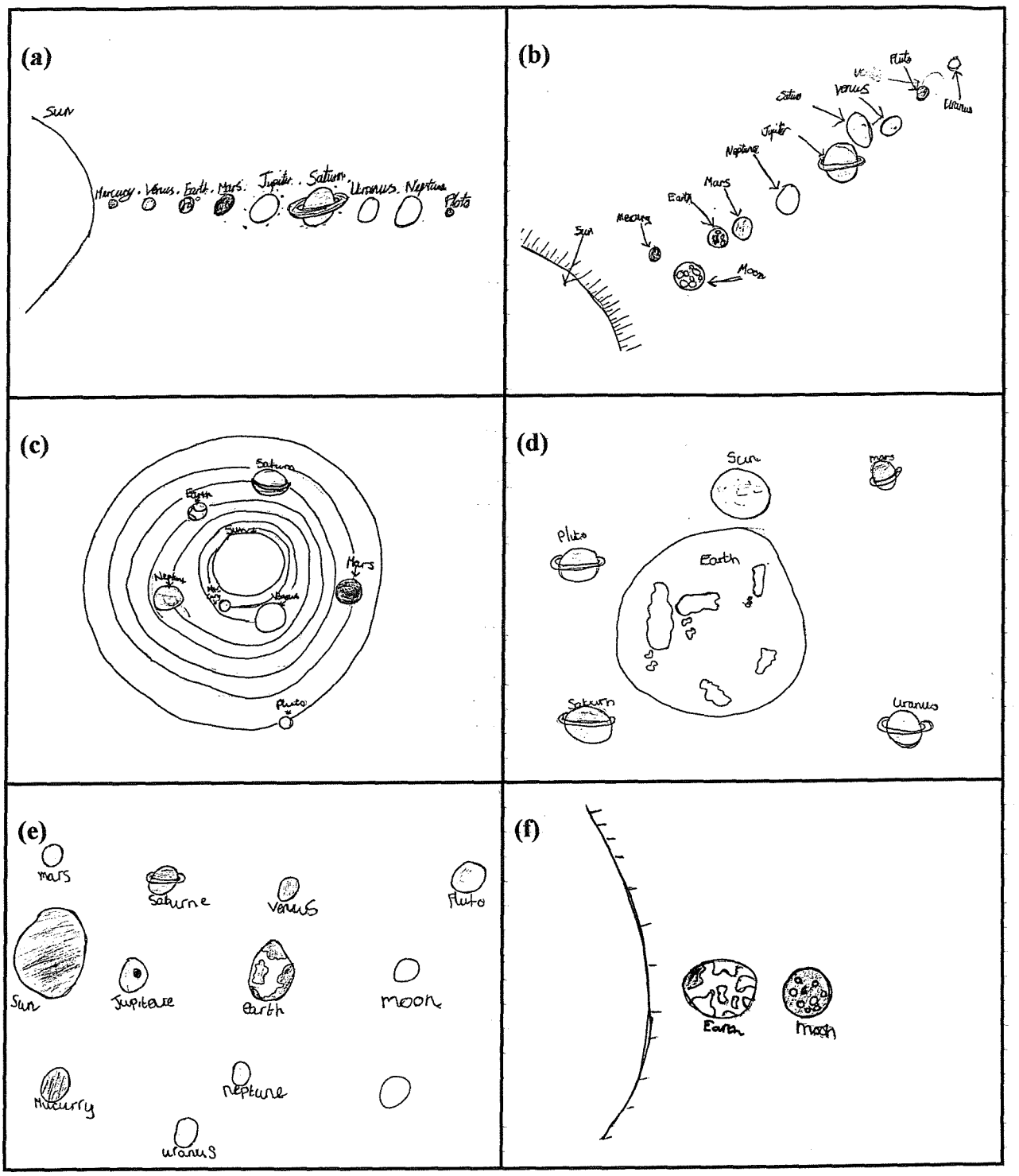


Fig. 6.14 Children's drawings of the Solar System (pre-experimental treatment)

(a) Model 1: heliocentric – complete/correct
(b) Model 2: heliocentric – complete/incorrect
(c) Model 3: heliocentric – incomplete/incorrect
(d) Model 5: processional – Earth-centred
(e) Model 6: random
(f) Model 7: Earth, Sun and Moon

6.11.2 Second interview: post-experimental treatment

Overviews of mental models, score frequency profiles and summated scores for the Solar System and wider Universe from children in the experimental group and control group at second interview (post-experimental treatment) can be found in Appendix VII.

(a) Correctness

The overall correctness of response in each of the twelve Solar System items considered is summarized as shown (Table 6.47). Increases in correctness in the experimental group were observed in all twelve Solar System items (SOL1-12). All frequencies in the experimental group were greater relative to changes in the control group (up between 3 percentage points in the case of SOL1: contents to 81 percentage points in the case of SOL3: names of planets). Relatively low frequencies were still recorded in SOL4 (picture recognition), 8 (relative distances) and 11 (Solar System age).

	Experimental group			Control group		
Item	Boys	Girls	Total	Boys	Girls	Total
SOL 1: Contents	17 (100.0)	14 (100.0)	31 (100.0)	17 (100.0)	14 (100.0)	31 (100.0)
SOL 2: Number of planets	17 (100.0)	14 (100.0)	31 (100.0)	6 (35.3)	3 (21.4)	9 (29.0)
SOL 3: Names of planets	16 (94.1)	13 (92.9)	29 (93.5)	2 (11.8)	1 (7.1)	3 (9.7)
SOL 4: Picture recognition	5 (29.4)	3 (21.4)	8 (25.8)	1 (5.9)	0 (0.0)	1 (3.2)
SOL 5: Solar System map	12 (70.6)	10 (71.4)	22 (71.0)	1 (5.9)	0 (0.0)	1 (3.2)
SOL 6: Features	8 (47.1)	6 (42.9)	14 (45.2)	0 (0.0)	0 (0.0)	0 (0.0)
SOL 7: Relative sizes	13 (76.5)	6 (42.9)	19 (61.3)	6 (35.3)	0 (0.0)	6 (19.4)
SOL 8: Relative distances	4 (23.5)	0 (0.0)	4 (25.8)	0 (0.0)	0 (0.0)	0 (0.0)
SOL 9: Movements of planets	12 (70.6)	8 (57.1)	20 (64.5)	6 (35.3)	0 (0.0)	6 (19.4)
SOL10: Forces	9 (52.9)	5 (35.7)	14 (45.2)	1 (5.9)	0 (0.0)	1 (3.2)
SOL11: Solar System age	4 (23.5)	2 (14.3)	6 (19.4)	1 (5.9)	0 (0.0)	1 (3.2)
SOL12: Origin	12 (70.6)	9 (64.3)	21 (67.7)	2 (11.8)	0 (0.0)	2 (6.5)

Table 6.47 Solar System correctness by item (frequency and percentage)

(b) Mapping the Solar System

The general pattern of models observed between groups was no longer similar (Table 6.48). In the experimental group, the most common model of the Solar System was heliocentric, complete and correct (previously random).

Models	Experimental group			Control group		
	Boys	Girls	Total	Boys	Girls	Total
1. Heliocentric (complete/correct)	12 (70.6)	10 (71.4)	22 (71.0)	1 (5.9)	0 (0.0)	1 (3.2)
2. Heliocentric (complete/incorrect)	2 (11.8)	0 (0.0)	2 (6.5)	0 (0.0)	0 (0.0)	0 (0.0)
3. Heliocentric (incomplete/incorrect)	1 (5.9)	1 (7.1)	2 (6.5)	7 (41.2)	2 (14.3)	9 (29.0)
4. Spiral	1 (5.9)	0 (0.0)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
5. Processional (Sun-centred)	0 (0.0)	1 (7.1)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
6. Processional (Earth-centred)	1 (5.9)	0 (0.0)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)
7. Random	0 (0.0)	2 (14.3)	2 (6.5)	8 (47.1)	4 (28.6)	12 (38.7)
8. Earth, Sun and Moon	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.9)	7 (50.0)	8 (25.8)

Table 6.48 Mental models of the Solar System (frequency and percentage)

With the loss of geocentric (incomplete/incorrect), only six of the original seven mental models were identified. The responses provided by the children in the experimental group indicated the presence of two others. The children in the experimental group presented ideas consistent with Models 1 to 7.

- Model 1: heliocentric - complete/correct (22 children in the experimental group; 1 child in the control group). The children assigned to this model drew Solar Systems including all nine planets. The planets were arranged both linearly (18 cases) and concentrically (4 cases), in the correct order from the Sun, and correctly named. The increased frequency of children assigned to this model was particularly notable (up 65 percentage points relative to changes in the control group).
- Model 2: heliocentric – complete/incorrect (2 children in the experimental group; 0 children in the control group). The one child in the experimental group assigned to this model initially now provided responses consistent with Model 1.
- Model 3: heliocentric – incomplete/incorrect (2 children in the experimental group; 9 children in the control group). The eight children assigned to this model initially now provided responses consistent with Model 1. The reduced frequency of children assigned to this model was particularly notable (down 19 percentage points relative to changes in the control group).
- Model 4: spiral (1 child in the experimental group; 0 children in the control group). Not previously identified. The one child in the experimental group assigned to this model

provided initial responses consistent with Model 6. Planets within the Solar System were arranged appearing to follow a spiral path around the Sun.

- Model 5: processional – Sun-centred (1 child in the experimental group; 0 children in the control group). Not previously identified. The one child in the experimental group assigned to this model provided initial responses consistent with Model 6. Planets within the Solar System were arranged in a single orbit around the Sun.
- Model 6: processional – Earth-centred (1 child in the experimental group; 0 children in the control group). One of the four children in the experimental group assigned to this model initially now provided responses consistent with Model 1.
- Model 7: random (2 children in the experimental group; 12 children in the control group). Eight of the ten children in the experimental group assigned to this model initially now provided responses consistent with Model 1. The reduced frequency of children assigned to this model was particularly notable (down 16 percentage points relative to changes in the control group).
- Model 8: Earth, Sun and Moon (0 children in the experimental group; 8 children in the control group). One of the three children in the experimental group assigned to this model initially now provided responses consistent with Model 1. The reduced frequency of children assigned to this model was particularly notable (down 26 percentage points relative to changes in the control group).

One child in the control group could not be assigned to any model (no drawing produced). In addition to the Sun and planets, almost all of the children in the experimental group presented a combination of *'moons'*, *'comets'*, *'meteorites'*, and *'asteroids'* as Solar System objects with seven individuals remembering them all in detail. All of the children knew that there were nine planets in the Solar System and almost all could recall their names. One child indicated the *'possibility of a tenth planet called Planet X'*. While about a quarter of the group were able to identify all nine planets from pictures, most identified a range from four to eight (in order of frequency of mention – Earth, Mars, Saturn, Jupiter, Venus, Pluto, Neptune, Uranus and Mercury). Planets and other Solar System objects depicted in 'maps' were usually drawn with recognizable features in most cases, about half of the children representing good detail overall (e.g. colour, craters, Jupiter's banding and Great Red Spot, rings around Saturn and most other gas giants, moons other than the Earth's Moon, and so on). In addition to the relative sizes of the Sun and the planets being shown on over half of

the 'maps' drawn, almost all of the children remembered that Jupiter was the largest planet and Pluto was the smallest. While the relative distances between the planets were only shown correctly in a small number of cases, a few children indicated that the planets were *'millions of kilometres apart'*. One child pointed out that the distance between the Earth and the Sun was about *'93 million miles'*. Where considered, almost all children with heliocentric models of the Solar System were aware that the planets orbited the Sun at different times and that they remained in orbit because of *'the Sun's gravity pulling them towards it'*. One child pointed out that *'the Sun has a strong pull of gravity which pulls ... the planets try to escape but they can't ... the Moon moves from the Earth at 3cm a year'*. Many children also pointed out that Mercury orbited the Sun in the shortest time (e.g. *'88 days')* because it was closest and Pluto orbited the Sun in the longest time (e.g. *'248 years')* because it was furthest away. Only a few children in the experimental group knew that the Solar System is *'billions of years old'*. In one case, it was said that *'it's 1997 now so it must be old'*. As before, but with a particularly notable increase in the frequency of responses and additional detail, the origin of the Solar System, within the context of the wider Universe, was provided with reference to events stemming from the origin of the Universe at the time of the *'Big Bang'* (e.g. *'at the Big Bang everything explode and galaxies flew out ... nebulae created the planets and stars and asteroids and comets were made'*). Features of the wider Universe mentioned included *'stars'*, *'galaxies'*, *'gas clusters'*, *'gas and dust'*, *'Pillars of Creation'* (gas columns in the Eagle nebula), *'black holes'*, *'worm holes'*, *'white dwarfs'*, *'quasars'*, *'satellites'*, *'probes'*, *'space junk'* and *'extra-terrestrials'*. Typical examples of acceptable scientific drawings of the Solar System from two children in the experimental group at second interview are provided as shown (Fig. 6.15).

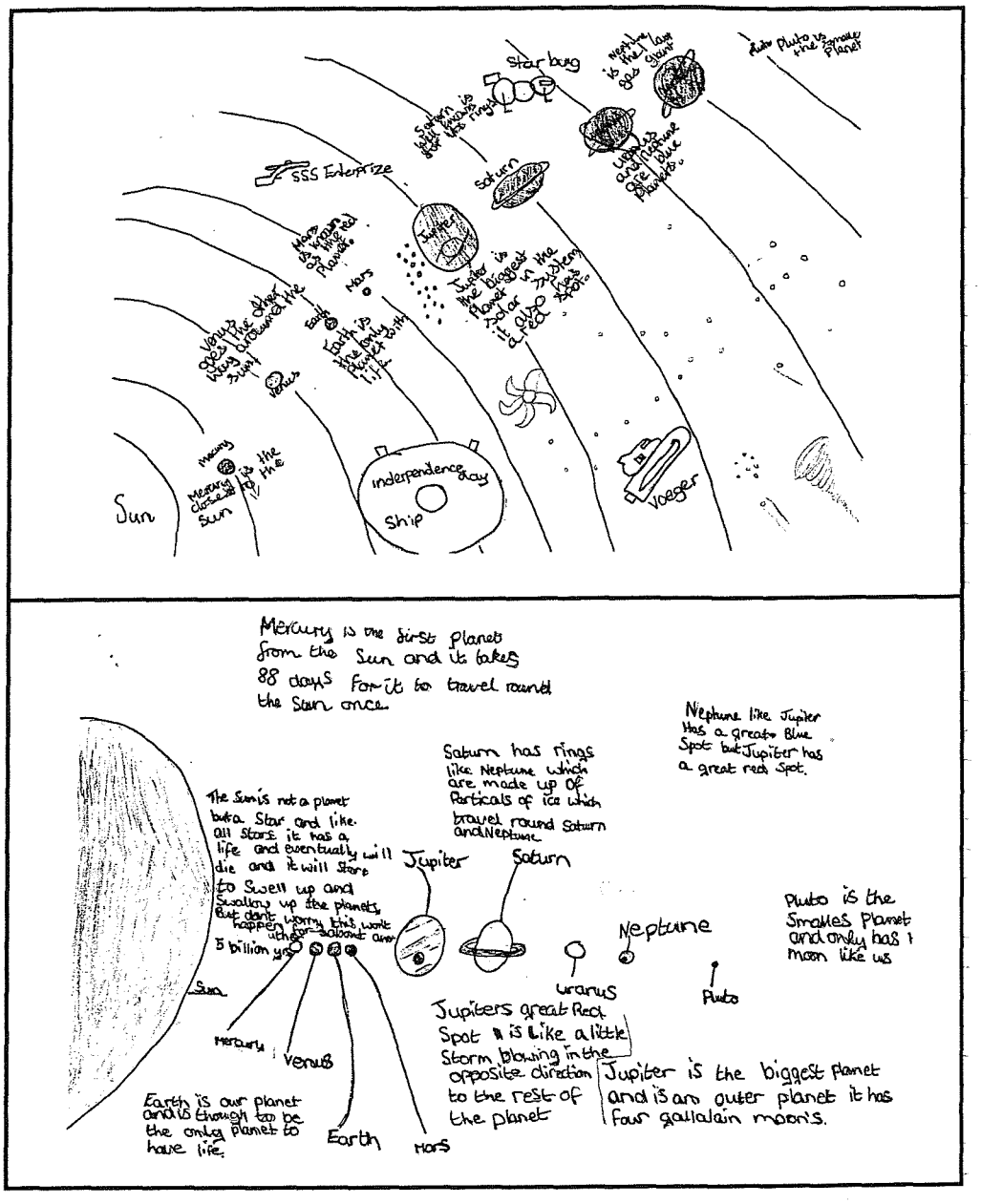


Fig. 6.15 Children's drawings of the Solar System (post-experimental treatment)

6.11.3 Summary of inferential analyses

For a complete treatment of the quantitative data see Appendix VIII.

(i) Pre-experimental treatment

At first interview, overall scores in the experimental group ranged from 0 to 16 with a mean of 10.1 (SD 3.74). Score profile percentages included 33.6% 0s, 48.9% 1s, 17.5% 2s and 0.0% 3s. 19 children scored between 0 and 11 (61%) and 12 children between 12 and 23 (39%). Overall scores in the control group ranged from 4 to 17 with a mean of 9.6 (SD 3.29). Score profile percentages included 37.1% 0s, 46.0% 1s, 16.7% 2s and 0.3% 3s. 22 children scored between 0 and 11 (71%) and 9 children between 12 and 23 (29%). The observed differences between the experimental group and control group in overall mean scores, score profile percentages and median scores in items of particular interest (SOL5, 9, 10, 11 and 12) at first interview were not significant.

Boys in the experimental group appeared to score more highly than the girls overall and the observed difference in their mean scores, 11.9 and 7.9 (SDs 3.00 and 3.42), was significant ($t=3.49$, $df=29$, $p=0.002$; normality for boys $D_{xb}=0.113$, $p>0.15$; normality for girls $D_{xg}=0.195$, $p>0.15$; F-ratio=1.30) and this was also reflected in an analysis of the score profile percentages by gender (test statistic $D_{xbg}=0.234$, critical value $K_D=0.170$ for $\alpha=0.01$). In those items of particular interest (SOL5, 9, 10, 11 and 12), observed differences in median scores between boys and girls were significant in SOL5 (Solar System map: $W_{xb}=311.0$, $W_{xg}=185.0$, $p=0.017$) and SOL9 (movements of planets: $W_{xb}=325.5$, $W_{xg}=170.5$, $p=0.011$). On this occasion too, boys in the control group appeared to score more highly than the girls overall and the observed difference in their mean scores, 11.0 and 7.9 (SDs 3.35 and 2.37), was also significant ($t=2.88$, $df=29$, $p=0.007$; normality for boys $D_{cb}=0.060$, $p>0.15$; normality for girls $D_{cg}=0.131$, $p>0.15$; F-ratio=2.00), again reflected in an analysis of the score profile percentages by gender (test statistic $D_{cbg}=0.229$, critical value $K_D=0.142$ for $\alpha=0.05$). In those areas of particular interest (items SOL5, 9, 10, 11 and 12), observed differences in median scores between boys and girls were significant in SOL9 (movements of planets: $W_{cb}=368.0$, $W_{cg}=128.0$, $p=0.000$).

(ii) Post-experimental treatment

At second interview, overall scores in the experimental group ranged from 11 to 30 with a mean of 18.6 (SD 4.90), a significant change from before (matched $t=-13.89$, $p=0.000$,

normality of differences in experimental scores D_{dx}=0.089, p>0.15; F-ratio=1.72). Overall score profile percentages included 11.8% 0s, 29.3% 1s, 51.1% 2s and 7.8% 3s, again a significant change from before (test statistic D_x=0.414, critical value K_D=0.120 for α=0.01). 1 child scored between 0 and 11 (3%), 24 children between 12 and 23 (77%) and 6 children between 24 and 36 (19%). Overall scores in the control group ranged from 4 to 19 with a mean of 8.7 (SD 3.14). Score profile percentages included 44.4% 0s, 39.2% 1s, 16.1% 2s and 0.3% 3s. 27 children scored between 0 and 11 (87%) and 4 children between 12 and 23 (13%). The observed change in mean score (lower than before) was also significant (matched t=2.12, p=0.043, normality of differences in control scores D_{dc}=0.086, p>0.15; F-ratio=1.10). More importantly, however, the mean gain in individual scores from children in the experimental group (O_3-O_1) and control group (O_4-O_2), 8.5 and –0.9 (SDs 3.41 and 2.46), was significant (t=12.50, df=54, p=0.000; normalities D_{dx}=0.089, D_{dc}=0.086, p>0.15; F-ratio=1.92 which is significant at α=0.05) as was the post-experimental treatment analysis of the score profile percentages (test statistic D_{xc}=0.425, critical value K_D=0.120 for α=0.01). In those items of particular interest (SOL5, 9, 10, 11 and 12), observed differences in median scores between the experimental group and the control group were significant in all (SOL5: Solar System map W_{x2}=1398.5, W_{c2}=554.5, p=0.000; SOL9: movements of planets W_{x2}=1245.5, W_{c2}=707.5, p=0.000; SOL10: forces: W_{x2}=1182.5, W_{c2}=770.5, p=0.000; SOL11: Solar System age W_{x2}=1221.5, W_{c2}=731.5, p=0.000; SOL12: origin W_{x2}=1277.5, W_{c2}=675.5, p=0.000). Within the experimental group, multiple linear regression analysis using age, intellectual maturity and science curiosity as independent predictor variables was significant (R^2=0.342, F=4.68, p=0.009, df=3), but with only age and intellectual maturity contributing to the differences in summated scores between individuals.

No significant gender differences were observed in the experimental group. Boys in the control group continued to significantly outscore the girls overall (means 9.9 and 7.1, SDs 3.44 and 1.88; t=2.88, df=25, p=0.008; normality for boys D_{cb}=0.199, p=0.073; normality for girls D_{cg}=0.138, p>0.15; F-ratio=3.35 which is significant at α=0.01) though this was no longer reflected in an analysis of the score profile percentages by gender. In those items of particular interest (SOL5, 9, 10, 11 and 12), observed differences in median scores between boys and girls remained in SOL9 (movements of planets: W_{cb}=329.5, W_{cg}=166.5, p=0.006).

6.11.4 Knowledge acquisition and concept learning

Within the experimental group at first interview, and before the experimental treatment, children's declared knowledge and understanding as probed suggested that their concept of the Solar System was in a poor state of development. Only one scientific model was evident at all, at least in terms of a 'map' of its structure and composition, and this was reduced to zero in combination with other factors (Table 6.49).

	Pre-experimental Total	+/-	Post-experimental Total	+/-	Delayed Total
Solar System map	1 (3.2)	+21	22 (71.0)	-2	19 (61.3)
Movements of planets	4 (12.9)	+16	20 (64.5)	+5	25 (80.6)
Forces	1 (3.2)	+13	14 (45.2)	-2	12 (38.7)
Map + movements	0 (0.0)	+19	19 (61.3)	0	19 (61.3)
Map + movements + forces	0 (0.0)	+11	11 (35.5)	-1	10 (32.3)

Table 6.49 Summary of scientific mental models of the Solar System and wider Universe (frequency and percentage)

At second interview, and after the experimental treatment, increases in the frequencies of a basic scientific model in the form of a Solar System 'map' together with other factors demonstrated considerable improvements (Table 6.49). Features associated with knowledge acquisition and concept learning in the experimental group relative to the control group are summarized as follows:

- models of the Solar System, in terms of 'maps' outlining a more accurate and detailed structure and composition, improved significantly (though details associated with the relative distances between the planets remained poor);
- children's ideas about the orbital movements of the planets around the Sun and the Sun's gravitational attraction improved significantly;
- children's ideas about the age and origin of the Solar System improved significantly (though details associated with age remained poor);
- children's knowledge of the wider Universe improved substantially (often focusing on the exotic);

- the experimental treatment appeared to close the gap in the differences observed between boys and girls completely (correctness, mean score, median scores in all items of particular interest);
- the number of children with summated scores in the 24 to 36 range, reflecting more 2s and 3s, increased notably with a corresponding and significant increase in score profile percentages, overall mean score and mean gain;
- only the predictor variables age and intellectual maturity contributed significantly to the differences in summated scores between individuals.

Knowledge acquisition and concept learning in the experimental group, at least in terms of the structure and composition of the Solar System, are perhaps best accounted for in terms of both weak (accretion and tuning) and radical restructuring. Radical restructuring is particularly well illustrated in the mapped movements or routes and pathways in children's ideas themselves (Fig. 6.16; see also Appendix VII for a delayed overview). Interestingly, initial routes and pathways (pre- to post-) revealed 2 'non-movers' (original ideas retained – horizontal links) and 29 'risers' (original ideas progressed – positive gradient links). Later routes and pathways (post- to delayed) revealed 19 'non-movers', 4 'risers' and 8 'fallers' (original ideas regressed – negative gradient links), 6 of whom had made progress initially. Weak restructuring is particularly well illustrated in terms of correctness associated with items SOL1-4 which deal with Solar System contents, the number and names of planets recalled and the pictures of planets identified. Interestingly, in those areas of children's ideas about the Solar System which received most attention earlier (SOL5, 9, 10, 11 and 12), observed differences in median scores between second and third interviews (post-experimental treatment and delayed) were not significant indicating a high degree of retention and recall.

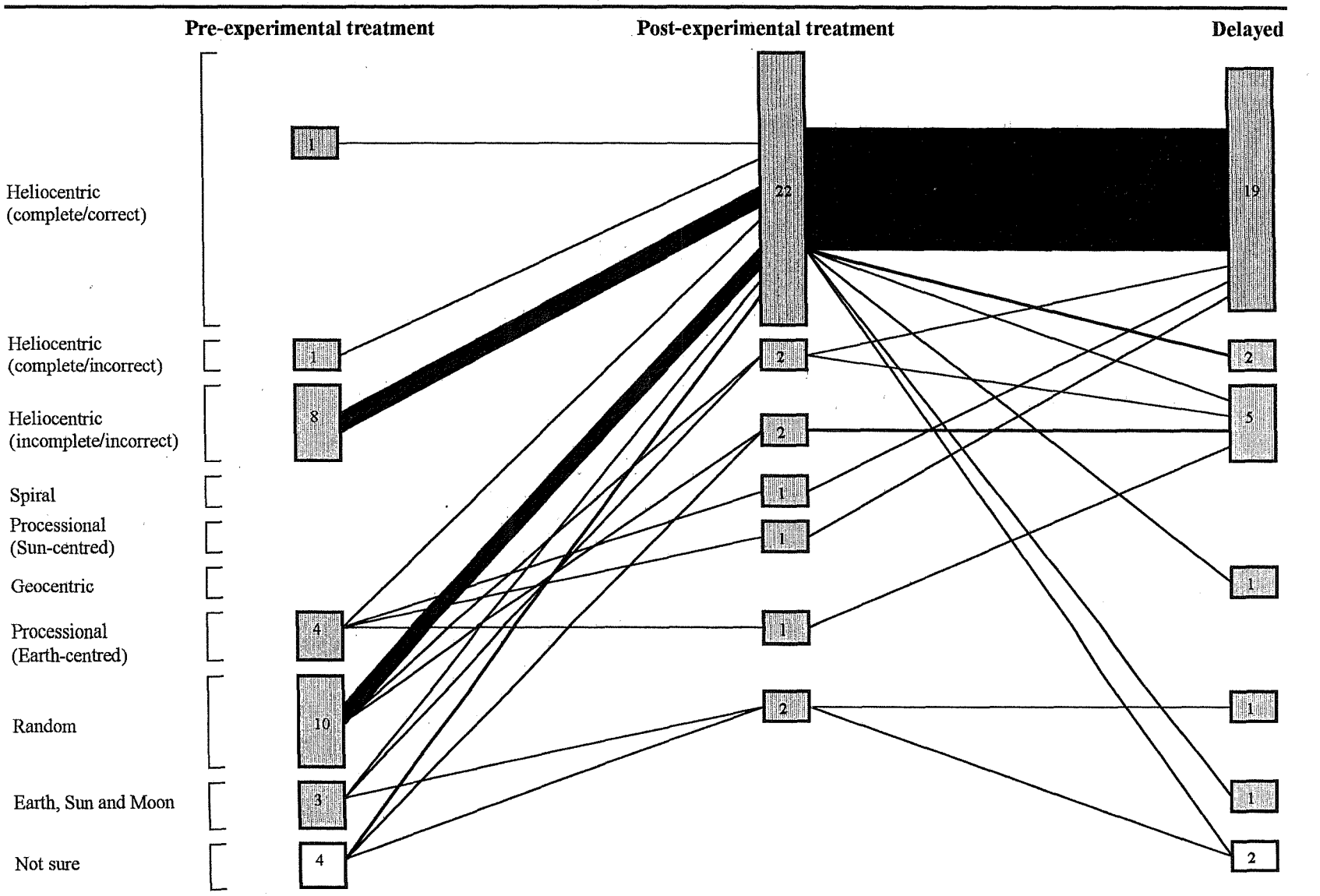


Fig.6.16 Knowledge acquisition and concept learning: mapped changes in children's mental models of the Solar System

6.12 Extended transcripts

While it is certainly useful to support the ideas and models presented in all previous sections with examples of children's responses, it is also useful to provide more extended transcripts of responses obtained at interview as a whole. As indicated in Chapter 4, for example, despite the many advantages of using interviews as a tool for collecting data, interviews can also be subject to many different interviewer effects including distortion of meaning, misrepresentation, bias associated with selective translation and transcription in order to support a position, and so on. Interviews are also often punctuated by sometimes important gestures, faltering and irregular pausing and other features which are rarely presented. In order to help allay any suggestion of bias and to illustrate the interview process more completely, two extended transcripts from children in the experimental group have been selected. At second interview, following the experimental treatment, responses from Ian (I) and Bethan (B) were among the best obtained and worthy of special treatment. Ian's ideas about the Earth, the Sun, the Moon and the Earth-Sun-Moon System were impressive for a child his age as were Bethan's ideas about the Solar System and wider Universe. Together, they demonstrate the highest levels of attainment witnessed as a result of the experimental treatment.

6.12.1 Ian

Ian was 10 years and 11 months old at the time of the interview. He received an intellectual maturity score of 97 using the Harris-Goodenough Drawing test (a score of 100 is average for a child his age) and a science curiosity rating of 86 using the Harty-Beall Science Curiosity Measure (curiosity ratings range from low at 30 to high at 150). At home Ian watched *Star Trek, Thunderbirds, Red Dwarf* and *Equinox*. (R=researcher.)

Earth

R: What shape is the Earth?
I: *It's like a sphere. [Explored.] Because the equator comes out more than the rest of the Earth ... it bulges out.*
R: Is there a shape here that's most like the Earth (2D and 3D selection provided)?
I: *That one.* [Picks up a sphere.]
R: How do people know it's that shape?
I: *Because they've been up in space rockets and they've sent up satellites.*
R: Can you draw a picture of what you think the Earth would look like from space?

[Draws a circle with readily identifiable land masses.]
R: What colour would it be?
I: *Green* (land), *blue* (water), *white for clouds, yellow for deserts*, and *white at the poles.*
R: What would you expect to see all around it?
I: *Stars ... darkness.*
R: How come we can't see the Earth's 'roundness' when we look out of the window?
I: *It's far too big to see. You have to go up into space.*
R: How big?
I: *Read about it ... can't remember.*
R: Have you ever heard of anybody falling off the Earth?
I: *No.* [Laughs.] *Yes ... maybe in the Bermuda Triangle.* [Laughs.]
R: Could anybody ever fall off the Earth?
I: *Not unless they could jump into space rocket ... because there's lots of gravity and it pulls you down to the Earth like this* (demonstrates by picking up a sphere and letting it go).
R: What is the Earth?
I: *It's a planet. It's like a rock.*

Sun

R: What is the Sun?
I: *It's a big ball of burning gas.*
R: What shape is the Sun (2D and 3D selection provided)?
I: *A sphere.*
R: Is there a shape here that's most like the Sun?
I: *This one.* [Picks up a sphere.]
R: How do people know it's that shape?
I: *Because as we go round ... unless the Sun turns like this as we go round it it's the same shape* (picks up a disk for the Sun and a sphere for the Earth to demonstrate how a disk must rotate in order to maintain apparent shape). *They could launch a rocket to see if was like this* (disk) *or if it was this shape* (compares a sphere with shapes having circular outlines).
R: Can you draw a picture of what you think the Sun would look like from space?
[Draws a circle with flame-like structures referred to as *'flares'* around the circumference and dark spots referred to as *'cooler areas of gas'* internally.
R: What colour would it be?
I: *Orange, yellow and red.*
R: Does anything live on the Sun?
I: *No ... it's far too hot.* [Explored.] *It's about six thousand degrees on the outside and about fifteen million in the inside.* [Explored.] *It's gas ... mm ... burning gas ... mm ... helium gas it might be. It's fuelling the Sun. It started by ... it ... the Sun was really big and starting pulling things in really fast. It just started like a nuclear bomb but slower 'cause it's really big.*
R: Is the Sun a star or is a star something else?
I: *It's a star. They're the same but other stars are further away.*

Moon

R: What shape is the Moon?
I: *It's like a sphere and it's got a very small pull on the Earth which controls the tides ... but don't ask me how it does this 'cause I don't know.*

R: Is there a shape here that's most like the Moon (2D and 3D selection provided)?
I: *That one.* [Picks a sphere.]
R: How do people know it's that shape?
I: *Because they've been to the Moon.*
R: Can you draw a picture of what you think the Moon would look like from space?
[Draws a circle with patches described as *'seas'* and circles with rays described as *'craters'*. Half of the Moon is shaded darker than the rest, the terminator is curved.
R: What colour would it be?
I: *Grey.*
R: Does the Moon always appear that shape?
I: *No.* [Explored. Draws eight conventional phases from new through full to waning crescent. Time taken for these changes to take place is given as *'27 point something days'*.]
R: Does anything live on the Moon?
I: *No.* [Explored.] *When spacemen go up and build something they might. You can jump six times higher on the Moon than on the Earth. There's no atmosphere there ... the Moon's gravity is a lot weaker than the Earth's ... about six or seven times less. The Moon's moving away from the Earth at three centimetres per year.*
R: What is the Moon?
I: *It's another rock like the Earth ... it orbits the Earth.*

Relative size

R: Are the Earth, the Sun and the Moon all the same size or are they different?
I: *The Sun's millions of times bigger than the Earth. The Moon is six or seven times smaller 'cause its gravity is six or seven times weaker.* [Explored.] *They look the same size but they're different distances away. It would take twenty years to reach it* [the Sun] *travelling at the speed of an aeroplane.*

Ian's responses were particularly interesting not only in terms of their scientific content but the scientific language and other means of expression used, the logic and reasoning involved, the information sources cited, and so on. His comments about the true shape of the Earth being *'like a sphere'* but bulging out at the equator, how we might test the notion of a spherical Sun, and the effects of the Moon's gravity demonstrated a level of understanding that would certainly put most adults to shame! Ian's drawings of what causes day and night, the seasons to change and the phases of the Moon were particularly advanced (recall, detail, spatial representation) as shown (Fig. 6.17). In describing his drawings, clear reference was made to the importance of the tilt of the Earth's axis in relation to variations in daylight hours, areas of the Earth's surface which experience perpetual night and day, and the differences between summer and winter. Some errors and 'alternative' interpretational frameworks remained.

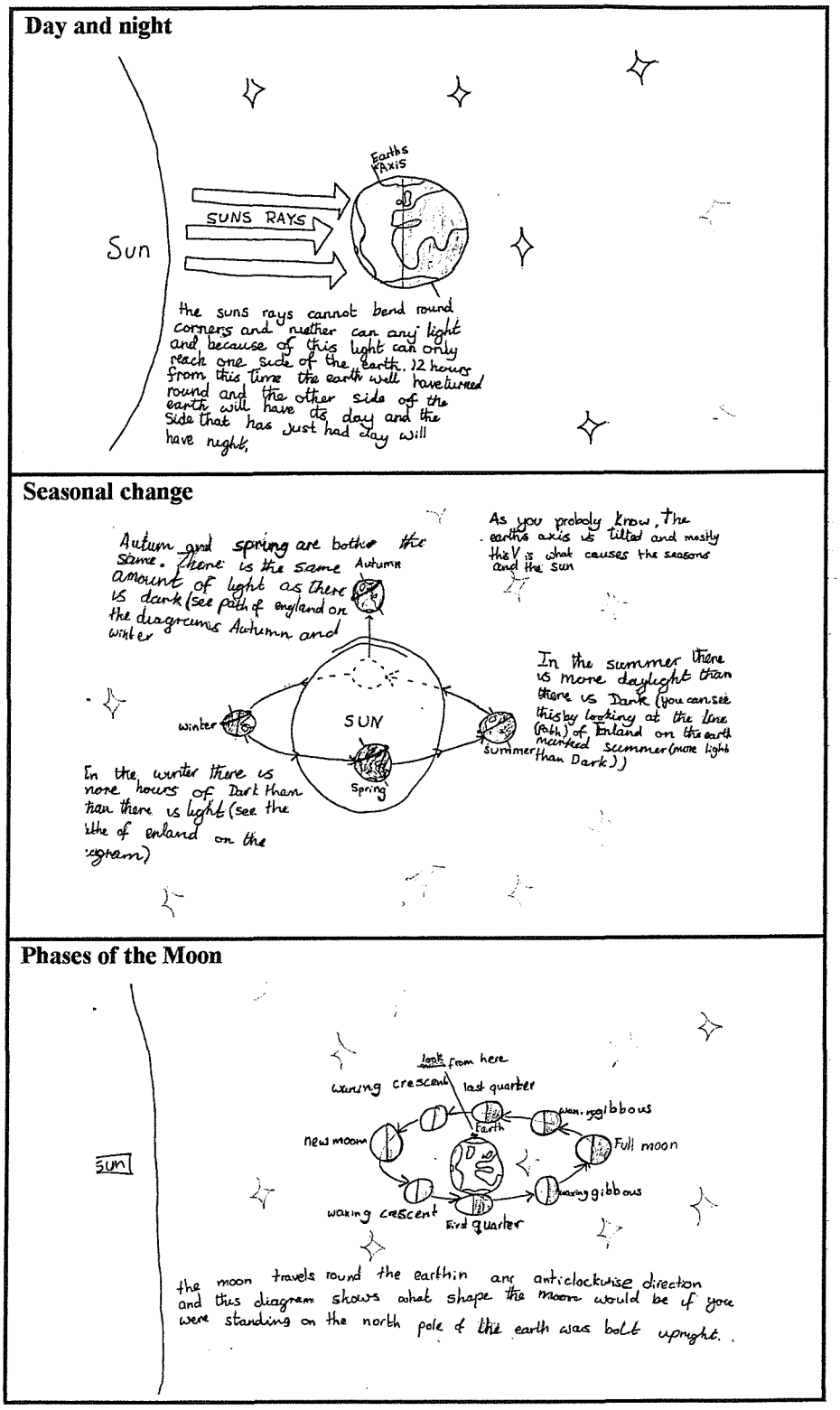


Fig.6.17 Ian's drawings of Earth-Sun-Moon System phenomena

6.12.2 Bethan

Bethan was 11 years and 2 months old when her Solar System and concept maps were produced. She received an intellectual maturity score of 100 using the Harris-Goodenough Drawing test (a score of 100 is average for a child her age) and a science curiosity rating of 100 using the Harty-Beall Science Curiosity Measure (curiosity ratings range from low at 30 to high at 150). Bethan had no TV at home but had read lots about space. Her father was mentioned as a strong influence on her ideas. Bethan's drawing of the Solar System is provided as shown (Fig. 6.18). (R=researcher.)

Solar System (and wider Universe)

R: Besides the Earth, the Sun, and the Moon, what else is there in space?
B: *Comets, galaxies ... lots of things really ... meteorites, nebulas, black holes, planets ... their moons.* [Explored] *A black hole is when a certain type of star dies ... a nebula is where stars are born ... like the Sun. Galaxies are great big masses of stars and planets. Meteorites ... lumps of rock and stone. Comets are gas mostly ... most of them.*
R: Do you know the names of the planets?
B: *Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto. There might be one beyond that, we don't know.*
R: Can you draw me a 'map' showing where all of these different things are?
[Draws a 'map' as shown with some details added later. Planets correctly named and ordered away from the Sun. Relative sizes, colour and surface details good. Rings around major planets. Jupiter shown with spot and moons though Saturn was described as having most. Largest and smallest planets known. Unsure about absolute sizes other than *'very big'*, the Earth was thought to be *'12 thousand or something kilometres'* across. Absolute distances not remembered but referred to as *'very far apart!'*. Hottest planet known to be Venus (*'it's got clouds all around it and it's very hot'*), the coldest Pluto (*'furthest away'*). Mercury was known to orbit the Sun in the shortest time and Pluto in the longest (*'because one's got a bigger circle to go round ... like if you go around a corner on one side of the road, it's ... on the inside of the road, so it takes shorter to walk round it than it does people on the other side of it'*).
R: Do the planets stay where they are or do they move?
B: *They move around the Sun.*
R: How come they go around the Sun like that, why don't they just 'shoot off' into space?
B: *'Cause the Sun's gravity's pulling them in so it makes them go around the Sun.*
R: Do they have an age like you and me or have they always been there (Sun and planets)?
B: *Yes ... they've been there a long time.* [Origin explored.] *After the Big Bang a load of old gas and stuff just splodged out and the planets just formed.*
R: Does anything live on any of the other planets?
B: *We don't know.*
R: Do you recognize any of the objects in these pictures (Sun, Moon, nine planets shown)?
[All 9 planets, the Sun and the Moon correctly identified.]

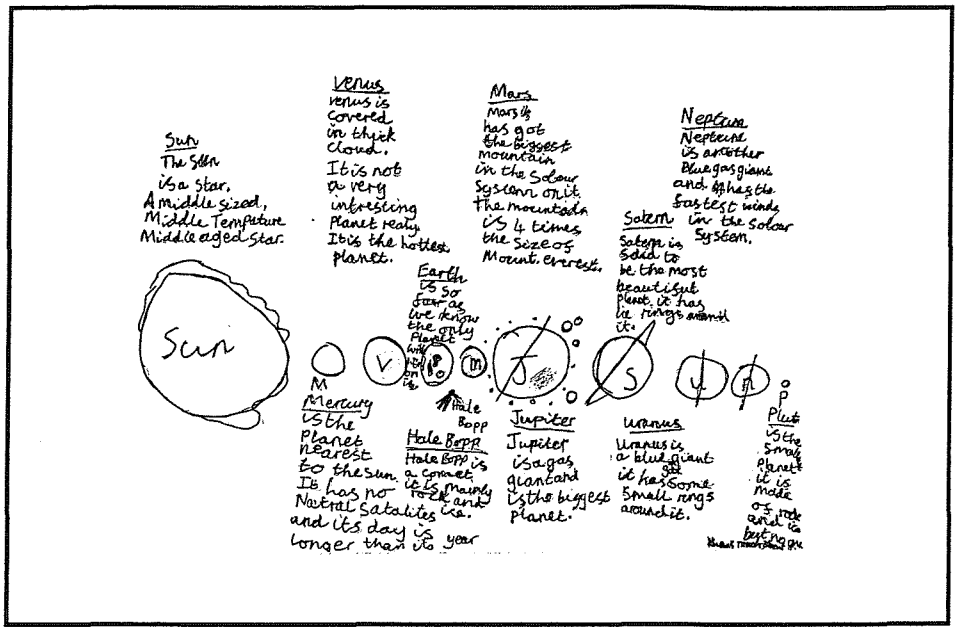


Fig. 6.18 Bethan's drawing of the Solar System

Bethan's responses were also interesting. Her knowledge of the Solar System and wider Universe was also particularly advanced and included reference to work undertaken beyond school reflecting some of the homework and wider reading that the children were expected to do as well as other influences. Her emergent understanding of features such as black holes and the Big Bang was common among many others in the class confirming the interest and curiosity young children have for 'exotic' science. As with Ian, some errors and 'alternative' interpretational frameworks remained. Bethan's concept map provided further information about the depth and structure of her knowledge of the Solar System and wider Universe (Fig. 6.19). Concept maps reveal conceptual relationships (superordinate and subordinate elements), propositions (meaningful relationships between elements expressed in words), cross-links (connections between elements shown by lines) and examples (specific objects and events). Bethan's map is hierarchical with the Universe centrally placed assuming an overall importance and dominance. Below this level, her map is reasonably well integrated reflecting her organization of knowledge and thoughts. The economical use of some sites (e.g. *'giant'*) and some factual inaccuracies remained.

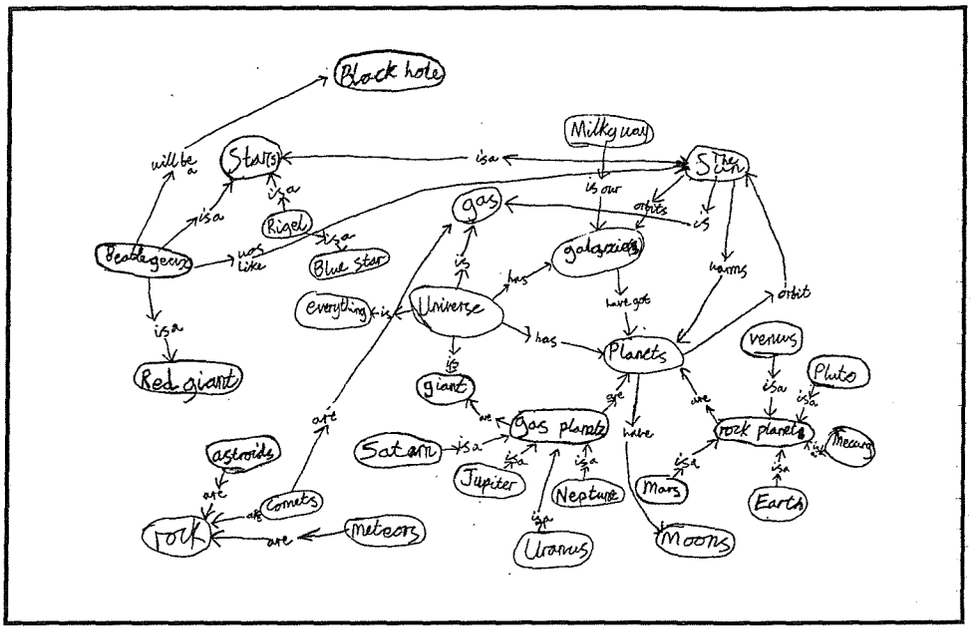


Fig. 6.19 Bethan's concept map of the Solar System and wider Universe

6.13 Summary

Overall, the research findings presented here are considered particularly encouraging. From a mixed starting point in terms of the range and types of models presented at first interview (e.g. intuitive, transitional and scientific), the levels of scientific conceptualization attained by most children in the experimental group in most of the content areas considered following exposure to the experimental treatment were particularly high. This was notably so with the Earth (e.g. shape 100%, drawing 100% and nature 97%), the Sun (e.g. shape 90%, drawing 87% and nature 94%) and the Moon (e.g. shape 84%, drawing 90% and to a lesser extent nature 52%), relative size (81%), what causes day and night (77%) and the Solar System (map 71%). Where noted, and with the exception of the Sun, gender differences observed only in the experimental group and always favouring boys were generally reduced or eradicated completely. While the children in the experimental group encountered astronomy earlier at school as infants (5-7 years), and having done so already considered at least the shape of the Earth, the Sun and the Moon and scientific models of the day and night cycle, many of the other content areas and specific items within them here were introduced formally for the first time. Further, the research findings are considered particularly encouraging

given the high levels of retention in those content areas after a delay of three months. That said, however, and despite the initial progress made, levels of scientific conceptualization associated with models of seasonal change and the phases of the Moon remained relatively low (48% in both cases) and retention was poor suggesting that in these content areas at least, the additional spatial, temporal and dynamic factors involved perhaps presented particular learning difficulties which placed them beyond the cognitive abilities or developmental potential of about half of the children involved. While it is also true that these content areas could have been taught badly, within the context of the experiment, the preparation and the effectiveness of the experimental treatment elsewhere, this seem unlikely. Overall, and relative to changes in the control group, learning astronomy here can be summarized in terms of a generally improved response correctness together with reductions in linguistic variation, an increase in the correct use of scientific vocabulary, better representation in drawing style and better descriptions of the nature of objects, particularly with the Earth, the Sun and the Moon, a generally improved response correctness together with improved use of verbal descriptions, props and drawings, particularly with Earth-Sun-Moon System phenomena, and a generally improved response correctness together with improved 'map' representation, particularly with the Solar System. These qualitative changes were also reflected, usually significantly relative to changes in the control group, in the increased numbers of children with summated scores in the 24 to 36 range in 12-item probes (Earth, Sun, Moon, Solar System) and the 12 to 18 range in 6-item probes (day and night, seasonal change, phases of the Moon) together with corresponding changes in score profile percentages, mean score and mean score gain. Throughout this work, not only was it possible to probe and penetrate cognitive structure and describe and measure the ideas and models presented by children qualitatively and quantitatively, it was also possible to map out the routes and pathways involved in knowledge acquisition and concept learning too and to illustrate the processes of weak (accretion and tuning) and radical knowledge restructuring which typified the knowledge acquisition and concept learning described. Although the experimental treatment was not directly observed itself, the constructivist learning environment negotiated with, and considered established, by Jack was clearly effective in achieving the intended learning outcomes. In the chapter which follows, the research findings presented here are summarized further and discussed more broadly within the context of the original research questions outlined in Chapter 1, and the research process, together with its limitations, are evaluated. Conclusions are presented alongside the discussion in order to avoid repetition.

Chapter 7

Discussion and Conclusions

7.1 Introduction

The research presented here has attempted to identify, categorize and describe children's ideas and mental models in the 'traditional' content areas of astronomy by means of elicitation, and to measure and map the changes in those ideas and models as a result of knowledge acquisition and concept learning following a period of formal astronomy teaching at school. It attempted to do these things within an experimental context. As a result, this work is located firmly, though, as will be demonstrated later, not exclusively, within the cognitive domain. The main 'fieldwork' phases of the research spanned a period of six months in the 1996/1997 academic year and were undertaken in Big Town CPS, one of eight LEA maintained primary schools located within the east Devon town of Exmouth (see Phases 3 to 6 in Fig. 1.1, Chapter 1 and Fig. 5.1 in Chapter 5). All 62 of the children in two vertically grouped upper primary Year 5/6 classes were involved. One class was designated the experimental group, the other the control group. The children in the experimental group were taught astronomy by Jack, an experienced class teacher and deputy head teacher at the school. Jack's curricular expertise in the field of astronomy, that is his subject knowledge and subject related pedagogy, was assessed in a variety of ways and considered exemplary. Jack's general attitude and orientation towards science, and astronomy in particular, were considered positive. While the children in the experimental group were exposed to the experimental treatment and taught astronomy, the children in the control group were taught materials (astronomy later). This arrangement fell naturally in line with the school's own organization and management of the National Science Curriculum in force at that time. Working within an experimental context provided the advantage of minimizing internal threats to the validity of the findings (e.g. not due to history, maturation, regression) and helped to ensure that any significant changes observed could be attributed to the experimental treatment with a higher degree of confidence than might not otherwise have been possible.

At the start of the research, the children in both the experimental and control groups were between 9 and 11 years of age (mean 124.9 and 124.1 months, median 126.0 and 126.0 months respectively). Both groups contained equal numbers of participants (n=31) including equal numbers of boys and girls (n=17 and n=14 respectively). In addition to class size, gender composition and age, the children in both groups were also statistically inseparable in terms of ethnicity, socio-economic background, intellectual maturity, science interest and curiosity and informal science experiences. In this chapter, the original research questions are used as the basis for discussion and formulating concluding statements. The discussion and conclusions, brought together to avoid unnecessary repetition, fully recognize and acknowledge the limitations of the overall design (quasi-experimental), the methodology (instrumentation, data collection, operationalization and data analysis) and the theoretical framework (interpretation) presented in earlier chapters. Further limitations are also considered.

7.2 Describing and measuring knowledge acquisition and concept learning in astronomy

During the main 'fieldwork' phases of this research, the children's knowledge and understanding of astronomy were successfully elicited from the experimental and control groups using a multiple method survey instrument administered in the form of largely structured one-to-one interviews. The children in both groups initially provided a similar range of qualitatively different ideas and models in each of the 'traditional' content areas of astronomy considered. With the exception of the new material presented, and where comparisons with children of a similar age can be made (bearing in mind the difficulties associated in making such comparisons), particularly with respect to Earth shape and gravity (e.g. Nussbaum 1979; Mali and Howe 1979; Sneider and Pulos 1983; Vosniadou and Brewer 1992) and the day and night cycle as part of the Earth-Sun-Moon System (e.g. Jones et al. 1987; Vosniadou and Brewer 1994; Diakidoy et al. 1997) where most previous work has been undertaken, the findings in terms of the range of ideas and mental models outlined here were broadly similar to those found elsewhere. The same is also true of studies involving children of a similar age undertaken within the UK (e.g. Baxter 1989; Arnold et al. 1994; Osborne et al. 1994; Russell et al. 1994a-c; Sharp 1996). Following the experimental treatment, and as might have been expected, knowledge acquisition and concept learning among children in the experimental group was particularly evident and most of the individuals involved were able to provide scientific causal reasoning within a remote and

objective reference frame in most content areas while ignoring many of the obvious visual and other distractions usually associated with hindering the learning of astronomy. The research findings suggest that, for those children and those areas of astronomy at least, an acceptable knowledge and understanding of sometimes complex and abstract information is attainable in the upper primary age phase. Where research findings here differ mostly from previous studies is in the frequency of occurrence of scientific ideas and mental models detected (Tables 7.1 and 7.2). Levels of scientific conceptualization among children in the experimental group observed at second interview (post-experimental treatment) were

		Experimental group			Control group		
		first	second	delayed	first	second	delayed
Earth	shape	29 (93.5)	31 (100.0)	31 (100.0)	30 (96.8)	30 (96.8)	nd
	drawing	30 (96.8)	31 (100.0)	30 (96.8)	30 (96.8)	30 (96.8)	nd
	gravity	25 (80.6)	26 (83.9)	26 (83.9)	26 (83.9)	29 (93.5)	nd
	nature	27 (87.1)	30 (96.8)	28 (90.3)	22 (71.0)	26 (83.9)	nd
Sun	shape	25 (80.6)	28 (90.3)	28 (90.3)	23 (74.2)	26 (83.9)	nd
	drawing	18 (58.1)	27 (87.1)	24 (77.4)	18 (58.1)	20 (64.5)	nd
	nature	10 (32.3)	29 (93.5)	28 (90.3)	16 (51.6)	20 (64.5)	nd
Moon	shape	20 (64.5)	26 (83.9)	27 (87.1)	24 (77.4)	24 (77.4)	nd
	drawing	23 (74.2)	28 (90.3)	25 (80.6)	23 (74.2)	19 (61.3)	nd
	nature	4 (12.9)	16 (51.6)	12 (38.7)	7 (22.6)	3 (9.7)	nd

Table 7.1 Summary of the frequencies and percentages in scientific models of the Earth, the Sun and the Moon by item of interest and interview (nd = not determined)

	Experimental group			Control group		
	first	second	delayed	first	second	delayed
Earth (shape-drawing-nature)	25 (80.6)	30 (96.8)	27 (87.1)	21 (67.7)	25 (80.6)	nd
Sun (shape-drawing-nature)	7 (22.6)	24 (77.4)	24 (77.4)	10 (32.3)	13 (41.9)	nd
Moon (shape-drawing-nature)	4 (12.9)	15 (48.4)	11 (35.5)	5 (16.1)	2 (6.5)	nd
Relative size	14 (45.2)	25 (80.6)	26 (83.9)	14 (45.2)	17 (54.8)	nd
Day and night	11 (35.5)	24 (77.4)	23 (74.2)	13 (41.9)	11 (35.5)	nd
Seasonal change	0 (0.0)	15 (48.4)	9 (29.0)	2 (6.5)	3 (9.7)	nd
Moon's phases	0 (0.0)	15 (48.4)	7 (22.6)	1 (3.2)	2 (6.5)	nd
Solar System map	1 (3.2)	22 (71.0)	19 (61.3)	0 (0.0)	1 (3.2)	nd

Table 7.2 Summary of the frequencies and percentages in scientific models in all areas investigated by interview (nd = not determined)

as good if not better than in all of the studies mentioned previously. This was particularly true of the Earth (shape and gravity), the Sun (shape), the Moon (shape), relative size, what causes day and night, and the Solar System (map) where most children not only attained a

high level of scientific conceptualization, the scientific ideas and models were largely retained after a post-experimental treatment delay of three months. As mentioned previously, the reason, in part at least, may lie in fact that all of the children involved here, including those in the control group for whom high levels of scientific conceptualization were also detected in certain areas at first interview (e.g. Earth shape), were taught astronomy as infants (5 to 7 years of age). This was supplemented with work in other curricular areas including geography (DfE 1995). Science Programmes of Study determined that the children would have been expected to know, for example, that the Earth, the Sun and the Moon are separate spherical bodies, be able to describe the apparent daily motion of the Sun in the sky and explain why night occurs, observe, where possible, the position of the Moon in the sky and its changing appearance, and be able to describe the seasonal changes that occur in the weather and in living things. It is also true, of course, that within the context of the experimental design, conditions for knowledge acquisition and concept learning were perhaps at their most favourable. That said, other than for the shape of the Earth and how it looks from space, scientific conceptualization was not achieved in every area and by every child, particularly in seasonal change and the phases of the Moon, and consequently the development of children's knowledge and understanding overall remained somewhat variable if considerably less so than before. Interestingly, and again as mentioned previously, while significant gains were made in terms of what causes seasonal change and the phases of the Moon, scientific attainment remained low and retention was poor relative to the other areas considered. Overall, this suggests that these areas of astronomy are particularly demanding in terms of conceptual difficulty, including the spatial, temporal and dynamic factors involved, and generally lie beyond the cognitive abilities or development potential of most children this age. This supports similar findings documented elsewhere (e.g. Baxter 1989; Russell et al. 1994a-c; Osborne et al. 1994; Sharp 1996).

7.2.1 Modelling mental models

While identifying scientific and non-scientific (intuitive and transitional) mental models in a work such as this is essential for a variety of practical, analytical and theoretical purposes, establishing what is meant by scientific and non-scientific and the working boundaries between them is not as straight forward as it might at first appear. It has already been established, for example, that the children's responses obtained at interview were reduced according to pre-determined operational parameters and definitions prior to qualitative and

quantitative analysis and that the scientific mental models identified as a result often included acceptable deviations and semantic ambiguities provided these did not seriously detract from, or appear in conflict with, the responses that might be predicted or expected for the models themselves. What this study has highlighted, therefore, are children's 'expressed' scientific models, those considered scientifically acceptable for children of this age when considered alongside appropriate conceptually or consensually agreed scientific models of the astronomy target systems involved including those taught at school (e.g. Norman 1983; Duit and Glynn1996; Boulter 1998; Greca and Moreira 2000). Appropriate conceptually or consensually agreed scientific models of the astronomy target systems involved here were stated explicitly, an important if almost always consistently overlooked feature of children's ideas research as a whole. It is worth remembering, of course, that mental models only reflect an individual's knowledge and understanding of specific subject matter including perceptions of task demands and task performances (Johnson-Laird 1980, 1983; Gentner and Stevens 1983; Brewer 1987) and that mental models are often incomplete, unstable, parsimonious and lack firm boundaries (Gentner and Stevens 1983). This presents particular problems associated with the oversimplifying children's psychology as noted by Claxton (1993) and the methodological and interpretational problems of the misinterpretation of intended meaning between the researcher and the interview associated with 'frames of reference' and the 'translation interface' as noted by Johnson and Gott (1996). Nevertheless, attempting to understand the mental models that each child used here to answer questions and to solve problems provided important information about the content of their knowledge-base and the organization and relations within it.

While never entirely straight forward, some of the areas investigated here and the response categories obtained were easier to address in terms of model identification and assignment than others. It is not unreasonable, for example, to consider a child to hold an acceptable scientific model of the shape of the Earth, the Sun and the Moon if he or she chooses a sphere from a selection of different shapes even if that child begins by describing the Earth, the Sun and the Moon as *'round'* or even *'circular'*. While the selection of a sphere does not by itself exclude the possibility of shapes other than spheres (e.g. hemispherical models of the Earth), the inclusion of as wide a range of evidence as possible helps to minimize decision-making errors (e.g. a sketch of how the Earth looks from space). Similarly, it is not unreasonable to consider a child to hold an acceptable scientific model of what causes day and night if this is demonstrated using props and in a drawing even if that child begins by explaining what

causes day and night simply as *'it goes around'*. The interpretation of linguistic variation and linguistic structure clearly requires support from other sources. By way of contrast, drawings of the Earth, the Sun and the Moon can present their own difficulties. The stylistic variation described in children's drawings of the Earth, the Sun and the Moon here, for example, differed only in attention to the detail represented and the descriptive information provided and suggested a drawing continuum rather than the notion of each drawing type as a discrete model in its own right. In the field of geography, where children's freehand sketch maps of the world on flat and spherical surfaces have already been considered, Wiegand (1995, 1997) faced the same dilemma of defining whether or not model boundaries were continuous or discrete. In Wiegand's work, with the advantage of having children's place knowledge and drawing ability to consider too (e.g. relative size, shape and spatial orientation of land masses), discrete models were preferred. But children's 'proto-mapping' abilities were not of immediate interest here, only their ability to recognise that from space, land masses and oceans are prominent features of the Earth's surface. While global and Anglocentric representations are clearly the most advanced, many children in the experimental and control groups may have simply attended to the task at hand which was to produce and describe a sketch. Similar difficulties also arise with depth of probing. Some children may, for example, indicate that they know that people do not fall from the Earth because of gravity. Explored further, however, gravity might be considered either a pulling force or a pushing force, of which only the former is correct. Similarly, some children might seem to indicate an implicit knowledge of gravity without ever mentioning it at all. Interestingly, none of these issues are discussed in the extensive Earth shape and gravity literature available where all of the probes employed serve only to elicit a mainly implied rather than explicit knowledge of gravity. Additionally, in all aspects of phenomena associated with the Earth-Sun-Moon System, there is an issue to be considered in the use of props. Where no verbal accounts of what causes day and night, the seasons to change or the phases of the Moon were forthcoming, children were provided with the means to construct a perfectly plausible explanation, however unlikely, on the spot, and this should not be overlooked (the possibility that mental models may be constructed on the spot has also been discussed by Vosniadou and Brewer 1992, 1994). The subdivision of non-scientific mental models into intuitive and transitional categories (e.g. Vosniadou 1991a, b; Sharp 1996), popular in works associated with Earth shape and what causes day and night, also presents its own problems. It could be argued, for example, that the only intuitive mental models of the Solar System and wider Universe are those which involve the Earth, the Sun, the Moon and stars, the objects children

might be most familiar with from their own observations of the sky. It seems reasonable to suggest, however, that children with additional knowledge of the planets acquired by whatever means available to them within their own cultural setting might intuitively represent these planets in a map of the Solar System in random fashion. All things considered, however, and with the limitations discussed, a preliminary assessment of the range of scientific, transitional and intuitive models identified here is presented as shown (Table 7.3). In considering some of the psychological, methodological and interpretational challenges entrenched in a work such as this, particularly in terms of labelling mental models as intuitive, transitional and scientific, the research findings may give the impression of well developed conceptual hierarchies, each model within a given content area or even each response combination within a given model with its own perceived status within that hierarchy, when in fact there are none at all. While the very nature of the responses obtained here suggests that conceptual hierarchies probably do exist, though perhaps not as vertically, linearly and sequentially developed and ordered as might be implied, the very notion of such findings should be treated with care.

Model	Earth	Sun	Moon	Relative size
Scientific	The Earth is spherical or near-spherical in shape. Land masses are distributed all over. Gravity acts 'inwards' towards the Earth's surface. The Earth is a planet.	The Sun is spherical or near-spherical in shape. Surface features, heat and light are clearly depicted. The Sun is a star.	The Moon is spherical in shape. Surface features include craters and/or seas. The Moon is the Earth's satellite or a ball of rock and dust.	The Sun is greater in size than the Earth which is, in turn, greater in size than the Moon (S>E>M).
Transitional	The Earth is perhaps domed or hollow in shape. Land masses are not represented but described. Ideas about gravity and the nature of the Earth are uncertain.	The Sun is perhaps hemispherical or cylindrical in shape. Surface features are not represented but described. The Sun is light, heat, fire or a planet on fire.	The Moon is perhaps hemispherical or cylindrical in shape. Surface features are not represented but described. The Moon is a planet, a star or an asteroid.	The Sun is the largest (S>M>E, S>M=E). The Moon is the largest (M>S>E, M>E>S). All three bodies are the same size (S=E=M).
Intuitive	The Earth is perhaps flat and disk shaped. Gravity acts 'downwards'.	The Sun is perhaps flat and disk shaped. The Sun's shape in drawings may also appear unconventional.	The Moon is perhaps flat and disk shaped, shaped like a banana or semi-circular.	The Earth is the largest (E>S>M, E>M>S, E>S=M).

Model (cont.)	Cause of day and night	Cause of seasonal change	Cause of Moon's phases	Solar System map
Scientific	The Earth rotates once every 24 hours.	The tilt of the Earth's axis as the Earth orbits the Sun once a year.	The lit side of the Moon seen as it orbits the Earth.	Heliocentric (complete/correct).
Transitional	The Earth rotates over a variable period of time.	The Earth orbits the Sun.	Earth shadow. The lit side of the Moon seen as the Earth rotates.	Heliocentric (complete/incorrect and incomplete/incorrect). Spiral. Processional (Sun-centred).
Intuitive	The Sun and Moon orbit the Earth. The Earth orbits the Moon. The Earth orbits the Sun. The Moon orbits the Earth. The Sun rotates. Satellites cause Earth rotation. Mixed verbal models.	The Sun orbits the Earth. The Sun heats up and cools down. The rotation of the Earth. The Earth and the Sun move closer together and further apart. The Moon gets in the way. The Sun moves up and down. The Sun's dark side. Mixed verbal models.	Planets get in the way. Clouds. The Moon goes behind the Sun. Mixed verbal models.	Geocentric. Processional (Earth-centred). Random. Earth, Sun and Moon.

Table 7.3 Examples of intuitive, transitional and scientific mental models in this study

7.2.2 Progression in children's ideas and models

Throughout this work it has been possible within the experimental group to identify progression in children's ideas and mental models both qualitatively and quantitatively and to illustrate that progression in part at least in the form of mapped routes and pathways associated with change. Progression was observed in all aspects of correctness but to different degrees both within and between different content areas. In terms of the Earth, the Sun and the Moon, progression was noted in linguistic variation and the increasingly precise use of scientific vocabulary (e.g. describing all three objects as *'spherical'* rather than *'round'*) and stylistic variation in drawings (e.g. providing more Anglocentric drawings of the Earth, more drawings of the Sun showing flares, prominences and sunspots, and more drawings of the Moon showing craters and 'seas'). Children also seemed more familiar with the nature of the Earth as a planet, the Sun as a star and the Moon as a ball of rock and/or dust as well as the Earth's only natural satellite. Progression was also noted perhaps more subtly in terms of children's verbal responses and manipulative and drawing skills associated with Earth-Sun-Moon System phenomena (Table 7.4). Children initially found to describe features associated with day and night, seasonal change and the Moon's phases later provided more causal explanations of them. The numbers of children initially indicating that they were *'not sure'* in response to what causes day and night, seasonal change and Moon's phases decreased substantially in all cases. Progression in children's knowledge and understanding of the Solar System and wider Universe, particularly in their ability to represent the Solar System in the form of a map, was particularly impressive. Overall, and following the experimental treatment, responses were noticeably, and at times measurably, more structured, coherent and accurate.

		First interview (pre-)			Second interview (post-)		
		Verbal	Props	Drawing	Verbal	Props	Drawing
Exp. gp.	Day and night	17 (54.8)	15 (48.4)	9 (29.0)	26 (83.9)	27 (87.1)	18 (58.1)
	Seasonal change	0 (0.0)	0 (0.0)	0 (0.0)	15 (48.4)	16 (51.6)	13 (41.9)
	Moon's phases	0 (0.0)	0 (0.0)	0 (0.0)	15 (48.4)	16 (51.6)	7 (22.6)
Con. gp.	Day and night	15 (48.4)	15 (48.4)	9 (29.0)	18 (58.1)	17 (54.8)	13 (41.9)
	Seasonal change	2 (6.5)	2 (6.5)	2 (6.5)	3 (9.7)	3 (9.7)	3 (9.7)
	Moon's phases	0 (0.0)	1 (3.2)	1 (3.2)	0 (0.0)	2 (6.5)	2 (6.5)

Table 7.4 Progression in acceptable verbal responses, use of props and drawings to account for Earth-Sun-Moon System phenomena (frequency and percentage)

Progression was also observed in terms of the differences in mean scores before and after the experimental treatment, mean score gains, score profile percentages, and children scoring in the 24 to 36 range for 12-item probes and 12 to 18 range for 6-item probes (Table 7.5). The quantitative data set available reflects not only changes in overall knowledge and

		Mean score (first/second)	Mean gain	Score profile % (2s and 3s)	Score range % (24-36/12-18)
Experimental group	Earth[12]	20.0 - 22.9	+2.9	71 - 80	13 - 48
	Sun[12]	15.4 - 20.1	+4.7	49 - 69	0 - 26
	Moon[12]	13.3 - 19.1	+5.9	33 - 63	0 - 13
	Day and night[6]	7.3 - 10.4	+3.2	49 - 74	16 - 48
	Seasonal change[6]	3.3 - 9.0	+5.8	13 - 53	0 - 42
	Moon's phases[6]	3.5 - 7.7	+4.3	15 - 48	0 - 16
	Solar System/Universe[12]	10.1 - 18.6	+8.5	18 - 59	0 - 19
Control group	Earth[12]	19.2 - 19.3	+0.1	69 - 72	19 - 16
	Sun[12]	15.5 - 15.4	-0.1	47 - 54	0 - 0
	Moon[12]	14.1 - 13.9	-0.2	36 - 34	0 - 0
	Day and night[6]	7.3 - 7.2	-0.1	47 - 51	23 - 10
	Seasonal change[6]	3.8 - 4.0	+0.2	20 - 23	0 - 3
	Moon's phases[6]	3.9 - 3.2	-0.7	17 - 12	0 - 0
	Solar System/Universe[12]	9.6 - 8.7	-0.9	17 - 16	0 - 0

Table 7.5 Summary of progression in measured variables (pre- to post- with 12-item and 6-item probes indicated)

understanding in each of the content areas probed but the qualitative changes noted earlier and throughout the research findings. Interestingly, within the data set available, patterns in terms of perhaps the development and rate of learning are evident. By comparing like with like (e.g. all 12- and 6-item probes together), and at both first and second interview, children's overall knowledge and understanding of the Earth as measured was greater than their knowledge and understanding of the Sun. This, in turn, was greater than their knowledge and understanding of the Moon. The trend in mean score gains, however, was the reverse, greatest for the Moon and least for the Earth. The observed differences in mean scores at first and second interview as well as in mean score gain were significant (one-way ANOVA: differences in mean score pre- $F=26.91$, $p=0.000$; differences in mean score post- $F=6.15$, $p=0.003$; differences in mean score gain $F=7.22$, $p=0.001$; $df=2$ in all cases). Somewhat similarly, children's overall knowledge and understanding of day and night as measured was greater than their knowledge and understanding of seasonal change and phases of the Moon at both first and second interview. Mean score gain was least for day and night. The observed differences in mean scores at first and second interview as well as in mean

score gain were also significant (one-way ANOVA: differences in mean score pre- $F=22.59$, $p=0.000$; differences in mean score post- $F=3.15$, $p=0.047$; differences in mean score gain $F=3.93$, $p=0.023$; $df=2$ in all cases). At this stage, the data not only appear to be suggesting that the children learned least about those areas with which they were already very familiar, but that there is 'differential progression' perhaps indicative of a 'learning differential' or hierarchy between content areas in terms of the extent to which the other areas 'catch up'. The suggestion that progression in learning about some of the 'traditional' content areas of astronomy might also be hierarchical with some proceeding in advance of others, though not necessarily predetermining or constraining them, will be returned to later.

Interestingly, all items targeting absolute figures other than the length of a day, a month and a year, progression was poor, particularly so in the absolute sizes of the Earth, the Sun and the Moon, the temperature of the Sun, and the age of the Solar System. The same was also true of children's general ability to relate the orbit of the Earth around the Sun to the length of a year and the orbit of the Moon around the Earth to the length of a month (despite the lengths of a year and a month being well known) and their knowledge of the relative distances between planets. The reasons for this are uncertain but are almost certainly related to a lack of revision and reinforcement in teaching and retention in learning.

7.2.3 Children's explanations

Children's verbal accounts of the objects, events and phenomena of astronomy were particularly interesting (see also descriptions in drawings). While examples of Piagetian-type response categories (see Chapter 2) occurred in different places throughout this work, pre-causal responses, particularly those involving animism and anthropomorphism, were perhaps less common than expected based on the prevalence of their occurrence noted elsewhere. Piagetian-type response categories are important when provided for they reveal *how* as well as *what* children think (e.g. *'the Sun goes down when it gets tired'*, the Moon appears to get smaller because it *'gets cold'*, and so on). Perhaps the greatest variety of pre-causal responses were revealed in the mixed verbal models of phenomena associated with the Earth-Sun-Moon System. Interestingly, while Watts and Bentley (1994) have proposed reviving and exploring animistic and anthropomorphic thought for its pedagogical value and as a means of humanizing and feminizing a science curriculum, stating that 'a science that is alive, animate and caring of relationships is a model which may be imperfect by the standards

of objective, causal and mechanistic orthodoxy, but is it any more imperfect than any other model used in school science', their sentiment, though well intentioned, may not necessarily, as indicated here, apply to all science domains or across the entire primary age range.

Another important feature of the experimental and control group's responses was their occasional use of figurative language. Solomon (1986) has reported, that the use of simile and metaphor as well as other forms of productive comparison can be an essential part of children learning science, helping them to clarify their thoughts and ideas, particularly when working in new and unfamiliar territory. Although many forms of comparison provided here could be described as productive (e.g. direct and descriptive, or in a position to facilitate conceptual change) others were less so. Describing the Earth, the Sun and the Moon as *'round like ball'*, for example, is particularly productive because of its 'proximity' to *'spherical'*. Describing the Earth's gravitational attraction as *'like a magnet'* or the Sun's thermonuclear reactions as *'like oil burning'* are perhaps more problematic. Children's use of figurative language gives rise to the notion of taught or instructional analogy which has had some success amongst primary teachers in helping them to improve their 'visualization' of certain science concepts and to come to terms with some of the technical demands of the National Science Curriculum (e.g. Summers 1992). As with Watts and Bentley (1994), however, the very suggestion of using analogies, 'alive' or otherwise, or any other form of productive comparison raises fundamental questions about the theoretical, philosophical and empirical nature of science teaching and a science curriculum itself. Nevertheless, teaching by introducing the shape of the Earth, the Sun and the Moon as *'round like a ball'* before progressing on to *'spherical'*, for example, might prove more effective than simply referring to them as *'round'*. The use of taught or instructional analogy (e.g. teacher- or text-based) to enhance knowledge acquisition and concept learning in science as well as the construction of scientific explanations, including affective and creative factors, is, however, unsubstantiated. According to Dagher (1994, 1995), 'while reasoning by analogy is considered a natural ingredient that underlies learning and thought, the role of instructional analogies in the acquisition of science concepts is less clearly demarcated'. While productive comparisons would no doubt help some children to clarify their thoughts and ideas and to learn, the effectiveness of taught or instructional analogy as a pedagogical device remains to be fully evaluated.

As a final point, it may not have gone unnoticed from the research findings that many children presented ideas about astronomical objects, events and phenomena which bear a striking resemblance to those found throughout the history of the development of astronomy as a science (Berry 1961; Blacker and Loewe 1975; Wright 1995). While some authors have attempted to draw analogical parallels between the development of children's ideas and the development of ideas from the history of science, and the evolutionary and revolutionary theory changes which take place therein (e.g. McCloskey and Kargon 1988), referring as they do to concept learning in terms of conceptual evolution and revolution, such parallels should be drawn with care. While scientists often find themselves engaged in trying to push back the boundaries of science or discover and explore new paradigms within which to work, children, by learning science, often find themselves engaged in trying to integrate existing and accepted scientific knowledge with existing and personal or shared knowledge structures derived from experience. That children's ideas do bear a strong resemblance to the development of ideas from the history of science, however coincidental or not, may have pedagogical significance particularly in terms of developing metacognitive awareness. This was taken advantage of in the experimental treatment itself. The value of constructivist-historical approaches to science teaching at all levels has also been demonstrated elsewhere (e.g. Nussbaum and Sharoni-Dagan 1983; Sneider and Ohady 1998).

7.2.4 Gender and age

Gender studies within science education have been widely reported. Studies of the relationship between gender and attitude towards science, for example, have consistently found that girls tend to be more alienated and negative towards science, and the physical sciences in particular, than boys, often because of science being perceived as a wholly masculine construct (Sjøberg 1989; Murphy 1994; Watts and Bentley 1994; Whitelegg 1996). Nowhere is this more vividly portrayed than in children's images of science, scientists and the nature of science revealed in drawings (Mead and Métreaux 1957; Chambers 1983; Newton and Newton 1991; Tuckey 1992). Images of science, scientists and the nature of science, from which positive or negative attitudes towards science are thought to form, appear early in children's school lives and are difficult to change later. Interestingly, in a recent study designed to investigate whether or not the *third version* of the National Science Curriculum (DfE/WO 1995) had any impact on children's widespread and conventional stereotype of a scientist as a balding, bespectacled man in a long coat working with

dangerous chemicals in a laboratory, Newton and Newton (1998) administered a Draw-a-Scientist test (Chambers 1983) to one thousand 4 to 11 year olds attending a wide range of schools in the north east of England. Newton and Newton concluded that little had changed and the stereotypes were still present. Unfortunately, as in other studies (e.g. Head 1989), many children, boys as well as girls, continued to see science as remote from everyday life, hard to learn, and only of relevance to those who wish to pursue science as a career.

In this study, gender differences, usually in favour of boys, were evident in both groups in correctness, response category frequencies and the frequencies of acceptable scientific mental models presented. Gender differences, almost exclusively in the experimental group and always in favour of boys, were detected quantitatively in overall mean scores and, to a lesser extent, score profile percentages and performance on individual items of particular interest (see Appendix VIII for full details) and in all areas other than relative size and day and night (Table 7.6). Reasons for the clear difference in gender performance between groups are uncertain but could be due, in part at least, to the children's different background experiences in and out of school not considered here (see also below). Following the experimental treatment, however, and with the exception of the Sun, overall gender effects were reduced and the gaps between boys and girls closed. In the case of the Solar System and wider Universe the gender gap was eliminated completely.

	Experimental group		**Control group**	
	first	second	first	second
Earth	mean score, E1, 4, 11	mean score, E1	no differences	no differences
Sun	mean score, SPP, S2	mean score, SPP, S1, 2, 4	no differences	no differences
Moon	mean score, SPP, M1, 2	mean score, SPP, M11	no differences	no differences
Relative size	no differences	no differences	no differences	no differences
Day and night	no differences	DN6	no differences	no differences
Seasonal change	mean score	SPP	no differences	no differences
Moon's phases	mean score, SPP, MP1-3	SPP	no differences	mean score, MP2, 3
Solar System (map)	mean score, SPP, SOL5, 9	No differences	mean score, SPP, SOL9	mean score, SOL9

Table 7.6 Gender differences detected at interview (mean score, score profile percentages or SPP, and items of particular interest)

Towards the end of the Phase 6 (end June) of the overall quasi-experimental design, in a minor but important diversion from the main thrust of this work, the children in all three of Big Town CPS's upper primary classes were invited to produce a science 'top ten' based on the main areas of science presented to them since they had been at school (Table 7.7). The

third group was an independent group that had no previous contact with the author of this work (19 boys and 14 girls of similar age and background). A scale of 1 (most liked) to 10 (least liked) was adopted. The areas of science were presented in random order and labelled as they appeared in the school's own scheme of work and how the children would recognize them. Once ranked, the order was reversed to identify and rectify omissions and mistakes (10 most liked to 1 least liked) and mean scores for individual areas obtained. Outcomes generally reflected the established gender differences in science preferences of boys and girls with boys appearing to favour the physical sciences more than girls and girls the biological sciences more than boys. Astronomy, as the Earth in space, was an important exception in all three groups, perhaps more so in the experimental and control groups as would be expected. Within the experimental group, while the girls rated astronomy highly, it was, nevertheless placed second and with a lower score than that of the boys. The slight difference in score relative to the gender difference observed in the control group may have contributed something to the overall gender effects described earlier. The extent to which gender should be included as a matter for consideration for teaching science and curriculum design is an emotive issue. The gender aspect of this study highlights the difficulties in arriving at sensible and valid conclusions when sampling and dealing with small sample sizes.

Experimental group		Control group		Independent group	
Boys		***Boys***		***Boys***	
Earth and space	8.35	Earth and space	7.24	Earth and space	8.29
Electricity and magnetism	5.82	Energy and power	6.88	Electricity and magnetism	7.50
Forces and structures	5.76	Minibeasts	6.18	Energy and power	6.86
Energy and power	5.65	School grounds	6.06	Ourselves	6.21
School grounds	5.59	Electricity and magnetism	5.76	Minibeasts	5.64
Materials	5.59	Forces and structures	5.00	Forces and structures	4.79
Ourselves	5.53	Light and sound	4.88	School grounds	4.29
Minibeasts	5.29	Ourselves	4.59	Light and sound	4.29
Light and sound	3.88	Plants	4.35	Materials	4.14
Plants	3.53	Materials	3.94	Plants	3.00
Girls		***Girls***		***Girls***	
School grounds	8.29	School grounds	8.79	School grounds	8.32
Earth and space	7.29	Earth and space	6.86	Minibeasts	7.84
Materials	7.14	Plants	6.64	Ourselves	7.21
Ourselves	6.50	Minibeasts	6.29	Plants	6.79
Minibeasts	6.07	Ourselves	6.14	Earth and space	6.47
Forces and structures	5.21	Light and sound	5.00	Materials	5.63
Plants	5.14	Materials	4.43	Light and sound	4.16
Energy and power	3.36	Forces and structures	4.07	Electricity and magnetism	3.05
Light and sound	3.21	Energy and power	3.50	Forces and structures	3.00
Electricity and magnetism	2.79	Electricity and magnetism	3.29	Energy and power	2.53

Table 7.7 Children's science 'top ten'

More importantly perhaps, the multiple linear regression analyses carried out here strongly suggests that chronological age, and to a lesser extent intellectual maturity and curiosity in science, may be a major limiting or controlling factor associated with learning and gender and learning, not so much in the nature of ideas and models presented at interview but in children's overall knowledge and understanding as measured and reflected in summated scores in each of the content areas probed. This was true of children in both the experimental and control groups at first and second interview (see Appendix VIII). As with gender, however, the effect of age on performance or attainment should be treated with care. While tempting to ascribe age effects to some form of developmental readiness (e.g. intellectual, physical, social, emotional), as is commonly the case, the importance of birthdate effects should not be overlooked (see Chapter 5). The 'goodness of fit' observed throughout the models of multiple linear regression analysis using the exploratory variables adopted indicated that not only did the youngest children within the combined Year 5/6 classes perform less well than their older peers, the youngest within each Year group also performed less well than the oldest. It is interesting to note that despite there being no difference in mean age between boys and girls within the experimental group, the youngest children by 5 months tended to be girls. This was not the case in the control group. The gender differences observed in the experimental group here appear perhaps to have been underpinned more by the range of chronological age among the children, and as a consequence any factors associated with learning and chronological age, together with something of their likes and dislikes of certain areas of science, including their science curiosity, than any other readily identifiable cause.

7.2.5 The validity and reliability of scoring children's responses

As mentioned in Chapter 1, the research presented here was considered creative in its use of adapting a system of scoring children's responses first proposed by the primary geographers Harwood and Jackson (1993). It was suggested that this system of scoring and measurement, essentially involving the quantification of qualitative data, may also need to be subjected to the rigours of evaluation by further empirical research and statistical analysis. While the validity, reliability, sensitivity and precision associated with experiments (e.g. Campbell and Stanley 1963; Kerlinger 1969; Denscombe 1998), interviews (e.g. Cannell and Kahn 1968; Powney and Watts 1987) and elicitation techniques within the multiple-method survey

instrument (e.g. Gunstone 1992), together with operationalization, the notion of scale transformations, the generation and use of summated scores and dimensionality, have already been considered (see Chapter 4), it is important to address validity, reliability, sensitivity and precision with respect to the scoring and measurement here too. In this section, predictive validity and reliability in terms of stability and equivalence are given particular attention (Cohen et al. 2000).

Predictive validity is normally concerned with how well the results on a particular test measure accurately or predict subsequent performance. Here, however, predictive validity is concerned with the nature of the changes observed in children's measured responses between first and second interviews and whether or not these changes matched the outcomes expected within the context of the quasi-experimental design. In other words, predictive validity can be claimed if the changes observed in the performance of the experimental group as a result of the experimental treatment were significant relative to changes observed in the control group. Reliability as stability is concerned with how well an instrument will yield similar data from similar respondents over time. In other words, stability can be claimed by considering only those data say from the control group, not only in terms of observed performance on mean scores but in their correlation. Detailed inferential analyses support both claims (see Table 7.5 and the full treatment of quantitative data presented in Appendix VIII). Reliability as equivalence is concerned with the fallibility of human judgement. However well the scoring was operationalized here, an element of subjectivity and potential bias and distortion on part of the researcher, with implications for gender and group preference effects, not to mention experimental validity as a whole, is always a distinct possibility. Subjectivity, bias and distortion can be assessed through inter-rater reliability. As with the Goodenough-Harris measure of children's intellectual maturity, a second rater, the same female lecturer known to the researcher but unfamiliar with the details of the study, was involved. Rater 2 scored children in the experimental group's responses to the 12-item Earth probe obtained at first interview only (see Appendix VII). The observed difference in mean scores between Raters for the Earth at first interview, 20.0 and 18.7 (SDs 3.77 and 4.00 respectively), was not significant (matched $t=3.85$, $p=0.001$; normality of differences between raters $D_{xr}=0.081$, $p>0.15$; F-ratio=1.13), the correlation between pairs of data was high (Pearson's $r=0.874$, $p=0.000$) and no significant differences were observed in score profile percentages (test statistic $D_{xr}=0.062$, critical value $K_D=0.100$ for $\alpha=0.05$). For Rater 2,

boys in the experimental group also appeared to score more highly than the girls overall and the observed difference in their mean scores, 20.1 and 16.9 (SDs 3.64 and 3.78 respectively) was significant (t=2.44, df=29, p=0.021; normality for boys D_{xb}=0.121, p>0.15; normality for girls D_{xg}=0.143, p>0.15; F-ratio=1.08). This was also reflected in an analysis of the score profile percentages by gender (test statistic D_{xbg}=0.156, critical value K_D=0.142 for α=0.05). Inter-rater reliability was considered acceptable. Interestingly, the sensitivity of the system of scoring and measurement used here can be demonstrated in two ways. The first has already been presented and discussed in terms of drawing attention to the gender differences within and between groups. The system of scoring and measurement was also sensitive in the analysis of individual items of interest where it revealed significant differences in linguistic, stylistic and descriptive variation in response categories where there were sometimes no noticeable differences in the frequencies of model types presented (e.g. shape of the Earth). Despite its sensitivity, the system of scoring and measurement, was not as precise as originally hoped. This lack of precision is demonstrated in the mismatch between the frequencies of acceptable scientific mental models detected in different content areas, and mean scores at first and second interviews and the numbers of children scoring in the higher ranges of the 12-item and 6-item probes at first and second interviews (see Table 7.5). In some respects, this might have been anticipated as mental model determination usually relied upon a relatively small number of items of particular interest (e.g. E1, E2 and E4 for Earth shape) while summated scores considered all items in each probe together (e.g. E1 to E12). While other systems of scoring and measurement were possible (e.g. the differential allocation of points in accordance with linguistic, stylistic and descriptive variation within and between models or, say, points allocated to the exact numbers of planets named and identified, and so on), the continuity and subsequent value of being able to compare 12-item and 6-item probes found useful here would have been lost. While the method of scoring and measuring children's knowledge and understanding of astronomy developed and used here was certainly of great value, and has considerable potential as a classroom-based assessment and general research tool, much development work remains to be done.

7.3 Routes and pathways in knowledge acquisition and concept learning in astronomy

Following the means of analyzing the mental models of University students attending an elementary astronomy course in rural Minnesota first proposed by Targan (1987), having

identified the response categories and mental models in each of the 'traditional' content areas probed throughout the 'fieldwork' phases of this research, maps of the routes and pathways involved in knowledge acquisition and concept learning were prepared (see Chapter 6). While only undertaken for the experimental group, the routes and pathways observed provided a graphic illustration of 'constructivism in action' and the weak (accretion and tuning) and radical knowledge restructuring described by Carey (1985, 1986) and Vosniadou and Brewer (1987). Vosniadou and Brewer (1987), who located their work within the development of astronomy schemata in children, for example, referred to weak restructuring as the enrichment of, or adding to, existing knowledge and the 'accumulation of new facts and the formation of new relations between existing concepts' (the accretion and tuning of Rumelhart and Norman 1978), and radical restructuring as the abandoning of old knowledge for the appearance of new knowledge and a 'change in core concepts, a change in structure, and a change in the phenomena to be explained'.

In summary, between first and second interviews, many children determined to have entered the experiment with acceptable scientific mental models often presented new or more elaborate responses which were also more accurate and consistent. Mapping linguistic variation within spherical models of the shape of the Earth, the Sun and the Moon provided the best examples and these 'intra-model' changes highlighted the process of weak restructuring most convincingly. Many children determined to have entered the experiment with non-scientific (intuitive and transitional) models or 'alternative' interpretational frameworks also presented new or more elaborate responses which sometimes indicated that they had acquired sufficient elements of acceptable scientific models to be assigned to that category or, where not, to be assigned to other non-scientific categories that might be considered more advanced (including some between second and third interviews which had not been identified earlier). Mapping models of relative size, phenomena associated with the Earth-Sun-Moon System and the Solar System (map) provided the best examples and the 'intra-model' and 'inter-model' changes highlighted the processes of both weak and radical restructuring depending on the nature and significance of the actual changes involved. Children who indicated initially that they were *'not sure'* often presented information which allowed them to be assigned to a model for the first time (scientific, transitional and intuitive). Interestingly, while both weak and radical restructuring often led to scientific conceptualization, restructuring itself did not predetermine that scientific conceptualization would always take place. It was clear, however, that in most cases, both weak and radical

restructuring, and the knowledge acquisition and concept learning brought about as a result, did allow significant progress to be made within almost all of the content areas probed. This was true even of seasonal change and the phases of the Moon where levels of scientific conceptualization were poor. In areas other than seasonal change and the phases of the Moon, the maps suggest that knowledge acquisition and concept learning in astronomy may not be entirely as slow and as gradual as interpretations of many other studies conducted with children of this age have indicated (e.g. Nussbaum 1979; Mali and Howe 1979; Vosniadou and Brewer 1992,1994; Diakidoy et al. 1997). For many children within the experimental group, scientific conceptualization was certainly achieved rapidly and in a single conceptual leap. Just as it is possible to consider knowledge acquisition and concept learning between first and second interviews, the changes observed after a delay of three months were also important. With the notable exceptions of seasonal change and the phases of the Moon, for most children, and in all of the other content areas probed, retention was good and any regression indicated was not significant. Interestingly, almost all of the children found to regress over the three month period between second and third interviews were the same children that made 'good' progress initially. While some of those children reverted to the ideas and models held beforehand, this was not always the case. More importantly, the routes and pathways between first, second and third interviews also illustrated the individuality, commonality and non-linearity of learning. Children identified as having similar ideas and mental models initially but who subsequently ended up in different places as a result of the experimental treatment illustrate the individuality of learning, a kind of 'learning divergence'. Children identified as having different ideas and mental models initially but who subsequently ended up in the same place as a result of the experimental treatment illustrate the commonality of learning, a kind of 'learning convergence'. The individuality and commonality of learning and the progression and regression observed in the maps over time draw attention to the non-linearity of learning. Learning astronomy is clearly a complex and dynamic process.

Interestingly, the knowledge acquisition and concept learning identified can be mostly accounted for or described in general terms by conventional schema theory and existing theories of learning science (see Chapter 1). Within conventional schema theory and existing theories of learning science, including astronomy, the knowledge structures which give rise to mental models are thought to constitute the most influential factors affecting the rate, accuracy and effectiveness of bringing about conceptual change. This, often understated

element of most conventional learning theories, underpins the acts of personal and social cognition which define constructivism in science education. With this, the routes and pathways in the maps reveal something of each individual learner's state of mind in terms of the processing of information and how that information is stored, integrated and retrieved from long-term memory (e.g. Posner et al. 1982; Osborne and Wittrock 1983; West and Pines 1985; Vosniadou and Brewer 1987). Despite the high levels of persistent scientific conceptualization attained in most areas, for many children, particularly those with poor retention and ideas which regressed significantly over as little as three months, the new information presented to them within the boundaries of the experimental treatment may not have been acquired and stored in a sufficiently meaningful way. Perhaps the knowledge structures in long-term memory used to generate meaning were inadequate or inappropriate or isolated leading to confusion or non-scientific outcomes. Perhaps only minimal or insufficient links were established between the content of the science lessons themselves and the prior knowledge structures in long-term memory and this brought about only partial or short term change. For those children, knowledge restructuring was temporary. As Gilbert and Watts (1983) and Millar (1991) pointed out, some science can be hard to learn simply because it has no 'pay off' in terms of the effort required to learn, the cost of change outweighing the benefit of change. It is also possible, that, over time, the lack of retention and regression observed in learning outcomes could also be explained by the children's familiarity and boredom with the course of events and the many phases of interviewing undertaken, a lack of concentration, forgetfulness, carelessness, and so on. A more advanced model of learning science which perhaps more adequately accounts for the changes identified will be presented and discussed in the following section. Interestingly, in a study of the impact on Estonian children's definitions and explanations of astronomical definitions (equator, axis, orbit) and phenomena (day and night, seasonal change) provided by Kikas (1998), results from twenty 10 to 11 year-olds indicated that, while short-term retention was good, after a delay of four years with no further instruction many children resorted to their original everyday and inaccurate accounts. This was thought due to heavy reliance on textbook and didactic teaching methods rather than those involving children's ideas themselves. The integration of everyday and scientific knowledge was never thoroughly achieved so children simply forgot what they had learned and resorted to what they knew from before. Unlike here, the provision of 'good answers' to the knowledge probes employed indicated that the children involved were often found to repeat wording memorized from texts and did not indicate that the material taught had actually been understood.

7.4 The nature and status of children's ideas in astronomy and learning theory

It should, of course, be noted that the research findings presented here were, to a large extent, predicted by and, in a positivistic sense, lend further support to the constructivist view of learning summarized by Tasker (1981) and Driver and Bell (1986). It should also, of course, be noted that many children in both the experimental and control groups entered the experiment conducted here already in possession of acceptable scientific ideas and mental models and the constructivist focus on the 'alternative' rather than the scientific requires a certain care in its widespread use and the educational implications that lie therein. Nevertheless, and as mentioned in the previous section, the observed changes in children's ideas and mental models as mapped for the experimental group provided a graphic illustration of 'constructivism in action' and the processes of weak (accretion and tuning) and radical knowledge restructuring in the knowledge acquisition and concept learning process. While knowledge acquisition and concept learning particularly in seasonal change and the phases of the Moon proved a challenging and demanding prospect for some children involved, learning outcomes as a whole were considered more than favourable and at least on a par with learning outcomes in other areas of science (perhaps even better). In this section, the notion of 'constructivism in action' is extended by considering the contribution of research findings to the nature and status of the children's ideas in astronomy and learning theory.

7.4.1 Ontological and epistemological considerations

In *Conceptions of the World*, Piaget (1929) discussed children's egocentricity by which he meant how children ignore more or less completely the points of view of others having not yet discovered the 'multiplicity of possible perspectives' inherent in human nature. Two different forms of egocentricity were identified: ontological and logical or epistemological. According to Piaget, at the root of both lay the same 'egocentric illusions', namely, confusion between a child's own thoughts and the thoughts of others and confusion between the self and the external world. The ontology of learning science, that is considering what children take to be the nature of things in the world around them, as well as the epistemology of learning science, that is considering the grounds and quality of children's knowledge itself, both now receive the attention they deserve (Bliss 1995). According to Vosniadou (1994a, 1997), for example, the construction of a mental model of the Earth as a cosmic body or of

the day and night cycle depends upon an individual's representations of a number of interacting concepts and these are constrained by entrenched ontological and epistemological presuppositions. Vosniadou's position helps to explain why, given exposure to information regarding the spherical nature of the Earth, some children may find difficulty accepting this as a scientific fact. Vosniadou has suggested that children find accepting this difficult because they fail to recognize that the Earth upon which they live is an astronomical body surrounded by space. According to Vosniadou, very young children seem to categorize the Earth as a physical rather than an astronomical object and apply to it all of the presuppositions that apply to all physical objects in general. Ontologically, therefore, the Earth is solid, stable and 'layered' with respect to the sky and the ground. Epistemologically, things become described and explained as they appear to be. This is reinforced by children's experiences of what they see all around them. Consequently the Earth is believed to be 'flat', stationary and that unsupported objects fall downwards. Despite the apparent 'universality' of this finding, there is considerable room for cultural variation as ideas develop naturally or by encountering scientific ideas as a result of formal instruction (Vosniadou 1994b). As described, entrenched presuppositions place what Vosniadou refers to as first-order constraints on children's developing cosmologies resulting in, for example, initial 'flat' Earth models. Initial 'flat' Earth models place further second-order constraints on developing cosmologies in, say, the form of geocentric accounts of the day and night cycle.

By arguing that concepts are embedded within larger theoretical structures that constrain them, Vosniadou (1994a, 1997) distinguished between naïve framework theories of physics, which children are assumed to construct early in infancy, and which consist of ontological and epistemological presuppositions, and various subject-specific theories, which are intended to describe the internal cognitive structure of the conceptual sub-domain within which the concepts are embedded. Both framework and specific theories affect the knowledge acquisition and concept learning processes in sub-domains such as astronomy. Weak and radical knowledge restructuring and concept learning of the sort required to bring about conceptual change and changes in beliefs and mental models not only require revision to specific theories but may require revision of the entrenched ontological and epistemological presuppositions of the framework theory which constrain them. This, of course, is difficult to do because they provide coherent and consistent explanatory networks supported by years of experience and personal observation. According to Vosniadou, therefore, conceptual change is seen as the product of the slow and gradual lifting of

constraints, as presuppositions, beliefs and mental models are added, eliminated, suspended or revised during the knowledge acquisition process.

It is possible to explore Vosniadou's naïve framework/specific theory hypothesis within the context of astronomy learning here using the extended research findings presented. In terms of first order constraints, it might be said that the existence and potential influence of entrenched presuppositions receives some support from some of the content areas probed, particularly in terms of the range of non-scientific (intuitive and transitional) ideas and mental models presented by children in both the experimental and control groups at first interview. This support is limited, however, given the relatively high initial frequencies of scientific mental models of the shape of the Earth, the Sun and the Moon and, to a lesser extent, relative size and day and night. Within the experimental group alone, however, the existence and potential influence of entrenched presuppositions receives even less support at second interview following the experimental treatment where, as indicated earlier, levels of scientific attainment were, other than in seasonal change and the phases of the Moon, generally high overall. Learning astronomy was for many children anything other than slow and gradual and any influence from entrenched ontological and epistemological presuppositions was not at all evident. It is worth remembering, of course, that the children entering the experiment here encountered many areas of astronomy formally at school as infants (5 to 7 years of age). In terms of second order constraints, the picture of the existence and influence of entrenched presuppositions painted by Vosniadou may be overly simplistic. The research findings presented here strongly suggest that the development of scientific models of what causes day and night, for example, were constrained, if constrained is indeed the correct word to use, by something other than the shape of the Earth. Could other factors be involved? Following Vosniadou's logic and reasoning, it could be argued, for example, that children might construct a view early in childhood that the Earth is much larger than the Sun and the Moon which would both appear readily visible to them as relatively small objects in the sky. Ontologically, therefore, it might be assumed that the apparent size of the Earth, together with the fact that the children live upon its surface, elevates its importance as an object which might also result in a geocentric view of what causes day and night. Even in possession of a spherical Earth model, relative size could be a second order constraint to learning (this is supported to a certain extent by the size of the Earth in many drawings). A glance at Tables 7.2 and 7.9 reveals that not only are the frequencies of scientific and non-scientific (intuitive and transitional) models of relative size and day and night comparable,

with the development of relative size proceeding slightly in advance of day and night in all instances, their association, particularly in the experimental group at second interview is also particularly strong. However, some children were also observed to hold scientific models of day and night without scientific models of relative size. Of course, it is far easier to see how the development of a scientific model of what causes day and night might be more constrained by children's observations of the apparent movement of the Sun and the Moon across the sky rather than the shape of the Earth or its relative size but this information was not collected. Overall, it seems reasonable to conclude, therefore, that the entrenched presuppositions and the first and second order constraints they might impose as described by Vosniadou, played only a limited part in the knowledge acquisition and concept learning observed, at least in terms of Earth shape, relative size and day and night. As far as seasonal change and phases of the Moon are concerned, the naïve framework/ specific theory hypothesis may hold more water. Interestingly, Driver et al. (1994b) have pointed out that learning science as a process of knowledge acquisition and conceptual change and the associated generation of new meaning or sense-making may also be overly simplistic and that children need not necessarily have to learn science by having to abandon their 'alternative' interpretational frameworks or common-sense ideas even as a result of teaching but have these ideas of science available to them within appropriate scientific contexts (context-specific reasoning or situated cognition). This view reflected that presented earlier by Linder (1993) who argued that children could construct a repertoire of conceptions of objects, events and phenomena ('domains of knowledge') and that learning by 'conceptual appreciation' might be more appropriate than learning by conceptual change. In such instances, entrenched presuppositions and the naïve frameworks behind them, should they exist at all, could be 'suppressed' rather than 'lifted'.

7.4.2 Coherent theories and knowledge-in-pieces

Many authors have raised the issue of whether or not progress in children's ideas towards scientific conceptualization represents a change to any coherent theory-like structures the children may be using (McCloskey 1983; Carey 1985, 1988) or whether progress is better characterized by simple improvements in pieces of unrelated knowledge which are essentially independent resulting in a lack of ability to transfer and generalize from one situation to another (di Sessa 1988, 1993). Both positions have caused much debate within the worlds of science education and cognitive psychology (Solomon 1983; Engel-Clough and Driver 1986;

Driver 1989; Chi and Slotta 1993; Marton 1993; Ueno 1993). Interestingly, throughout the work of Vosniadou (1991a, 1994a, 1997), Vosniadou and Brewer (1992, 1994) and other studies in which they have been involved (e.g. Samarapungavan et al. 1994; Diakidoy et al. 1997), coherent theory-like structures form the very basis of their domain-specific position on knowledge acquisition and concept learning while throughout the work of other authors, including Osborne et al. (1994), Sharp (1995, 1996), Sharp et al. (1997) and Kikas (1998), such a theoretical position has never been firmly established. While the differences between theory-like structures and knowledge-in-pieces are important, both from the point of view of learning theory and teaching science in the classroom, a lack of published empirical research data makes disentangling the varied interpretational perspectives and issues involved far from straight forward and the exact relationship between developmental and experimental studies or the coherency or otherwise of ideas and mental models within or between science domains uncertain.

As with naïve frameworks and specific theories, it is also possible to explore the coherent theory/knowledge-in-pieces hypothesis using the extended research findings presented here. In terms of the consistency of scientific mental models and their use, that is their robustness, it is possible to investigate which children presented scientific mental models from first to second interview and second to third interview (extending the work of Osborne et al. 1994). As indicated by the experimental group (Table 7.8), robustness between first and second interview was good, particularly in the areas of shape (the Earth 100%, the Sun 96% and the Moon 90%), relative size (86%) and day and night (91%), where almost all of the children who provided acceptable scientific models before the experimental treatment also provided the same models afterwards. The robustness of models presented after a delay of three months following the experimental treatment was also good (e.g. >75%) other than in seasonal change (53%) and the phases of the Moon (40%). Results show that for most content areas other than seasonal change and the phases of the Moon, once scientific conceptualization had been attained, the scientific models presented were indeed relatively robust and retained. The coherent theory/knowledge-in-pieces hypothesis can also be considered in terms of the relationship between models and pairs of associations of interest. In their study of children's ideas of what causes the day and night cycle, for example, Vosniadou and Brewer (1994) also collected information about Earth shape In their analysis, Vosniadou and Brewer concluded that the nature of this paired association suggested that scientific models of Earth shape were a necessary but not sufficient condition for the

acquisition of a scientific model of what causes day and night (supporting, of course, the naïve framework/specific theory hypothesis). By way of contrast, however,

	Content area/item	Presented at both	Presented before	Presented after	Presented at neither
First to second interview	Earth shape	29	0	2	0
	Sun shape	24	1	4	2
	Moon shape	18	2	8	3
	Relative size	12	2	13	4
	Day and night	10	1	14	6
	Seasonal change	0	0	15	16
	Moon's phases	0	0	15	16
	Solar System (map)	0	0	22	9
Second to third interview	Earth shape	31	0	0	0
	Sun shape	28	0	1	2
	Moon shape	25	1	2	3
	Relative size	24	1	2	4
	Day and night	20	4	3	4
	Seasonal change	8	7	1	15
	Moon's phases	6	9	1	15
	Solar System (map)	17	5	3	6

Table 7.8 Scientific models presented and retained by the same children between first, second and third interviews (frequency - experimental group only)

Osborne et al. (1994) noted no such association between models of Earth shape and gravity supporting a view that these attributes are seen by some children as unrelated and that by choosing a shape of the Earth those children did not necessarily conceive of it as the ground on which they live. As indicated by the experimental group (Table 7.9), some associations of interest at first and second interview are revealing. Scientific models of Earth shape and gravity appear associated before and after the experimental treatment and to the same degree though the development of shape appears to occur slightly in advance of gravity in both cases. Scientific models of Earth shape and day and night appear more associated after the experimental treatment than before and to almost the same degree as Earth shape and gravity. Scientific models of relative size and day and night appear associated before and after the experimental treatment but to different degrees. Their development appears very closely related and similar in occurrence to the association between scientific models of Earth shape and day and night following the experimental treatment. Scientific models of day and night and seasonal change appear more associated after the experimental treatment than before but their development is not well related at all. The development of day and night appears to occur well in advance of seasonal change. Scientific models of seasonal change and the

Moon's phases appear associated before and after the experimental treatment and to develop together at almost exactly the same rate. Scientific models of day and night and the Solar System (map) appear associated after the experimental treatment only and almost to the same degree as the association between Earth shape and gravity and Earth shape and day and night.

	Association (content area or item)	Both presented	First only	Second only	Neither presented
First interview (pre-)	Earth shape/gravity	24	5	1	1
	Earth shape/day and night	11	18	0	2
	Relative size/day and night	8	6	3	14
	Day and night/seasonal change	0	11	0	20
	Seasonal change/Moon's phases	0	0	0	31
	Day and night/Solar System (map)	0	11	0	20
Second interview (post-)	Earth shape/gravity	26	5	0	0
	Earth shape/day and night	24	7	0	0
	Relative size/day and night	22	3	2	4
	Day and night/seasonal change	15	9	0	7
	Seasonal change/Moon's phases	9	6	6	10
	Day and night/Solar System (map)	20	4	2	5

Table 7.9 Associations of scientific models (frequency - experimental group only)

Taken together, robustness and association seem to present something of a mixed message. For the most part, progress towards scientific conceptualization is characterized by coherency both within and between models. The situation surrounding seasonal change and phases of the Moon, which have stood apart throughout this work, however, implies a knowledge-in-pieces component. As well as being hard to learn, the range of mental models of seasonal change and phases of the Moon presented suggests that some children do not find contradictory explanations within the Earth-Sun-Moon System problematic (perhaps reflecting a context dependency). Overall, it seems reasonable to conclude, therefore, that presenting coherent theories and knowledge-in-pieces as rivals is somewhat misleading. Both are evidently able to co-exist even within a single sub-domain such as astronomy never mind between them. Interestingly, not one child in the experimental group presented scientific mental models across all of the content areas probed initially and only six (19%) did so following the experimental treatment (reduced to two or 6% at third interview). Like many aspects of the research findings presented here, while robustness and association also draw further attention to an emerging hierarchy of development in scientific models between different content areas, to suggest that the prior development of any one area necessarily

constrains or predetermines the development of another remains uncertain. To avoid any unnecessary distortion in interpretation associated with prior learning, for example, serious consideration should be given to the rate as well as the extent of development. With this in mind, it could be argued that, with the exception of seasonal change and phases of the Moon, all other content areas considered here developed almost side by side.

7.4.3 The dynamics of change: towards a new theory of learning astronomy

In previous sections, it has been possible to demonstrate that for the children in the experimental group, knowledge acquisition and concept learning in astronomy was essentially constructive in nature and this could be readily accounted for in general terms by conventional schema theory and existing theories of learning science (e.g. Posner et al. 1982; Osborne and Wittrock 1983; West and Pines 1985) including astronomy (e.g. Vosnidou and Brewer 1987). However, it has also been possible to demonstrate that knowledge acquisition and concept learning in astronomy was complex and dynamic in nature too, the complexity and dynamics revealed most convincingly in the individuality, commonality and non-linearity of learning in the mapped changes which took place over time. Together with the conceptual hierarchies implied within and between content areas, 'learning divergence', 'learning convergence', and learning further characterized by the co-existence of coherent theory-like structures and knowledge-in-pieces, conventional schema theory and conventional theories of learning science and astronomy, often based upon the analysis of relatively simple semantic networks, currently lack the explanatory power fully required to adequately account for all of the features observed or provide suitable mechanisms by which they might occur at all (a point also noted by Osborne and Wittrock 1983). Fortunately, it is possible to draw comparisons between the empirical data and the interpretation of that data presented here and a relatively little known theoretical model for learning science proposed by Luffiego et al. (1994) which holds some promise. Basing their work on constructivist premises, and extrapolating from the non-linear principles of dynamical systems theory, including chaos, Luffiego et al. presented an extended and advanced schema-based learning model involving the evolution of a conceptual structure in order to describe the state of a learner's cognitive system before, during and after the input of new information associated with teaching or instruction (Fig. 7.1). While the application of dynamical systems theory and chaos to matters of a psychological and educational nature might at first seem unusual, their extension from the realms of mathematics and computing into many other disciplines as far and wide as

the sciences, engineering, electronics, geography, medicine and economics has met with some success, particularly in terms of explaining the sometimes odd behaviour and predisposition of evolving and largely deterministic dynamic systems that tend towards disorder, complexity and unpredictability, however brief that tendency might be (Gleick 1987; Casti 1991; Hall 1992). In essence, dynamical systems theory and chaos revolve around the notion that the evolutionary path of a dynamic system is a function of the sensitivity of its initial state. In its simplest sense, the well known metaphor of the 'butterfly effect' helps to explain just how sensitive initial states can be. The most classic example of chaos in action involves the evolution of weather systems. It might be expected, for example, that weather systems which appear similar in their measured attributes initially might follow similar evolutionary paths. Uncertainties in the exact nature of their initial states, however, including, it is said, the flapping of a butterflies wings, can produce local effects resulting in an unforeseen chain of events leading to the subsequent departure from prediction often observed.

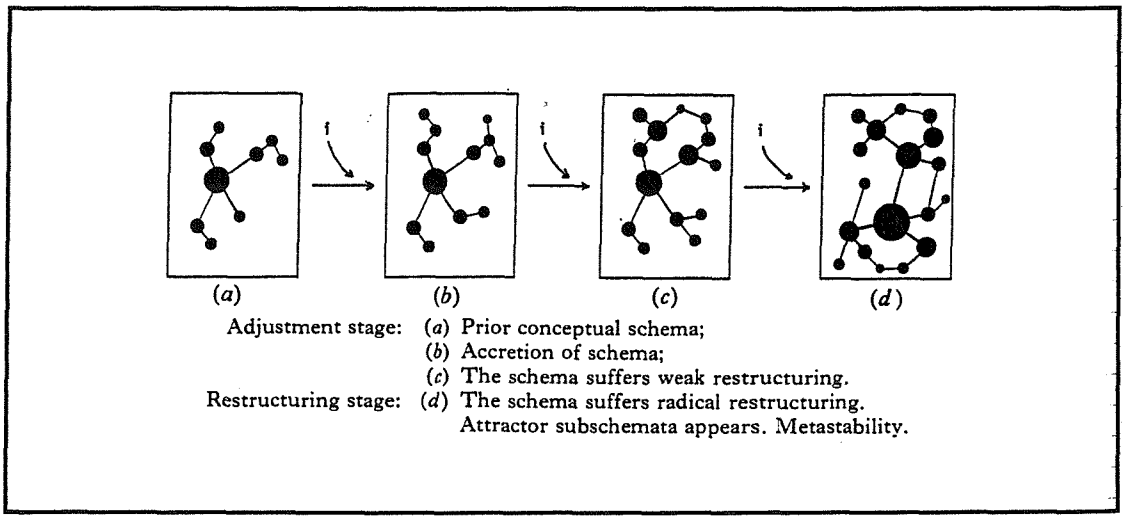


Fig. 7.1 A systemic model of conceptual evolution (from Luffiego et al. 1994)

According to Luffiego et al., the human cognitive system is an open and dynamic system capable of selecting, storing and processing information and subject to extreme variability between individuals. As a result, learning is sensitive to the initial state of the cognitive system of an individual. The dynamic feature of an individual's cognitive system is,

therefore, that it is non-linear. With this, it is possible to consider the basic qualitative characteristics of the human cognitive system alongside all other non-linear dynamic systems even if they cannot be defined in pure mathematical terms. Within the context of dynamical systems theory and chaos, and with reference to Fig. 7.1, Luffiego et al. have suggested that the knowledge structures or conceptual schema within most cognitive systems are in fact powerful information 'attractors' for they exhibit general stability and resistance to change and give rise ultimately to 'final-states' of knowledge. When faced with new information, such as that presented at different stages within a single astronomy lesson or throughout a series of astronomy lessons, an individual's initial conceptual 'attractors' may not be not able to anchor parts of the new information input within the structures that already exist and so branching occurs and it is accreted elsewhere. As these 'stable' adjustments continue, eventually weak restructuring takes place during which the arrangement of content elements is changed and new relations between the content elements are formed. While peripheral adjustments take place, the 'attractor nucleus' or 'core' remains intact and the 'final states' of knowledge essentially the same. When faced with particularly challenging information, again as a single or repeated event, an individual's cognitive system may abandon 'stability' in favour of 'instability' during which time maximum chaos occurs and radical restructuring takes place with the formation of not only new and once again 'stable' information 'attractors' but new meaning and new sense-making potential. The potential formation of 'attractor' subschemata within the new information 'attractors' may give rise to only temporary 'stability' following which further changes might take place. As a result of initial variability and sensitivity between individuals, however, the new interpretational and explanatory networks which arise as a result may be indeterminate, even for individuals presenting very similar ideas and mental models initially, for such chaotic behaviour, by definition, imposes limitations on predicting future outcomes. As Luffiego et al. pointed out, however, if it were possible to detect certain information 'attractors' within a classroom environment and to chart their progress as learning takes place, these might reduce the scope in which future states are to be located making probabilistic or qualitative predictions of learning possible. In a sense, the response categories, mental models and mapped routes and pathways presented here, as a result of this work, do just that. With due care and attention, while the empirical data presented here and the interpretation of that data undoubtedly lend strong confirmatory support to the model of conceptual evolution proposed and can be better explained by it, providing, if little else, a new language of learning, this is, however, far from a true test. Unfortunately, the real test of the conceptual evolution theory proposed by

Luffiego et al. is more likely to lie within the field of neuroscience than science education if, as described by Pinker (1997), the 'fluttering in the brain that causes a hurricane of behaviour' is to be observed.

Some of the limitations associated with conventional schema constructs and semantic networks in cognitive psychology and science education have also been partially overcome by neuroscientists with the development of computational models of cognition involving neural or connectionist networks and information processing which is thought to more closely resembles the working of the human brain (Rumelhart and McClelland 1986; McClelland and Rumelhart 1988; Smolensky 1988; Bechtel and Abrahamsen 1991). Neural or connectionist networks consist of neurone-like units, the schema or schemata of cognitive psychology, which are connected together in layers so that a single unit has many links to other units. Units affect other units by exciting or inhibiting them. A representation of a concept, for example, could be stored in a distributed manner by a pattern of activation throughout the network. The same network could store many different patterns in this way without them necessarily interfering with each other. Models of information processing based on neurocognitive perspectives have found their way in to science education too (Anderson 1992, 1997; Roth 2000).

7.5 Teaching astronomy and curriculum design

As demonstrated here, and elsewhere, research findings support the view that children in the upper primary years can and do make significant progress towards scientific conceptualization as a direct result of effective astronomy teaching, particularly where that teaching establishes something of a constructivist learning environment and pays due regard to the nature and importance of children's ideas and mental models from the outset and resists traditional discovery or didactic methods as the sole mediums of communication (e.g. Vosniadou 1991c; Osborne et al. 1994b; Watts and Bentley 1987; Sharp et al. 1997; Sneider and Ohady 1998; Kikas 1998; Diakidoy and Kendeou 2001). With the limitations of extending constructivism beyond that of a view of learning expressed by Millar (1989) and Matthews (1994) very much in mind, the research findings presented here do bring with them certain implications for the teaching of astronomy in primary schools as well as curriculum design. These implications focus on the issues of teachers' curricular expertise and the choice and relational structure of content elements within the National Science Curriculum as

it existed at the time of this work (DfE/WO 1995) and as it currently exists (DfEE/QCA 1999b). The author's opinion of the strategic place of astronomy in the primary curriculum is also offered.

7.5.1 Implications for teaching astronomy

It would be entirely unreasonable within the context of the educational experiment conducted here not to lay some claim to the success of many of the children in the experimental group attaining high levels of scientific conceptualization to Jack's curricular expertise. As indicated by many authors, it is the curricular expertise of primary teachers, together with appropriate attitudes and a positive orientation towards science, that is the essential ingredient to effective science teaching (e.g. Shulman 1986, 1987; Cleminson 1990; Carré 1993; Lakin and Wellington 1994; Summers 1994; Harlen and Holroyd 1997). Within astronomy, as with many other areas of science, finding teachers with such an appropriate balance of attributes is not easy (e.g. Mant and Summers 1993; Summers and Mant 1995a). It seems almost inevitable, with hindsight, that the introduction of the National Curriculum for primary science in England and Wales would bring about certain unavoidable and perhaps much needed changes to the nature of Initial Teacher Training (ITT), which, as with pre-National Curriculum science education, was also embedded in 'localism' (Reid et al. 1994; Wilkin 1996). The recent introduction of an Initial Teacher Training National Curriculum for Primary Science (Annex E of DfEE 1998a), for example, set out to specify the subject knowledge, the pedagogy and the assessment methods which all trainee primary teachers in England should be taught in order to secure children's progress in science including astronomy and to be eligible for the award of Qualified Teacher Status (QTS). Though now replaced with less tightly specified criteria (DfES/TTA 2002), these requirements remain essentially in place. It is interesting to note, with some cynicism perhaps, that this development took place some 80 years after science training first ceased to be compulsory for intending primary teachers and some 20 years after the notion of such focused training was raised again in the *National Primary Survey* of schools (DES 1978). While many now believe that Initial Teacher Training in England has, like primary education itself, become increasingly centralized and politicized as a result of all new requirements and, by default, become responsible for ensuring compliance with educational policy as determined by Government (e.g. Furlong and Smith 1997; Rees 1998; DfE 1993; DfEE 1997; DfEE 1998a), few could argue with the basic motivation to improve science education provision and

astronomy within it. Recent critiques of the Initial Teacher Training National Curriculum as a whole, however, have been useful in pointing out that while every trainee primary teacher might be given an entitlement to what they should be taught in terms of subject and pedagogical knowledge and skills during training, successful Initial Teacher Training also involves a personal and less mechanistic interaction between teachers and children which is not accounted for in the current Initial Teacher Training climate (e.g. Richards et al. 1998; Reynolds 1999; Burgess 2000). The success of new Initial Teacher Training initiatives and the impact on science teaching in English primary schools, however that success might be measured, remains to be fully evaluated.

How teachers already in service can be supported in developing appropriate curricular expertise to teach astronomy also remains problematic and no real solution has ever been found (e.g. Parker and Haywood 1998). A Scheme of Work for Science at Key Stages 1 and 2 (QCA/DfEE 1998 with amendments 2000), produced almost ten years after the *first version* (DES/WO 1989) of the National curriculum for primary science itself, has been made available recently and could help. The Scheme of Work is presented as a series of Units which attempt to provide continuity and progression in science provision from Year 1 to Year 6. Broad guidance is offered on the nature and place of each Unit, how each Unit builds on previous Units, teaching activities and learning outcomes, expectations, the technical and scientific vocabulary to be used, resources required, health and safety, and links with Information and Communication Technology (ICT). Critically, however, any information relating to the Scheme's authorship and development, how it should be implemented by practising teachers, or its evaluation, is notable by its absence. Designed to support the National Science Curriculum, astronomy is represented only by a single Year 5 Unit (Unit 5E Earth, Sun and Moon) which, in comparison with other Units, stands rather alone. The research findings presented here, strongly suggest, however, that astronomy's place as a single Year 5 Unit might prove to be unfortunate, not only because of its isolation (remembering that astronomy was removed from Key Stage 1 during the revision of the *second version*), but that children taught astronomy in Year 5 could be disadvantaged simply by virtue of their age. Evidence would seem to suggest that the astronomy content within the National Science Curriculum as it exists might be more appropriately located in Year 6.

Perhaps the single biggest limitation to the research carried out here, and the single biggest threat to its external validity, was the lack of opportunity to provide detail concerning the

implementation of the experimental treatment and the nature of the constructivist learning environment established by Jack. While every effort was taken to negotiate the astronomy activities undertaken and the pedagogical devices that might be usefully employed, treatment fidelity itself could not be guaranteed other than through Jack's own verbal commitment to stay faithful to the experiment as conceived and negotiated. Despite its value (e.g. Fensham 1994; Driver et al. 1994b), no insightful information which might have led to any analysis of Jack's teaching strategies and styles, how he intervened in order to manage the direction of the activities and help take the children's ideas forward, the exact nature of the classroom interactions including how individuals engaged with the activities and resources (teacher, child, teacher-child, child-child), the wider social dimensions of learning, and so on, was obtained. Unfortunately, even the most cursory review of science education literature reveals studies of this type lacking. This is an area of science education research simply crying out for attention. Similarly, and despite its value (e.g. Carey 1986), no means of testing how to effect knowledge acquisition and concept learning lesson by lesson, strategy by strategy, activity by activity or resource by resource was possible.

7.5.2 Astronomy curricula and curriculum design

Not only are children evidently capable of learning astronomy, for the most part they are capable of learning it very well indeed. Perhaps the single greatest barrier to what they can achieve, however, is not what goes on around them or inside their own heads, but what adults are prepared to give them access to in the form of a science curriculum, a point also expressed by Millar (1996a, b). The 'plight' of astronomy within the National Curriculum for primary science as a result of years of educational reform in England and Wales has already been well documented (see Chapter 3). Of all the changes which took place to astronomy provision, the removal of the astronomy component at Key Stage 1 (5-7 years) and the removal of the Solar System from Key Stage 2 (7-11 years) between the second and third versions, with requirements becoming more focused around the objects, events and phenomena associated with the Earth-Sun-Moon System, perhaps stand out the most. As demonstrated here, many children in both the experimental and control groups entering the experiment did so with ideas and models in some content areas that were already scientifically acceptable and this can be attributed, in part at least, to their earlier encounter with astronomy as infants. By removing astronomy from Key Stage 1, those involved in the design of the National Science Curriculum may have inadvertently removed all scope for

continuity and progression between the two primary Key Stages. As also demonstrated here, not only did the children in the experimental group present high levels of acceptable scientific ideas and mental models of the Solar System as a result of the experimental treatment, levels which exceeded models of what causes seasonal change and the Moon's phases, those ideas and models were retained without significant regression for some time afterwards. The decision to include the Solar System in this work, despite its removal from the primary age phase in statutory documentation, was taken jointly by Jack and this author on the basis of their combined experience of teaching astronomy in primary schools, of providing what they considered to be a more broad, balanced and relevant content of most educational benefit and interest to the children involved, and to brighten up an otherwise 'dull' statutory entitlement. Sharp (1996) and Sharp et al. (1997) also noted that some children learning astronomy might actually use their knowledge and understanding of the Solar System in order to help locate and contextualize work associated with some of the more difficult aspects associated with the Earth-Sun-Moon System. As pointed out by Driver (1981), curriculum development in science needs to pay as much attention to the structure of thought of the child as it pays to the structure of the science to be taught and that the logical order of teaching a topic may not coincide with the psychological order of learning, a view reinforced by Vosniadou (1991a, b) within the sub-domain of astronomy itself. The removal of the Solar System and its relocation within the post-primary curriculum serves to illustrates this point perfectly. While there is no suggestion being made here that children should not be exposed to scientific models of seasonal change and the Moon's phases, for there is no evidence to suggest that low levels of scientific conceptualization are in fact detrimental to further encounters with these areas, their inclusion does need to be considered carefully in terms of current assessment frameworks and level descriptors which accompany statutory documentation and the expectations that lie therein.

It should be stressed, of course, that astronomy in the primary age phase is about more than learning facts and figures. It is certainly more than learning about the shape of the Earth, the Sun and the Moon or the periodic changes associated with how the Earth, Sun and Moon move with respect to one another. It is about the history and nature of science and the development of scientific thought. It is about human endeavour and human achievement and, at times, complete failure. It is about feelings and emotions in terms of children's relationships with each other and their relationships with nature. It is about public understanding, particularly at a time when matters of astronomical and socio-scientific

interest impinge upon children's everyday lives. For these reasons alone, it is asserted here that astronomy surely deserves a more prominent place in the primary curriculum. In the United States, Earth appreciation and Earth Systems Education are used as a basis for helping children to see the Earth not only in a physical or astronomical sense, and with that aspects of citizenship, planetary stewardship, responsible development and globalization, but as an object of outstanding natural beauty and of mystery, capitalizing fully on their sense of awe and wonder at what learning about the Earth in space has to offer (Mayer 1989, 1991, 1995; Van Matre 1990; NRC 1993). Closer to home, Millar and Osborne (1998) have commented in their influential report *Beyond 2000: science education for the future* that the National Science Curriculum should serve to 'sustain and develop the curiosity of young people about the natural world around them and build up their confidence in their ability to inquire into its behaviour, foster a sense of wonder, enthusiasm and interest in science so that young people feel confident and competent to engage with scientific and technical matters and help young people acquire a broad range of general understanding of the important ideas and explanatory frameworks of science, and of the procedures of scientific inquiry, which have had a major impact on our material environment and on our culture in general'. While Millar and Osborne noted that a choice of curriculum content is inevitable in order to avoid overcrowding and to provide time for reflection and discussion, astronomy education featured prominently as one of several 'explanatory stories' which they believe would make science education more interesting, meaningful, relevant and useful. According to Millar and Osborne, 'explanatory stories' incorporating inter-related sets of major scientific ideas as well as historical and contemporary case studies could provide a powerful and persuasive vehicle for emphasising the value of the narrative in communicating scientific ideas and in making those ideas more memorable. No 'explanatory stories' of this form exist within current curriculum provision.

Despite its apparent decline in National Curriculum terms, astronomy in English and Welsh primary schools remains popular, at least as far as can be determined from the professional articles which continue to appear on a regular basis (e.g. Sharp and Hitchin 1996; Ball 1999; Lund 1999; Phipps 1999; Stringer 1999; Marsh et al. 1999; Wilson 2000; Wilson and Wisbey 2000). It is suggested here, however, that its popularity does little to diminish its vulnerability. It is this author's opinion, based on the history of the development and evolution of the National Science Curriculum, that astronomy education provision remains vulnerable due to its minimalist presence within statutory documentation and the Scheme of

Work for Science at Key Stages 1 and 2, the incomplete and inadequate content and sequential structure of the content that currently exists, and the general lack of curricular expertise among primary teachers themselves. In addition, and according to de Boo (2001), the time for science and, therefore, by implication, the time for astronomy, is being unofficially cut by as much as 13% in some English primary schools in order to implement central Government's most recent drive towards improving literacy and numeracy (DfEE 1998b, 1999). With further reviews of the National Curriculum and the National Curriculum for primary science almost inevitable, past events suggest that the ultimate fate of astronomy remains uncertain. Interestingly, just as Luffiego et al. (1994) have offered an advanced schema-based model of learning involving extrapolation from dynamical systems theory and chaos, Macpherson (1995) has extended the notion of chaos to the belief that different theoretical, ideological and philosophical positions give rise to different types of curriculum 'attractor'. According to Macpherson, the role of chaos theory in science, engineering and economics has, for example, been productive in understanding complex, dynamic, non-linear systems and why things turn out the way they do. Macpherson wrote that 'the life-blood of institutional education does seem to be a sequence of powerful myths ... some of which are revivals of old ones and some of which seem to be novel, that are adopted with some passion for a few decades, run out of passion and are then replaced' and that attractors exist at all levels as a result of educational 'myth'. While not embraced by all, particularly those who claim that the practice of attaching novel scientific theories to matters far beyond what might be perceived as their legitimate zones of application (see Hunter and Benson 1997 with a rejoinder by Macpherson 1997), according to Macpherson, an 'attractor curriculum' can be identified and catalogued with reference to fundamental questions about curriculum design first proposed by Tyler (1949) including 'What are schools for?', 'What should the curriculum be like?', 'Who should design the curriculum?', 'Who should deliver the curriculum and how should they be selected and prepared?' and 'What are the mechanisms for compliance?'. While the national Curriculum, including the National Curriculum for primary science, can be closely identified with many of the 'attractor curricula' presented by Macpherson, it could be argued that the National Curriculum, including the National Curriculum for primary science, is its own 'attractor curriculum', one brought into being as a result of the centralization and politicization of education and directed by agenda of central Government as a result of the 'myths' of progressivism, topic work, learning by discovery, 'liberalism' and 'egalitarianism'; conditions of primary practice perceived by some

educational and political analysts as failing the education system miserably. Such 'attractors' are, however difficult, not impossible to change.

7.6 Summary

The research findings presented here, obtained from conducting a small-scale quasi-experimental study of knowledge acquisition and concept learning in one English primary school, attempted to identify, categorize, describe and measure children's ideas and mental models in the 'traditional' content areas of astronomy by means of elicitation. Within the context of the quasi-experimental design, and at first interview, the children in both the experimental and control groups presented a broadly similar range of ideas and models in each of the content areas probed. At second and third interviews, however, significantly greater levels of scientific conceptualization in most content areas among children in the experimental group, the group taught astronomy, were observed suggesting that, for those children at least, boys and girls, an acceptable scientific knowledge and understanding of sometimes complex and abstract astronomical information is attainable in the upper primary years of schooling and can be retained over time. This may be particularly true where the astronomy is taught by individuals with particular curricular expertise in the field, indicate a positive orientation towards science itself, and the teaching establishes something of a constructivist learning environment which pays due regard to the nature and importance of children's prior knowledge and understanding from the outset. That said, while significant gains were made in terms of children's ideas about what causes seasonal change and the phases of the Moon, scientific attainment remained low and retention was poor. Not only was the work undertaken within the experiment here successful in terms of detecting substantial progression in the experimental group both qualitatively and quantitatively, it was successful at an unprecedented level of detail. This was reflected in a number of different ways in different content areas but included linguistic, stylistic and descriptive variation associated with models of the Earth, the Sun and the Moon, the use of verbal descriptions, props and drawings associated with models of Earth-Sun-Moon System phenomena, the use of maps to depict the contents and structure of the Solar System, the differences in mean scores before and after the experimental treatment, mean score gains, score profile percentages, the implied conceptual and learning hierarchies observed, and so on. From the extended data set presented, progress towards scientific conceptualization could be further characterized, for the most part at least, and again with the exception of seasonal change and

the phases of the Moon, by coherency both within and between models with relatively little constraint, if indeed any at all, from entrenched ontological and epistemological presuppositions and beliefs. In addition, not only did the maps of knowledge acquisition and concept learning prepared provide a graphic illustration of 'constructivism in action' and the changes in response categories and mental models which took place over time, they also drew attention to the individuality, commonality, non-linearity and dynamic nature of learning astronomy as a whole. Perhaps the most exciting feature of the research findings presented here lay in the search for a causal mechanism to account for all of the learning attributes presented. Unfortunately, conventional schema theory and conventional theories of learning science including astronomy all lacked the explanatory power required at the level of detail established. A little known advanced schema-based systemic model of conceptual evolution based on the non-linear principles of dynamical systems theory and chaos was found which offered considerable promise. While it was certainly possible to draw comparisons between the overall nature of the empirical data and the interpretation of that data presented here and the notions of conceptual 'stability' and 'instability', information 'attractors' and 'final-states' of knowledge within the model proposed, however, the extent to which these comparisons provide confirmatory support reflecting a deeper significance or true test of the chaos model itself remains uncertain. Of course, as has been indicated before, despite all of the work undertaken, it is worth remembering that while experimental studies are in themselves relatively powerful in terms of what they set out to achieve, they are by no means perfect, and no single experimental approach can provide an irrefutable demonstration of cause and effect or result in unequivocal transferability, generalizability or representativeness. The replication of experimental approaches, especially those that seek to investigate different cause-effect relationships, together with approaches from within different research paradigms, are not only desirable but essential. Nevertheless, experimental studies such as this, rare though they are, do provide an essential evidence base for future comparative research and the desire to improve science education provision within the primary curriculum.

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Appendix I: Multiple Method Survey Instrument and Measurement System

The children's ideas in astronomy in this study were obtained using a multiple-method survey instrument administered in the form of largely structured one-to-one interviews. A combination of productive questions, shape selection, allowing individuals the opportunity to produce their own annotated drawings, focused activities involving the manipulation of props, picture recognition and, to a lesser extent, word association and concept mapping provided a relatively powerful and non-threatening combination of verbal and non-verbal techniques for exploiting explanatory strengths in different areas. Overall summaries of almost all techniques employed are provided by White and Gunstone (1992). The interview schedule containing the probes and interview items together with details of the coding and scoring adopted as a system of measurement are provided as follows.

1. Interview schedule

Children's Astronomy

School: **Year group:**

Name: **Age:** **Gender:**

Date:

Influences

TV/film/video

Book/comic/newspaper/magazine

Computer

Holiday

Play

Other (specify)

Earth probe

What shape is the Earth?

Is there a shape here that's most like the Earth?

How do you/other people know it's that shape?

Can you draw a picture of what you think the Earth would look like from space? (Box provided.)

What colour would it be?

What would you expect to see all around it?

How come we can't see the Earth's 'roundness' when we look out the window?

How big is the Earth?

Could anybody ever fall off the Earth? Have you ever heard of anybody falling off the Earth? (exploration of gravity.)

What is the Earth?

Picture recognition (obtained later in interview)?

Sun probe

What shape is the Sun?

Is there a shape here that's most like the Sun?

How do you/other people know it's that shape?

Can you draw a picture of what you think the Sun would look like from space? (Box provided.)

What colour would it be?

Does anything live on the Sun (exploration of conditions)?

How hot is the Sun?

Why is the Sun so bright and hot?

How big is the Sun?

What is the Sun?

Picture recognition (obtained later in interview)?

Moon probe

What shape is the Moon?

Is there a shape here that's most like the Moon?

How do you/other people know it's that shape?

Can you draw a picture of what you think the Moon would look like from space? (Box provided?)

What colour would it be?

Does anything live on the Moon (exploration of conditions)?

Does the Moon always appear that shape (exploration of phases)?

How long does it take for the Moon to appear to change shape (exploration of cycle)?

How big is the Moon?

What is the Moon?

Picture recognition (obtained later in interview)?

Relative size probe

Are the Earth, the Sun and the Moon all the same size or are they different? (Incorporated into Earth, Sun and Moon data separately.)

Day and night probe

What causes day and night (verbal)?

What causes day and night (props)?

What causes day and night (drawing – obtained after interview)?

How long does it take for that to happen (exploration of prop manipulation)?

How do you/other people know what causes day and night (interpretation of evidence)?

How long is a day?

Is there anywhere on the Earth that never gets daylight at all (exploration of variation)?

Seasonal change probe

What causes the seasons to change (verbal)?

What causes the seasons to change (props)?

What causes the seasons to change (drawing – obtained after interview)?

How long does it take for that to happen (exploration of prop manipulation)?

How long is a year?

When it's summer here is it summer all over the Earth at the same time?

Phases of the Moon probe

What causes the phases of the Moon (verbal)?

What causes the phases of the Moon (props)?

What causes the phases of the Moon (drawing – obtained after interview)?

How long does it take for that to happen (exploration of prop manipulation)?

How long is a month?

What is an eclipse?

Solar System and wider Universe probe

Besides the Earth, the Sun and the Moon, what else is there in space?

How many planets are there?

Which planets do you know?

Which planets can you identify (shown pictures of the Sun, the Moon and planets)?

Solar System 'map' (drawing of the Solar System).

Solar System features (colour, surface features, rings, moons, and so on).

Are all the planets the same size or are they different?

Are all the planets the same distance apart or are they different?

Do the planets move or do they stay where they are?

Why do they move around the Sun, why do they not just 'shoot off' into space (exploration of forces)?

Have all of these planets always been there or not? How were they formed (exploration of formation)?

Were all the planets formed at the same time or at different times (exploration of age of formation)?

2. Coding and scoring

The Earth

The Earth is the third planet from the Sun and unique in that it is currently the only planet in the Solar System known to support life. At a distance of about 150 million kilometres, and travelling at about 30 kilometres per second, the Earth orbits the Sun once every 365.25 days. The Earth also rotates on its axis once every 23 hours 56 minutes with a day and night cycle of 24 hours. The Earth's equatorial diameter measures 12 756 kilometres, about 42 kilometres more than the diameter measured from pole to pole. The Earth is, therefore, not entirely spherical in shape (oblate spheroid). About 70% of the Earth's surface is covered by water making it appear mostly blue when observed from space. Surface features on its land masses are wide and varied. Surface temperatures range from 60°C to –90°C. The Earth's atmosphere is dominated by nitrogen and oxygen with traces of other gases. The Earth has one moon, *the Moon*, its only natural satellite. The Earth has a gravitational attraction which

keeps our feet firmly on the ground wherever we stand. The Earth's gravitational attraction also keeps the atmosphere in place around it.

E1: Shape (verbal)

Correctness: the Earth is spherical or near-spherical in shape. Scoring: 0 – no response/not sure; 1 – round, circular, other appropriate 2D; 2 – spherical, like a ball, other appropriate 3D; 3 – 'sort of egg shaped'/other as appropriate.

E2: Shape (selection)

Correctness: sphere or sphere with qualification. Scoring: 0 – no response/not sure; 1 – any shape other than sphere; 2 – sphere; 3 – sphere with 'sort of', 'not quite', 'like this but', other as appropriate.

E3: Interpretation of evidence

Correctness: evidence should support spherical or near-spherical Earth. Scoring: 0 – no response/not sure; 1 – evidence provided sound but incorrectly interpreted; 2 – books, posters, video, TV, other, correctly interpreted; 3 – reference to space flight, lunar eclipses or ships at sea.

E4: Drawing

Correctness: view from space with land masses and oceans. Scoring: 0 – no drawing/not sure; 1 – blank 'circle', other; 2 – oceans and land masses other than Anglocentric or 'world map' shown; 3 – Anglocentric or 'world map' representation

E5: Colour

Correctness: from space, the Earth appears mostly blue. Scoring: 0 – no response/not sure; 1 – colours not including blue; 2 – blue and other colours for clouds, polar regions, land masses and oceans; 3 – colour depends on location of observer.

E6: 'Background'

Correctness: other astronomical objects against the blackness of space. Scoring: 0 – no response/not sure; 1 – astronomical objects not mentioned; 2 – selection from Sun, Moon, stars planets, blackness; 3 – all of Sun, Moon, stars planets, blackness

E7: 'Roundness'

Correctness: size of the Earth prevents its 'roundness' from being seen from surface. Scoring: 0 – no response/not sure; 1 – objects get in the way; 2 – reference to the Earth's size or the need to view from space; 3 – reference to lunar eclipse, horizon effects.

E8: Absolute size

Correctness: the Earth is 12 756 km in diameter. Scoring: 0 – no response/not sure; 1 – completely incorrect number; 2 – correct order of magnitude and approximation (e.g. thousands of kms); 3 – 12 756 km.

E9: Relative size

Correctness: the Sun is about 100 times the size of the Earth which is about 4 times the size of the Moon (diameters). Scoring: 0 – no response/not sure; 1 – incorrect sequence; 2 – S>E>M incorrect/without proportions; 3 – S>E>M correct proportions.

E10: Gravity

Correctness: the Earth's gravity is an invisible pulling force. Scoring: 0 – no response/not sure; 1 – objects/people fall from the Earth; 2 – implicit mention (e.g. nowhere to fall from) or explicit mention but incorrect (e.g. pushing force, like a magnet); 3 – explicit mention and correct (pulling force).

E11: Nature

Correctness: the Earth is a planet, an object which orbits the Sun. Scoring: 0 – no response/not sure; 1 – object other than planet; 2 – planet (label only/lack of orbit association); 3 – planet (orbits Sun).

E12: Picture recognition

Correctness: the Earth can be identified by its shape, colour, presence of oceans, atmosphere and land masses. Scoring: 0 – no response/not sure; 1 – wrong choice; 2 – correct choice based on any correct attribute; 3 – correct choice based on any correct attribute and with mention of specific continental outlines.

The Sun

The Sun is by far the most important feature of the Solar System and accounts for about 99.8% of its entire mass. With an equatorial diameter of about 1.4 million kilometres, the Sun is about 100 times the size of the Earth. The Sun's composition is very much dominated by hydrogen (74%) and helium (25%) with heavier elements making up the remainder (1%). Like all other typical stars, the Sun burns hydrogen in its core. The temperature within the core is about 15 million °C. The temperature nearer its outer margins is a mere 6000°C. The Sun is the only object within the Solar System which produces its own light. As the Sun is a

typical star it does not have a solid surface, it has layers of gas of different density. The outermost three include the photosphere, the chromosphere and the corona. The photosphere, the Sun's visible 'disk', varies in colour from yellow to red and has a granulated appearance due to the convection of hot gases from deep within the solar interior. Cooler areas of the photosphere which appear black are known as sunspots. Sunspots can reach up to tens of thousands of kilometres across. Sunspot studies reveals that the Sun rotates once every 25 days at its equator but once every 35 days at its poles. The chromosphere and the corona can only be seen during solar eclipses. Jets of glowing gas called prominences and flares of high energy radiation and atomic particles together form the Solar Wind which extends from the Sun's surface layers and reach far out into space.

S1: Shape (verbal)

Correctness: the Sun is spherical or near-spherical in shape. Scoring: 0 – no response/not sure; 1 – round, circular, other appropriate 2D; 2 – spherical, like a ball, other appropriate 3D; 3 – 'no real shape', 'roughly spherical'/other as appropriate.

S2: Shape (selection)

Correctness: sphere or sphere with appropriate qualification. Scoring: 0 – no response/not sure; 1 – any shape other than sphere; 2 – sphere; 3 – sphere with 'sort of', not quite', like this but', other as appropriate.

S3: Interpretation of evidence

Correctness: evidence should support spherical or near-spherical Sun. Scoring: 0 – no response/not sure; 1 – evidence sound but incorrectly interpreted; 2 - books, posters, video, TV, other, correctly interpreted; 3 – reference to telescopes, satellites, special equipment.

S4: Drawing

Correctness: view from space shows Sun's disk with heat/light representation. Scoring: 0 – no drawing/not sure; 1 – blank 'circle'; 2 – Sun's disk with any heat/light representation; 3 – Sun's disk with heat light representation as flares and prominences and/or sunspots.

S5: Colour

Correctness: from space, the Sun appears orange, yellow and red. Scoring: 0 – no response/not sure; 1 – colours other than yellow, orange or red; 2 – yellow, orange

or red or any combination of the three; 3 – yellow, orange, red and black (sunspots) or any combination including black.

S6: 'Life' (conditions)

Correctness:the Sun supports no known forms of life. Scoring: 0 – no response/not sure; 1 – reference to life including aliens; 2 – nothing lives on the Sun because it is too hot; 3 – nothing lives on the Sun for other appropriate reasons.

S7: Temperature

Correctness: the core temperature of the Sun is about 15 million °C, the surface temperature a mere 6000 °C. Scoring: 0 – no response/not sure; 1 – completely incorrect number; 2 – correct order of magnitude and approximation (e.g. millions or thousands of degrees); 3 – about 15 million °C or about 6000 °C.

S8: Source of heat and light

Correctness: the Sun's heat and light are produced by hydrogen burning in its core (nuclear fusion). Scoring: 0 – no response/not sure; 1 – inappropriate sources including reference to volcanism or being on fire; 2 – reference to gas burning (role of hydrogen and helium absent or confused); 3 – reference to gas burning or nuclear activity (role of hydrogen and helium implied and correct).

S9: Absolute size

Correctness: the Sun is 1.4 million kilometres in diameter. Scoring: 0 – no response/not sure; 1 – completely incorrect number; 2 – correct order of magnitude and approximation (e.g. hundreds of thousands of kilometres, a million kilometres); 3 – 1.4 million kilometres.

S10: Relative size

Correctness: the Sun is about 100 times the size of the Earth which is about 4 times the size of the Moon (diameters). Scoring: 0 – no response/not sure; 1 – incorrect sequence; 2 – S>E>M incorrect/without proportions; 3 – S>E>M correct proportions.

S11: Nature

Correctness: the Sun is a star, a ball of hot, glowing, burning gas. Scoring: 0 – no response/not sure; 1 – object other than a star; 2 – star (label only/ lack of other physical attributes); 3 – star (ball of hot/glowing/burning gas).

S12: Picture recognition

Correctness: the Sun can be identified by its relative size, shape, colour and other solar features (e.g. flares and prominences). Scoring: 0 – no response/not sure; 1 – wrong choice; 2 – correct choice based on size shape and colour only; 3 – correct choice based on size, shape, colour and other attributes.

The Moon

The Moon is the Earth's only natural satellite. At a distance of about 384 400 kilometres, and travelling at about 1 kilometre per second, the Moon orbits the Earth once every 27 days 7 hours. The Moon also rotates on its axis once every 27 days 7 hours explaining why only the Moon's 'near side' is ever seen. With an equatorial diameter of 3476 kilometres, the Moon is about 0.25 times the size of the Earth. Its heavily cratered surface and 'seas' or plains of old lava flows are its most prominent features. From space, the Moon is mostly grey and brown in colour. The Moon has no permanent atmosphere and no weather. Surface temperatures range from 130°C in direct sunlight to –180°C in darkness. Between 1969 and 1972, the Moon was visited and landed upon by American astronauts during six successful Apollo missions. Seismometers left behind at the Apollo landing sites have monitored meteoritic impacts and indicated seismic activity in the form of moonquakes. The Moon's gravitational attraction measures only one-sixth that of the Earth's. Gravitational forces between the Earth and the Moon (and the Sun) produce tides.

M1: Shape (verbal)

Correctness: the Moon is spherical or near-spherical in shape. Scoring: 0 – no response/not sure; 1 – banana, round, circular various, other appropriate 2D; 2 – spherical, like a ball, other appropriate 3D; 3 – 'almost spherical'/other as appropriate.

M2: Shape (selection)

Correctness: sphere or sphere with appropriate qualification. Scoring: 0 – no response/not sure; 1 – any shape other than sphere; 2 – sphere; 3 – sphere with 'sort of', not quite', like this but', other as appropriate.

M3: Interpretation of evidence

Correctness: evidence should support spherical or near-spherical Moon. Scoring: 0 – no response/not sure; 1 – evidence sound but incorrectly interpreted; 2 - books, posters, video, TV, other, correctly interpreted; 3 – reference to telescopes, satellites, special equipment, Moon landings.

M4: Drawing

Correctness: view from space shows Moon's craters and 'seas'. Scoring: Scoring: 0 – no drawing/not sure; 1 – blank 'circle'; 2 – Moon's disk with craters represented; 3 – Moon's disk with craters and 'seas'.

M5: Colour

Correctness: from space, the Moon appears mostly grey, brown and dusty. Scoring: 0 – no response/not sure; 1 – white, blue, yellow, silvery/other; 2 – grey, dusty; 3 – mention of brown.

M6: 'Life' (conditions)

Correctness: the Moon supports no known forms of life. Scoring: 0 – no response/not sure; 1 – too hot, too cold, no gravity or no water mentioned individually, reference to life including aliens; 2 – no air, no atmosphere, too hot, too cold, no water mentioned in combination; 3 – reference to scientific investigation including Moon landings.

M7: Phases

Correctness: the Moon is conventionally depicted as having a cycle of eight phases. Scoring: 0 – no response/not sure; 1 – up to three (including Full Moon, crescent and quarter phases); 2 – four or more phases (may be out of sequence); 3 – eight or more phases (in sequence).

M8: Cycle

Correctness: the Moon's phases change over a period of 29 days 12 hours. Scoring: *0 – no response/not sure; 1 – any response other than about one month; 2 – one month or about a month (including 4 weeks or equivalent in days); 3 - 29 days 12 hours.*

M9: Absolute size

Correctness: the Moon is 3476 kilometres in diameter. Scoring: 0 – no response/not sure; 1 – completely incorrect number; 2 – correct order of magnitude and approximation (e.g. few thousand kilometres); 3 – 3476 kilometres.

M10: Relative size

Correctness: the Sun is about 100 times the size of the Earth which is about 4 times the size of the Moon (diameters). Scoring: 0 – no response/not sure; 1 – incorrect sequence; 2 – S>E>M incorrect/without proportions; 3 – S>E>M correct proportions

M11: Nature

Correctness: the Moon is the Earth's only natural satellite. Scoring: 0 – no response/not sure; 1 – planet, star, asteroid, other; 2 – rock, ball of rock/dust; 3 – satellite.

M12: Picture recognition

Correctness: the Moon can be identified by its relative size, shape, colour and other lunar features (e.g. craters, 'seas'). Scoring: 0 – no response/not sure; 1 – wrong choice; 2 – correct choice based on craters only; 3 – correct choice based on craters and 'seas'.

Day and night

The parts of the Earth's surface that face towards the Sun are lit by it and experience day while the parts of the Earth's surface that face away from the Sun are in darkness and experience night. The day and night cycle is caused by the rotation of the Earth about its axis. Because the Earth always rotates the same way (anticlockwise looking 'down' on the North Pole), the Sun always appears to 'rise' at dawn generally towards the east and 'set' at dusk generally towards the west. The Earth rotates once every 23 hours 56 minutes. As it rotates, however, it is also moving in orbit around the Sun. As a result, the time from one 'sunrise' to the next, the day and night cycle, is 24 hours. Seasonal variations in where the Sun actually 'rises' and 'sets' and changes in the length of daylight hours throughout the year are due to the tilt of the Earth's axis. In the UK, the Sun 'rises' in the northeast, 'passes' at its highest in the sky, and 'sets' in the northwest. Days are long and nights are short (the Sun spends up to 18 hours above the horizon). In December, the opposite occurs. The northern hemisphere is tilted away from the Sun while the southern hemisphere is tilted towards it. In the UK, the Sun 'rises' in the southeast, 'passes' at its lowest in the sky, and 'sets' in the southwest. Days are short and nights are long (the Sun spends as few as 6 hours above the horizon). During March and September, the northern and southern hemispheres are tilted

neither towards nor away from the Sun. The Sun 'rise' due east and 'sets' due west. Day and night are of equal duration (the Sun spends 12 hours above the horizon).

DN1, 2 and 3: Day and night (verbal, use of props, drawing)

Correctness: the day and night cycle is caused by the Earth rotating about its axis. Scoring: 0 – no response/not sure; 1 – movement of the Earth uncertain, indication of movement of the Earth other than rotation or rotation but with other factors involved, involvement of the Sun and/or Moon rather than Earth rotation; 2 – clear indication of movement involving Earth rotation only (agreement in at least two out of three items); 3 – clear indication of movement involving Earth rotation with mention or other involvement of Earth's axis.

DN4: Period

Correctness: 24 hour cycle of day and night applies only to Earth rotation. Scoring: 0 – no response/not sure; 1 – 24 hour cycle indicated but in support of an incorrect model; 2 – 24 hour cycle indicated and in support of a correct model; 3 – mention of 23 hour 56 minute rotation.

DN5: Length of day

Correctness: the Earth rotates once every 23 hours 56 minutes, the day and night cycle (a 'day') takes 24 hours. Scoring: 0 – no response/not sure; 1 – any incorrect response; 2 – 24 hours; 3 – mention of 23 hour 56 minute rotation.

DN6: Variation in daylight hours

Correctness: variation in the length of daylight hours throughout the year is caused by the tilt of the Earth's axis in relation to its position in orbit around the Sun. Variation in the length of daylight hours at any point in time is a function of latitude. Scoring: 0 – no response/not sure; 1 – Earth rotation speeds up or slows down, Earth speeds up or slows down in its orbit around the Sun; 2 – variations linked to correct geographical locations (e.g. high/low latitudes, proximity to Arctic and Antarctic circles, polar regions); 3 – involvement of tilt of Earth's axis.

Seasonal change

In addition to causing variations in where the Sun 'rises' and 'sets' and the length of daylight hours throughout the year, the tilt of the Earth's axis relative to the plane of its orbit around the Sun also causes the annual cycle of seasonal change. This is achieved by affecting the

amount of solar energy received at the Earth's surface and troposphere. In the UK, the year long cycle of seasons includes spring (taken by astronomers to begin at the time of the spring equinox on the 21st of March when day and night are of equal duration), summer (taken by astronomers to begin at the time of the summer solstice on the 21st of June, the longest day), autumn (taken by astronomers to begin at the time of the autumnal equinox on the 22nd of September when day and night are of equal duration) and winter (taken by astronomers to begin at the time of the winter solstice on the 21st of December, the shortest day). In June, the northern hemisphere is tilted towards the Sun and experiences summer while the southern hemisphere is tilted away and experiences winter. In the UK, summer days are long and warm, the Sun 'rises' high above the horizon so the Sun's rays reach the surface of the Earth at a high angle, and the Earth is heated by the Sun for more than 12 hours and the Sun's heating effect is more efficient. In December, the opposite occurs. In the UK, winter days are cold and short, the Sun remains low above the horizon so the Sun's rays reach the surface of the Earth at a low angle, and the Earth heated by the Sun for less than 12 hours and the Sun's heating effect is less efficient. While the distance between the Sun and the Earth is about 150 million kilometres, there are times during its near-circular or elliptical orbit when it is closer and times when it is further away. Interestingly, at aphelion, when the Earth is furthest away (152 million kilometres), the northern hemisphere is tilted towards the Sun and experiences summer. The opposite is true at perihelion when the Earth is closest to the Sun (147 million kilometres). While distance does indeed make a difference to the amount of energy received from the Sun, the tilt of the Earth's axis is more significant.

SC1, 2 and 3: Seasonal change (verbal, use of props, drawing)

Correctness: seasonal change is caused by the tilt of the Earth's axis relative to the plane of its orbit around the Sun. Scoring: 0 –no response/not sure; 1 – objects get in the way of the Sun, the Earth and Sun move closer together, the Sun heats up and cools down, the Earth orbits the Sun but the role of the axis is not known with certainty, other; 2 – the Earth leans, tilts or faces towards the Sun in its orbit (agreement in at least two out of three items); 3 - clear indication with mention of involvement of Earth's axis as the Earth orbits the Sun.

SC4: Period

Correctness: annual cycle of seasons applies only to the Earth in orbit around the Sun. Scoring: 0 – no response/not sure; 1 – annual cycle indicated but in support of

an incorrect model; 2 – annual cycle indicated and in support of a correct model; 3 – mention of 365.25 day orbit.

SC5: Length of year

Correctness: the Earth orbits the Sun once every 365.25 days. Scoring: 0 – no response/not sure; 1 – any incorrect response; 2 – 12 months, 52 weeks, 365 days; 3 – 365.25 days.

SC6: Variation in seasons

Correctness: seasonal patterns vary across the world. The most notable variations occur between different hemispheres. Scoring: 0 – no response/not sure; 1 – mention of specific locations in isolation, focus of response may indicate weather rather than seasonal variation; 2 – mention of seasonal differences in specific locations in combination drawing attention to differences in hemispheres at the same time of year (e.g. UK and Australia); 3 - mention of specific locations in combination drawing attention to differences in hemispheres at the same time of year (e.g. UK and Australia) together with an appropriate explanation of why.

Phases of the Moon

Over a period of one lunar month, 29 days 12 hours, the Moon's shape appears to change in a regular and predictable way. A lunar month is longer than the Moon's rotation period by about 2 days because the Earth is moving in orbit around the Sun at the same time as the Moon is moving in orbit around the Earth. Like the Earth, the parts of the Moon's surface that face towards the Sun are lit by it and experience day (a lunar day) while the parts of the Moon's surface that face away from the Sun are in darkness and experience night (a lunar night). The apparent shapes or phases of the Moon are caused by the location of the Moon in its orbit around the Earth and the amount of the Moon's lit surface that can be seen by simply looking at it. From a new Moon, when the Moon is situated in orbit between the Earth and the Sun and not visible in the daytime sky, the Moon waxes or appears to 'grow' until it becomes full (the amount of visible surface increases through crescent, first quarter and gibbous phases). From a full Moon, when the Moon is situated in opposition to the Earth and the Sun and at its most visible in the night-time sky, the Moon wanes or appears to 'shrink' until it is not visible again (the amount of visible surface decreases through gibbous, last quarter and crescent phases). Total solar eclipses occur when the Moon is exactly positioned between the Sun and the Earth, and the Earth passes through the Moon's shadow. Solar

eclipses are spectacular events. While the Sun is about 400 times bigger than the Moon, it is also about 400 times further away from the Earth. Both the Sun and the Moon therefore appear the same size in the sky. The Moon covers the Sun's 'disk' perfectly and blocks out its light. Solar eclipses can only happen and be seen during the day. A total lunar eclipse occurs when the Earth is exactly positioned between the Sun and the Moon, and the Moon passes through the Earth's shadow. Lunar eclipses can only be seen from the Earth at night.

MP1, 2 and 3: Phases of the Moon (verbal, use of props, drawing)

Correctness: the phases of the Moon are caused by the location of the Moon in its orbit around the Earth and the amount of the Moon's sunlit side that can be observed by simply looking at it. Scoring: 0 – no response/not sure; 1 – Moon goes behind the Sun, clouds cover the Moon, objects get in the way, Earth shadow, other; 2 – Moon orbits the Earth (agreement in at least two out of three items); 3 - clear indication with mention of Moon orbiting the Earth with accurate descriptions of specific phases at specific locations.

MP4: Period

Correctness: the monthly cycle of phases applies only to the Moon in orbit around the Earth. Scoring: 0 – no response/not sure; 1 – lunar cycle indicated (e.g. one month) but in support of an incorrect model; 2 – lunar cycle indicated (e.g. one month) and in support of a correct model; 3 – mention of 29 day 12 hour orbit.

MP5: Length of month

Correctness: months vary from 28 to 31 days in length. Scoring: 0 – no response/not sure; 1 - any incorrect response; 4 weeks, 28, 30 or 31 days; 3 – 28, 30 and 31 days.

MP6: Eclipse

Correctness: Total solar eclipses occur when the Moon is exactly positioned between the Sun and the Earth, and the Earth passes through the Moon's shadow. A total lunar eclipse occurs when the Earth is exactly positioned between the Sun and the Moon, and the Moon passes through the Earth's shadow. Scoring: 0 – no response/not sure; 1 – object other than the Earth or Moon obscures the Sun; 2 – accurate description of Solar eclipse; 3 – accurate description of solar and lunar eclipse.

The Solar System and wider Universe

The Solar System is the name given to our nearest star, the Sun, together with its family of nine planets, their moons, and other objects. The planets of the Solar System are spherical or nearly spherical in shape and move around the Sun in nearly circular or elliptical orbits in the same direction (anticlockwise when viewed from 'above') and in pretty much the same plane. The planets are held in orbit around the Sun by the Sun's own gravitational pull. The planets are classified into two groups: the inner planets (Mercury, Venus, Earth and Mars) and the outer planets (Jupiter, Saturn, Uranus, Neptune and Pluto). The inner planets are also referred to as the terrestrial or rocky planets. The outer planets, with the exception of Pluto whose nature and origin is still uncertain, are also referred to as the Jovian planets or gas giants. Distances within the Solar System are not measured in light years but in astronomical Units (AU). 1AU is about 150 million kilometres or 93 million miles, the distance between the Sun and the Earth. Other objects within the Solar System, 'debris' not involved in the formation of planets and moons, include asteroids, comets and meteoroids. Most asteroids occupy a region of space between Mars and Jupiter known as the asteroid belt. Comets are essentially chunks of ice and other material that occupy a region of space well beyond the outer planets known as the Oort Cloud. Some comets travel in highly elliptical paths that bring them towards the inner planets as they orbit the Sun. Most meteoroids are particles of dust and rock fragments derived from comets. When a meteoroid enters the Earth's atmosphere it begins to burn up producing a trail known as a meteor or a shooting star. Meteoroids that survive and reach the Earth's surface are known as meteorites. The Universe is, quite literally, everything that exists: matter (from atoms and molecules to stars and galaxies); radiation (visible light together with the rest of the electromagnetic spectrum); and space (the vast 'emptiness' both within and between galaxies). The Universe is between about 12 and 15 billion years old. It most probably emerged from an explosive event generally referred to as the Big Bang. The Universe contains countless galaxies, assemblages of stars, nebulae and other interstellar material. Our own Sun, is located within a galaxy referred to as *the Galaxy* or the Milky Way. The Milky Way is also a term used to describe the faint band of stars that can be seen running across the sky on a clear night (the plane of the Galaxy viewed from within).

SS1: Contents (Solar System and wider Universe: focus on Solar System)

Correctness: the Solar System consists of the Sun, nine planets, moons, asteroids,

comets and meteoroids. Scoring: 0 – no response/not sure; 1 – range of objects mentioned but without planets; 2 – range of objects mentioned including planets; 3 - all Solar System components mentioned.

SS2: Number of planets

Correctness: there are currently nine planets in the Solar System. Scoring: 0 – no response/not sure; 1 – any incorrect response; 2 – nine; 3 – nine together with mention of others possible (e.g. Planet X).

SS3: Names of planets

Correctness: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto. Scoring: 0 – no response/not sure; 1 – selection provided; 2 – all nine provided; 3 – all nine provided together with details of others possible (e.g. Planet X).

SS4: Picture recognition

Correctness: children select planets from images drawn from familiar sources. Scoring: 0 – no response/not sure; 1 – selection of planets identified; 2 – all nine planets identified; 3 – all nine planets identified with consistently good evidence.

SS5: Solar System 'map' (drawing)

Correctness: drawings of the Solar System show all Solar System objects indicated earlier. Scoring: 0 – no response/not sure; 1 – at least the Sun and planets shown but incomplete or incorrectly sequenced; 2 – at least the Sun and planets shown, complete and correctly sequenced; 3 – Sun, planets and most other objects shown.

SS6: Features

Correctness: drawings and/or descriptions of the Solar System highlight surface features, colours, moons, and rings. Scoring: 0 – no response/not sure; 1 – limited number of features shown (e.g. one or two); 2 – extended number of features shown (e.g. three or four but incomplete); 3 – all features shown and complete.

SS7: Relative sizes of planets

Correctness: drawings and/or descriptions highlight relative differences between gas giants and other planets. Scoring: 0 – no response/not sure; 1 – no indication of relative size/ largest and smallest planets incorrect; 2 – clear indication of relative size/Jupiter known to be the largest planet and Pluto the smallest; 3 – clear indication of relative size/selection of planets described accurately (some absolute sizes offered accurately).

SS8: Relative distances between planets

Correctness: drawings and/or descriptions highlight relative distances between planets. Scoring: 0 – no response/not sure; 1 – all planets equidistant; 2 – clear indication of relative distances; 3 – clear indication of relative distances (some absolute distances offered accurately).

SS9: Movements of planets

Correctness: all nine planets orbit the Sun in the same direction and in roughly the same plane but the orbital periods vary. Scoring: 0 – no response/not sure; 1 – some or all planets orbit the Sun but at the same time or in different directions; 2 – all planets orbit the Sun in the same direction but with different orbital periods (the orbital periods of Mercury and Pluto may be given in relative terms); 3- all nine planets orbit the Sun in the same direction and with different orbital periods (the orbital periods of Mercury and Pluto may be given in absolute terms).

SS10: Forces

Correctness: all planets within the Solar System are kept in orbit around the Sun because of the Sun's gravitational attraction. Scoring: 0 – no response/not sure; 1 – causal factor other than gravity; 2 – simple mention of gravity; 3 – extended mention of the Sun's gravitational attraction as a pulling force or comparison with the Earth's gravitational attraction.

SS11: Age of Solar System

Correctness: the Solar System is about 4.6 billion years old. Scoring: 0 – no response/not sure; 1 – incorrect response; 2 - correct order of magnitude and approximation (e.g. few billions of years old); 3 – 4.6 billion years.

SS12: Formation of Solar System

Correctness: the Solar System formed from a collapsing and rotating cloud of gas, ice and dust. Scoring: 0 – no response/not sure; 1 – response indicates always been there or inappropriate links with Big Bang; 2 – Sun and planets formed from gas and dust, appropriate links with Big Bang (e.g. chronology); 3 – extended formation history including collision and accretion of materials.

Appendix II: Curricular Expertise

This appendix contains background notes associated with the development of teachers' curricular expertise in science together with details of the survey questionnaire developed by Summers and Mant (1995a) which was used to test Jack's subject knowledge of astronomy. The background notes supplement the information provided within the main body of the text and should be considered alongside them rather than on their own.

1. Subject knowledge and subject related pedagogy

Perhaps the most widely reported and instructive case of teachers acquiring curricular expertise was provided by Neale et al. (1990). (See also Smith and Neale 1989, 1991.) In this study, undertaken in the USA, eight teachers in grades K-3 (c.5-8 year olds) attended a four week summer in-service programme designed to develop their subject and subject-related pedagogical knowledge prior to implementing and teaching a two week conceptual change unit on light and shadows. All of the teachers were described as experienced (5-27 years service) and all but one were female. The classes they taught varied in size from 21 to 28 (mixed ability with 25-42% from ethnic minority backgrounds). At the time, conceptual change or constructivist teaching strategies were of particular interest because of the growing evidence that children brought with them their own ideas to the study of school science and that these ideas were 'powerful determinants' of what children gained from teaching. It was thought, however, that conceptual change or constructivist teaching would place heavy demands on the teachers whose belief systems in science were described as largely discovery oriented. While the teachers participating were considered competent in using strategies which matched their beliefs, implementing new strategies might return them to novices. In this respect they were regarded as 'cognitive apprentices'. During their 'apprenticeship', the new strategies were modelled by demonstration and observing expert conceptual change teachers at work. Scaffolding was provided by limiting training to a restricted amount of subject matter, by trial teaching with small groups of children, and by providing coaching in planning and teaching their own classes. The work was monitored and analysed using videotapes of lessons, interviews that measured children's pre- and post-unit changes, and teachers written evaluations of the unit. In summary:

- all eight of the teachers were able to implement the conceptual change unit in their classrooms in the way they were trained and continue to use the strategies involved for up to one year afterwards before any 'slippage' was noticed;
- the exact nature of implementation varied but the teachers largely used their new conceptual change or constructivist teaching strategies successfully;
- children's attainments in the areas taught and learned was considered significant.

Most of the teachers involved reported tackling their own subject knowledge and subject related pedagogy demanding and that adopting a similar approach over extended units and areas would be challenging. Broadly similar findings have since been reported elsewhere (Asoko 1993, 1996; Appleton and Asoko 1996; Summers et al. 1998).

In a two-year longitudinal study of the development of primary teachers' knowledge and understanding of targeted aspects of forces and energy within the National Science Curriculum, Summers and Kruger (1994) explored to what extent the non-science specialist or generalist can achieve 'non-trivial' and lasting scientific ideas and views. In many respects, this work represented the culmination of the Oxford-based Primary School Teachers and Science (PSTS) project to develop teacher education materials to help teachers to improve their knowledge and understanding of science. Fifty three primary teachers participated in what was described as a 'short burst' of in-service training with the research team (4 x 2-hour sessions with independent and supported self-study). All of the teachers were interviewed immediately before the training, one to three weeks afterwards, and six to twelve months later. Questionnaires and a variety of other techniques were used. The training incorporated evidence-based strategies which were very definitely constructivist in nature (Kruger et al. 1991a, b). These included elicitation, generating dissatisfaction with existing ideas and views, generating better alternatives, and consolidating and applying new knowledge. Activities required teachers to explore children's ideas and views and become aware of their own, and to confront and consider scientific ideas and views through discussion, social interaction, metacognition and the use of analogy. The results were very interesting:

- following in-service training, almost all of the teachers had moved from relatively little knowledge and understanding in certain aspects of forces and energy towards scientific ideas and views (some substantially, some modestly, some partially);
- some of the targeted concepts were more easily acquired than others;
- the co-existence of scientific and intuitive views and the inconsistency in their use and application was evident;
- some teachers' scientific ideas and view regressed over time (short term gains not retained with time);
- some teachers' misconceptions were retained even after intensive training and some developed new misconceptions as a result of it.

By the end of the training, many teachers reported that they were more sensitive to learning difficulties in science than before and they acknowledged children's ideas and views as valuable starting points. The research team went on to consider how to continue to support teachers following a period of science training given the lack of recognition of the time and effort this takes and the design and content of the National Science Curriculum in terms of the conceptual demands for teachers as well as for children.

Adopting a broader perspective, Parker and Haywood (2000) documented the case of forty four graduate PGCE trainees and thirty practising primary teachers learning about forces in the context of floating and sinking and the challenges faced in helping them to develop their own knowledge and understanding of the science content involved as well as translating that into effective teaching. Through a combination of structured questions, personal reflection and practical investigation, Parker and Haywood were able to explore not only how the trainees and teachers reasoned and thought about floating and sinking but how that reasoning and thinking was influenced through the teaching and learning experiences they encountered. With this approach, the trainees and teachers were able to identify valuable implications for their own teaching. Not only did the trainees and teachers develop and internalize coherent and causal explanations for floating and sinking, the explanations clearly provided the convincing rationale for their own observations and ideas. Parker and Haywood surmised that in this way, the trainees and teachers would be better placed to draw parallels between their own learning and how children learn and thus be better equipped to ascertain and challenge children's ideas in productive ways, know about the inherent difficulties children

have in particular areas of science, identify what children might see as abstract and how best to represent subject matter at the teaching interface.

Interestingly, and from the foregoing notes here and in the main body of the text, certain parallels can be drawn between teachers' curricular expertise and the expert-novice subject studies from within psychology. In problem solving in physics, for example, experts have been found to consistently remember better, have greater strategic knowledge and work problems forwards (forward chaining analysis) rather than backwards (means-end analysis), represent problems in different ways, complete tasks more quickly, and become expert by practising more (Larkin et al. 1980; Chi et al. 1981; Green and Gilhooly 1992; Snyder 2000). In one study involving the Earth and space sciences, Barba and Rubba (1993) compared the declarative, procedural and structural knowledge used by six expert and six novice Earth and space science teachers from high schools in eastern Pennsylvania. In summary, Barba and Rubba's study demonstrated:

- the experts brought more declarative knowledge to each problem than novices;
- experts used fewer steps to solve each problem and recognized non-productive solutions more rapidly than novices;
- experts generated more alternative solutions than novices;
- experts solved each problem more accurately than novices.

Among the implications discussed, Barba and Rubba suggested that while it might be improper to suggest that novices would not make good Earth and space science teachers, caution over using minimally trained Earth and space science teachers or teachers trained in other disciplines was advised. Broadly similar findings have also been recorded in psychological studies of expert-novice teachers. Expert teachers display a different level of professional expertise in the classroom, the professional knowledge that they bring with them allows them to interpret classroom situations and activity more accurately and deal with situations more speedily and effectively, they read classrooms better, their knowledge is more elaborate, more complex, more interconnected and more easily accessible than novices and experts have larger and better integrated stores of facts, principles and experience on which to draw upon as they plan, teach, assess and reflect (Carter et al. 1987; Livingston and Borko 1989; Swanson et al. 1990). Interestingly, the relationship between the terms expert,

experienced and specialist is not entirely clear and their frequent use as synonyms should be avoided.

It is interesting to note that in studies undertaken in the UK, USA, Canada and Sweden, all attempts to clarify, influence or change primary teachers' beliefs and attitudes towards science and the teaching and learning of science (pre- and in-service) have met with only limited and short-lasting success (Smith and Neale 1989; Carré 1993; Abell and Smith 1994; Gustafson and Rowell 1995; McComos 1998; Wolf-Watz 2000). Part of the difficulty appears to lie in the fact that experts themselves have difficulty in presenting a cogent and comprehensive picture of the nature of science and the teaching and learning of science and clarifying the teachers' pivotal role in initiating discussion about what science is and how scientists work (Chalmers 1978; Nussbaum 1989; Selley 1989; Dunbar 1995; Smith and Scharmann 1999; Bianchini and Colburn 2000). Such is the importance of this matter that calls for empirical research to explore all of the issues raised and the factors involved are now being made (e.g. Abd-El-Khalick and Lederman 2000).

2. Survey questionnaire

The Summers and Mant (1995a) survey questionnaire used to test Jack's subject knowledge and understanding of astronomy is reproduced in part below. All of the response categories provided have been omitted. Correct answers and the numbers of participants who answered correctly in the original survey are shown (n=120). Jack completed the survey questionnaire at home and in his own time, a departure from the 'test' conditions imposed by the original authors. While a good subject knowledge of science is important for science teaching itself, subject related pedagogy is equally so. A review of relevant studies is also provided.

Background

1. Gender? Male
2. Years' teaching experience? 15
3. Teaching qualifications? PGCE
4. Main subject? Science
5. Previous astronomy teaching experiences? Three terms

Section A: Observations of the sky

Imagine that you are outside somewhere in the UK and looking at the sky.

1. In which direction do you need to look to see the Sun rising? (East 114)
2. In which direction do you need to look to see the Sun setting? (West 114)
3. The Sun always follows the same path through the sky. (False 60)
4. At midday, in which direction do you need to look to see the Sun? (South 53)
5. In summer, the Sun travels further through the sky than in winter. (True 40)
6. The places on the horizon where the Sun rise and sets do not change. (False 55)
7. The Sun is directly overhead at midday. (Never 15)
8. I know exactly where to look for the Moon in the sky. (Exactly 3)
9. When the Moon is visible, it is always in the same place in the sky. (False 81)
10. The Moon is only visible at night. (False 115)
11. The Moon appears to move across the sky. (True 81)
12. The Moon appears to rise and set daily. (True 63)
13. The Moon appears to move across the sky from north to south. (False 21)
14. The Moon appears to follow roughly the same path as the Sun across the sky. (True 7)
15. When it is dark and there are no clouds in the sky, the Moon is always visible. (False 71)
16. If the Moon looked like a circle, one week later it would look like a semi-circle. (True 42)
17. If you look at the sky for one night, the stars are always in the same place. (False 21)
18. If you look at the sky for one night, some stars appear to move in circles. (True 20)
19. The planets are too far away to be seen in the sky. (False 86)
20. Planets look like dots of light, like stars. (True 77)

Section B: Explanations of day and night, the seasons and the phases of the Moon

21. The Sun goes around the Earth once in 24 hours. (False 109)
22. We have daytime when we are facing the Sun. (True 105)
23. The Earth turns around on a line from the north to the south pole once in 24 hours. (True 74)
24. The Moon has something to do with the reason for day and night. (False 91)
25. The Earth moves around the Sun once in 24 hours. (False 76)

26. In the summer it is hotter because we are closer to the Sun. (False 20)
27. The Sun moves around the Earth in a circle in one year. (False 102)
28. The Earth moves backwards and forwards in a line, towards and away from the Sun in a year. (False 94)
29. The Earth moves around the Sun in one year. (True 98)
30. In summer, in Britain, the Earth's north pole is slanted towards the Sun. (True 67)
31. If the Earth had no atmosphere, there would be no seasons. (False 39)
32. In winter, it is colder because the heat from the Sun is spread out more. (True 32)
33. The Moon does not move. (False 94)
34. The Moon moves around the Earth. (True 88)
35. We see the Moon because it reflects light from the Sun. (True 101)
36. The Moon appears to change shape because it moves into the Earth's shadow. (False 15)
37. As the Sun sets, the Moon rises. (False 76)
38. The Moon appears to have a different shape because something blocks the Moon preventing all of it from being seen. (False 43)
39. Half the Moon is illuminated by the Sun (True 49)
40. The proportion of the Moon seen on Earth depends on where the Sun, Moon and Earth are relative to each other. (True 108)

Section C: The scale of the Solar System

41. Imagine that the Sun is as big as a large ball – a basket ball about 25cm in diameter. How big do you think the Earth would be on the same scale? (2-3mm 38)
42. On the same scale again, how far away would the Earth be from the Sun? (30m 11)
43. How big is the Moon compared to the Earth? (Smaller 102)

Section D: The Solar System and Universe

44. The planets are at different distances from the Earth and they do not move. (False 93)
45. The planets move around the Earth. (False 97)
46. The planets are dotted around in space and move backwards and forwards in a line. (False 96)
47. The planets are different distances from the Sun. (True 118)
48. The planets move around the Sun. (True 99)

49. Stars are hanging around in space in the Solar System and beyond. (False 31)
50. Planets are always there, whereas stars are something which happened a long time ago and no longer exist. (False 62)
51. Stars are the same as planets but are out of the Solar System. (False 78)
52. Stars are planets in their early stages. (False 79)
53. Stars give out heat and light and planets don't. (True 44)
54. Stars go around planets. (False 69)
55. The stars are a long way away from the Solar System. (True 43)
56. Some stars are nearer, and some stars are further away than the planets. (False 40)
57. The Sun is a star. (True 92)

Appendix III: Nature of Science Profile

According to Nott and Wellington (1993), the way that teachers present and teach science in the classroom may be linked to their actual knowledge and understanding of the nature of science itself. Their 24-statement questionnaire is reproduced below. Jack completed his nature of science profile at home and in his own time. The category axes together with Jack's original and untransformed responses are provided (RP relativism – positivism; ID inductivism – deductivism; CD contextualism – decontextualism; PC process – content; IR instrumentalism – realism). In completing the activity, Jack was asked to give each statement a number ranging from +5 (strongly agree) to –5 (strongly disagree).

1. The results that pupils get from their experiments are as valid as anybody else's. (RP +3)
2. Science is essentially a masculine construct. (CD –5)
3. Science facts are what scientists agree that they are. (CD RP +4)
4. The object of scientific activity is to reveal reality. (IR +3)
5. Scientists have no idea of the outcome of an experiment before they do it. (ID –4)
6. Scientific research is economically and politically determined. (CD +3)
7. Science education should be more about the learning of scientific processes than the learning of scientific facts. (PC 0)
8. The processes of science are divorced from moral and ethical considerations. (CD –5)
9. The most valuable part of a scientific education is what remains after the facts have been forgotten. (PC +1)
10. Scientific theories are valid if they work. (IR –1)
11. Science proceeds by drawing generalizable conclusions (which later become theories) from available data. (ID 0)
12. There is such a thing as a scientific theory. (RP, IR 0)
13. Human emotion plays no part in the creation of scientific knowledge. (CD –2)
14. Scientific theories describe a real external world which is independent of human perception. (RP, IR –3)
15. A good solid grounding in basic scientific facts and inherited scientific knowledge is essential before young scientists can go on to make discoveries of their own. (PC –2)
16. Scientific theories have changed over time simply because experimental techniques have improved. (RP, CD –2)
17. Scientific method is transferable from one scientific investigation to another. (PC +3)

18. In practice, choices between competing theories are made on the basis of experimental results. (CD, RP –2)
19. Scientific theories are as much a result of imagination and intuition as inference from experimental results. (ID +1)
20. Scientific knowledge is different from other kinds of knowledge in that it has higher status. (RP +1)
21. There are certain physical events in the Universe that science can never explain. (RP, IR +1)
22. Scientific knowledge is morally neutral, only the application of the knowledge is ethically determined. (CD +4)
23. All scientific experiments and observations are determined by existing theories. (ID +1)
24. Science is essentially characterized by the methods and processes it uses. (PC +1)

Nott and Wellington provide definitions of the categories which are summarized as follows:

Relativism-Positivism

Relativism

You deny that things are true or false solely based on an independent reality. The truth of a theory will depend on the norms and rationality of the social group considering it as well as the experimental techniques used to test it. Judgements as to the truth of scientific theories will vary from individual to individual and from one culture to another i.e. truth is relative not absolute.

Positivism

You believe strongly that scientific knowledge is more valid than other forms of knowledge. The laws and theories generated by experiments are our descriptions of patterns we see in a real, external objective world. Science is the primary source of truth.

Inductivism-Deductivism

Inductivism

You believe that the scientists job is the interrogation of nature. By observing many particular instances, one is able to infer from the particular to the general and then to determine the underlying laws and theories i.e. scientists generalize inductively.

Deductivism (or hypothetico-deductivism)

You believe that scientists proceed by testing ideas produced by the logical consequences of current theories or of their bold imaginative ideas. Scientific reasoning consists of forming hypotheses which are not established by empirical data but suggested by them. Science then tests the observable consequences of these hypotheses i.e. scientists generalize deductively

Contextualism-Decontextualism

Contextualism

You hold the view that the truth of scientific knowledge is interdependent with the culture in which scientists live and in which it takes place.

Decontextualism

You hold the view that scientific knowledge is independent of its cultural location and sociological structure.

Process-Content

Process

You see science as a characteristic set of identifiable methods or processes. The learning of these is the essential part of science education.

Content

You think that science is characterized by the facts and ideas it has and that the essential part of science education is the acquisition and mastery of this body of knowledge.

Instrumentalism-Realism

Instrumentalism

You believe that scientific theories and ideas are fine if they work, that is they allow correct predictions to be made. They are instruments which we can use but they say nothing about an independent reality or their own truth.

Realism

You believe that scientific theories are statements about a world that exists in space and time independent of the scientists' perceptions. Correct theories describe things which are really there, independent of the scientists.

Appendix IV: Goodenough-Harris Drawing Test

Within the Goodenough-Harris Drawing test (Harris 1963), the Draw-a-Man point scale consists of 73 items which are credited (0 or 1) on the basis of presence or absence of a body part or attention to specific detail. The Draw-a-Woman point scale consists of 71 items which are credited similarly. Single raw scores for each drawing are obtained by simply adding all credited points. Raw scores are converted to standard score equivalents with a mean of 100 and a standard deviation of 15 using separate tables for the drawings of Men and Woman produced by boys and girls. Standard scores on the Man and Woman drawings can be averaged directly. The short scoring guides for Man and Woman drawings, used when researchers have become familiar with scoring procedures, are reproduced here.

(a) Short scoring guide: Man drawing point scale

1. Head present
2. Neck present
3. Neck, two dimensions
4. Eyes present
5. Eye detail: brow or lashes
6. Eye detail: pupil
7. Eye detail: proportions
8. Eye detail: glance
9. Nose present
10. Nose, two dimensions
11. Mouth present
12. Lips, two dimensions
13. Both nose and lips in two dimensions
14. Both chin and forehead shown
15. Projection of chin shown; chin clearly differentiated from lower lip
16. Line of jaw indicated
17. Bridge of nose
18. Hair I
19. Hair II
20. Hair III
21. Hair IV
22. Ears present
23. Ears present: proportion and position
24. Fingers present
25. Correct number of fingers shown
26. Detail of fingers correct
27. Opposition of thumb shown
28. Hands present
29. Wrist or ankle shown
30. Arms present
31. Shoulders I
32. Shoulders II
33. Arms at side or engaged in activity
34. Elbow joints shown
35. Legs present
36. Hips I: crotch
37. Hips II
38. Knee joint shown
39. Feet I: any indication
40. Feet II: proportion
41. Feet III: heel
42. Feet IV: perspective
43. Feet V: detail
44. Attachment of arms and legs I
45. Attachment of arms and legs II
46. Trunk present
47. Trunk in proportion, two dimensions
48. Proportion: head I
49. Proportion: head II
50. Proportion: face
51. Proportion: arms I
52. Proportion: arms II
53. Proportion: legs
54. Proportion: limbs in two dimensions
55. Clothing I
56. Clothing II
57. Clothing III
58. Clothing IV
59. Clothing V
60. Profile I
61. Profile II
62. Full face
63. Motor co-ordination: lines
64. Motor co-ordination: junctures
65. Superior motor co-ordination
66. Directed lines and form: head outline
67. Directed lines and form: trunk outline
68. Directed lines and form: arms and legs
69. Directed lines and form: facial features
70. Sketching technique
71. Modelling technique
72. Arm movement
73. Leg movement

(b) Short scoring guide: Woman drawing point scale

1. Head present	27. Elbow joint shown	51. No transparencies in figure
2. Neck present	28. Fingers present	52. Garb feminine
3. Neck, two dimensions	29. Correct number of fingers shown	53. Garb complete without incongruities
4. Eyes present	30. Detail of fingers correct	54. Garb a definite type
5. Eye detail: brow or lashes	31. Opposition of thumb shown	55. Trunk present
6. Eye detail: pupil	32. Hands present	56. Trunk in proportion, two dimensions
7. Eye detail: proportions	33. Legs present	57. Head-trunk proportion
8. Cheeks	34. Hip	58. Head: proportion
9. Nose present	35. Feet I: any indication	59. Limbs: proportion
10. Nose, two dimensions	36. Feet II: proportion	60. Arms in proportion to trunk
11. Bridge of nose	37. Feet III: detail	61. Location of waist
12. Nostrils shown	38. Shoe I: feminine	62. Dress area
13. Mouth present	39. Shoe II: style	63. Motor co-ordination: junctures
14. Lips, two dimensions	40. Placement of feet appropriate to figure	64. Motor co-ordination: lines
15. Cosmetic lips	41. Attachment of arms and legs I	65. Superior motor co-ordination
16. Both nose and lips in two dimensions	42. Attachment of arms and legs II	66. Directed lines and form: head outline
17. Both chin and forehead shown	43. Clothing indicated	67. Directed lines and form: breast
18. Line of jaw indicated	44. Sleeve I	68. Directed lines and form: hip contour
19. Hair I	45. Sleeve II	69. Directed lines and form: arms taper
20. Hair II	46. Neckline I	70. Directed lines and form: calf of leg
21. Hair III	47. Neckline II: collar	71. Directed lines and form: facial features
22. Hair IV	48. Waist I	
23. Necklace or earrings	49. Waist II	
24. Arms present	50. Skirt modelled to indicate pleats or draping	
25. Shoulders		
26. Arms at side or engaged in activity (behind back)		

			Experimental group								Control group				
			Raw score		Standardized score					Raw score		Standardized score		
Name	Sex	Age	Man	Woman	Man	Woman	Average	Name	Sex	Age	Man	Woman	Man	Woman	Average
1. Adam	m	135	28	23	87	78	83	1. Andrew	m	132	28	31	87	90	89
2. Brendan	m	134	38	32	101	92	97	2. Ben	m	131	28	30	90	92	91
3. Chris	m	133	42	42	106	107	107	3. Charlie	m	128	31	40	95	108	102
4. David	m	133	30	23	90	78	84	4. Dominic	m	128	28	23	90	80	85
5. Edward	m	133	31	34	91	95	93	5. Eamon	m	127	39	45	107	116	112
6. Francis	m	132	34	33	95	93	94	6. Freddie	m	127	20	24	78	82	80
7. Grant	m	131	30	31	93	93	93	7. George	m	127	45	39	116	107	112
8. Harry	m	128	31	32	95	95	95	8. Hugh	m	126	44	46	115	118	117
9. Ian	m	128	31	34	95	98	97	9. Ivor	m	126	27	31	89	93	91
10. James	m	127	41	41	110	110	110	10. John	m	125	36	34	102	98	100
11. Keith	m	126	46	39	118	107	113	11. Kevin	m	125	36	40	102	108	105
12. Liam	m	119	40	47	116	127	122	12. Lawrence	m	124	39	31	107	93	100
13. Matthew	m	119	35	33	107	102	105	13. Mark	m	124	33	28	98	89	94
14. Nigel	m	118	30	31	99	98	99	14. Neville	m	122	29	31	92	93	93
15. Oliver	m	117	35	35	107	105	106	15. Oscar	m	120	42	32	111	95	103
16. Peter	m	117	36	34	109	103	106	16. Paul	m	119	36	28	109	93	101
17. Roger	m	117	34	34	105	103	104	17. Richard	m	112	30	34	99	103	101
18. Alice	f	131	30	36	90	94	92	18. Anna	f	135	30	32	84	82	83
19. Bethan	f	131	35	41	98	102	100	19. Brianne	f	134	35	44	92	101	97
20. Claire	f	130	33	40	95	101	98	20. Carol	f	131	35	32	98	88	93
21. Deirdre	f	130	42	41	109	102	106	21. Doreen	f	130	37	37	101	96	99
22. Eve	f	126	46	32	116	88	102	22. Eugenie	f	129	39	38	104	97	101
23. Faith	f	125	35	41	98	102	100	23. Felicity	f	127	44	40	112	101	107
24. Grace	f	124	38	38	103	97	100	24. Gemma	f	127	39	42	104	104	104
25. Hannah	f	122	29	35	88	93	91	25. Harriet	f	124	27	25	85	77	81
26. Imogen	f	122	23	31	79	86	83	26. Isobel	f	119	42	42	118	111	115
27. Jessica	f	122	47	46	117	110	114	27. Joyce	f	116	38	36	111	101	106
28. Katy	f	119	31	35	98	100	99	28. Karen	f	116	35	32	105	94	100
29. Lucy	f	117	36	41	107	110	109	29. Larissa	f	113	33	42	102	111	107
30. Monica	f	113	38	33	111	96	104	30. Maeve	f	112	30	29	97	89	93
31. Nicky	f	112	32	36	100	101	101	31. Nuala	f	112	33	38	102	105	104

Point scores for drawings of the human figure at test

			Experimental group								Control group				
			Raw score		Standardized score						Raw score		Standardized score		
Name	Sex	Age	Man	Woman	Man	Woman	Average	Name	Sex	Age	Man	Woman	Man	Woman	Average
1. Adam	m	138	30	28	90	85	88	1. Andrew	m	135	26	30	84	89	87
2. Brendan	m	137	40	40	103	104	104	2. Ben	m	134	27	32	85	92	89
3. Chris	m	136	45	46	110	114	112	3. Charlie	m	131	27	32	89	95	92
4. David	m	136	28	34	87	95	91	4. Dominic	m	131	21	26	79	85	82
5. Edward	m	136	30	39	90	103	97	5. Eamon	m	130	48	38	121	105	113
6. Francis	m	135	37	37	99	100	100	6. Freddie	m	130	26	27	87	87	87
7. Grant	m	134	31	31	91	90	91	7. George	m	130	39	38	107	105	106
8. Harry	m	131	40	38	108	105	107	8. Hugh	m	129	42	38	111	105	108
9. Ian	m	131	39	34	107	98	103	9. Ivor	m	129	25	33	86	97	92
10. James	m	130	43	40	113	108	111	10. John	m	128	44	43	115	113	114
11. Keith	m	129	39	38	107	105	106	11. Kevin	m	128	37	31	104	93	99
12. Liam	m	122	42	46	111	118	115	12. Lawrence	m	127	36	32	102	95	99
13. Matthew	m	122	31	30	95	92	94	13. Mark	m	127	32	33	96	97	97
14. Nigel	m	121	35	35	101	100	101	14. Neville	m	125	32	38	96	105	101
15. Oliver	m	120	36	37	102	103	103	15. Oscar	m	123	37	36	104	102	103
16. Peter	m	120	36	36	102	102	102	16. Paul	m	122	30	36	93	102	98
17. Roger	m	120	31	34	95	98	97	17. Richard	m	115	30	36	99	107	103
18. Alice	f	134	40	39	100	93	97	18. Anna	f	138	28	36	81	88	85
19. Bethan	f	134	37	43	95	99	97	19. Brianne	f	137	34	40	91	95	93
20. Claire	f	133	36	43	94	99	97	20. Carol	f	134	33	38	89	91	90
21. Deirdre	f	133	47	45	110	103	107	21. Doreen	f	133	36	42	94	98	96
22. Eve	f	129	45	34	114	91	103	22. Eugenie	f	132	38	34	97	85	91
23. Faith	f	128	33	41	95	102	99	23. Felicity	f	130	43	41	111	102	107
24. Grace	f	127	38	38	103	97	100	24. Gemma	f	130	36	43	100	105	103
25. Hannah	f	125	31	39	91	99	95	25. Harriet	f	127	32	35	93	93	93
26. Imogen	f	125	33	40	95	101	98	26. Isobel	f	122	42	52	109	120	115
27. Jessica	f	125	45	44	114	107	111	27. Joyce	f	119	32	31	100	93	97
28. Katy	f	122	33	26	95	78	87	28. Karen	f	119	34	31	104	93	99
29. Lucy	f	120	40	39	106	99	103	29. Larissa	f	116	32	37	100	103	102
30. Monica	f	116	33	36	102	101	102	30. Maeve	f	115	31	32	98	94	96
31. Nicky	f	115	33	36	102	101	102	31. Nuala	f	115	37	38	109	105	107

Point scores for drawings of the human figure at retest

			Experimental group								Control group				
			Raw score		Standardized score						Raw score		Standardized score		
Name	Sex	Age	Man	Woman	Man	Woman	Average	Name	Sex	Age	Man	Woman	Man	Woman	Average
1. Adam	m	135	5	4	90	82	86	1. Andrew	m	132	4	5	82	91	87
2. Brendan	m	134	6	5	98	91	95	2. Ben	m	131	4	5	84	93	89
3. Chris	m	133	7	6	107	100	104	3. Charlie	m	128	5	6	93	103	98
4. David	m	133	4	4	82	82	82	4. Dominic	m	128	4	5	84	93	89
5. Edward	m	133	5	5	90	91	91	5. Eamon	m	127	6	7	102	112	107
6. Francis	m	132	5	5	90	91	91	6. Freddie	m	127	4	4	84	84	84
7. Grant	m	131	5	5	93	93	93	7. George	m	127	7	6	111	103	107
8. Harry	m	128	5	6	93	103	98	8. Hugh	m	126	7	7	111	112	112
9. Ian	m	128	5	5	93	93	93	9. Ivor	m	126	4	5	84	93	89
10. James	m	127	6	6	102	103	103	10. John	m	125	6	6	102	103	103
11. Keith	m	126	7	6	111	103	107	11. Kevin	m	125	6	6	102	103	103
12. Liam	m	119	7	8	115	128	122	12. Lawrence	m	124	6	5	102	93	98
13. Matthew	m	119	5	6	96	108	102	13. Mark	m	124	5	5	93	93	93
14. Nigel	m	118	5	5	96	98	97	14. Neville	m	122	5	5	93	93	93
15. Oliver	m	117	5	6	96	108	102	15. Oscar	m	120	6	6	102	103	103
16. Peter	m	117	6	6	106	108	107	16. Paul	m	119	5	6	96	108	102
17. Roger	m	117	6	6	106	108	107	17. Richard	m	112	5	6	96	108	102
18. Alice	f	131	5	5	91	86	89	18. Anna	f	135	4	5	78	84	81
19. Bethan	f	131	6	6	100	95	98	19. Brianne	f	134	5	7	87	101	94
20. Claire	f	130	5	6	91	95	93	20. Carol	f	131	5	6	91	95	93
21. Deirdre	f	130	7	6	109	95	102	21. Doreen	f	130	6	6	100	95	98
22. Eve	f	126	7	6	109	95	102	22. Eugenie	f	129	6	6	100	95	98
23. Faith	f	125	6	6	100	95	98	23. Felicity	f	127	7	7	109	104	107
24. Grace	f	124	6	5	100	86	93	24. Gemma	f	127	6	7	100	104	102
25. Hannah	f	122	6	6	100	95	98	25. Harriet	f	124	4	4	82	77	80
26. Imogen	f	122	5	5	91	86	89	26. Isobel	f	119	7	6	114	100	107
27. Jessica	f	122	8	7	118	104	111	27. Joyce	f	116	6	6	104	100	102
28. Katy	f	119	5	5	94	91	93	28. Karen	f	116	6	5	104	91	98
29. Lucy	f	117	6	6	104	100	102	29. Larissa	f	113	5	6	94	100	97
30. Monica	f	113	6	5	104	91	98	30. Maeve	f	112	4	5	85	91	88
31. Nicky	f	112	5	5	94	91	93	31. Nuala	f	112	5	6	94	100	97

Quality scores for drawings of the human figure at test (first rater)

			Experimental group								Control group				
			Raw score		Standardized score					Raw score		Standardized score			
Name	Sex	Age	Man	Woman	Man	Woman	Average	Name	Sex	Age	Man	Woman	Man	Woman	Average
1. Adam	m	135	5	4	90	82	86	1. Andrew	m	132	4	5	82	91	87
2. Brendan	m	134	6	5	98	91	95	2. Ben	m	131	4	5	84	93	89
3. Chris	m	133	6	6	98	100	99	3. Charlie	m	128	5	6	93	103	98
4. David	m	133	4	4	82	82	82	4. Dominic	m	128	4	5	84	93	89
5. Edward	m	133	5	5	90	91	91	5. Eamon	m	127	6	7	102	112	107
6. Francis	m	132	5	5	90	91	91	6. Freddie	m	127	4	4	84	84	84
7. Grant	m	131	5	5	93	93	93	7. George	m	127	7	6	111	103	107
8. Harry	m	128	5	6	93	103	98	8. Hugh	m	126	7	7	111	112	112
9. Ian	m	128	5	6	93	103	98	9. Ivor	m	126	5	6	93	103	98
10. James	m	127	6	6	102	103	103	10. John	m	125	6	6	102	103	103
11. Keith	m	126	6	6	102	103	103	11. Kevin	m	125	6	6	102	103	103
12. Liam	m	119	7	8	115	128	122	12. Lawrence	m	124	6	5	102	93	98
13. Matthew	m	119	5	6	96	108	102	13. Mark	m	124	5	5	93	93	93
14. Nigel	m	118	5	4	96	88	92	14. Neville	m	122	5	5	93	93	93
15. Oliver	m	117	5	5	96	98	97	15. Oscar	m	120	6	6	102	103	103
16. Peter	m	117	6	6	106	108	107	16. Paul	m	119	5	6	96	108	102
17. Roger	m	117	5	6	96	108	102	17. Richard	m	112	5	5	96	98	97
18. Alice	f	131	5	5	91	86	89	18. Anna	f	135	5	5	87	84	86
19. Bethan	f	131	6	6	100	95	98	19. Brianne	f	134	6	7	96	101	99
20. Claire	f	130	5	6	91	95	93	20. Carol	f	131	6	6	100	95	98
21. Deirdre	f	130	7	6	109	95	102	21. Doreen	f	130	6	6	100	95	98
22. Eve	f	126	7	7	109	104	107	22. Eugenie	f	129	6	6	100	95	98
23. Faith	f	125	5	7	91	104	98	23. Felicity	f	127	7	7	109	104	107
24. Grace	f	124	6	5	100	86	93	24. Gemma	f	127	6	6	100	95	98
25. Hannah	f	122	5	6	91	95	93	25. Harriet	f	124	4	4	82	77	80
26. Imogen	f	122	4	5	82	86	84	26. Isobel	f	119	7	7	114	109	112
27. Jessica	f	122	7	7	109	104	107	27. Joyce	f	116	6	6	104	100	102
28. Katy	f	119	5	5	94	91	93	28. Karen	f	116	5	5	94	91	93
29. Lucy	f	117	6	6	104	100	102	29. Larissa	f	113	5	6	94	100	97
30. Monica	f	113	6	5	104	91	98	30. Maeve	f	112	4	5	85	91	88
31. Nicky	f	112	5	5	94	91	93	31. Nuala	f	112	5	6	94	100	97

Quality scores for drawings of the human figure at test (second rater)

Appendix V: Science Curiosity Measure

The Harty and Beall (1984) science curiosity scale, as administered in this study, is reproduced below. The statements are scored in the direction of high curiosity with the rating scores of eight negatively presented statements reversed (Statements 5, 6, 10, 15, 21, 25, 28 and 29). Total scores could range from 30 (low curiosity) to 150 (high curiosity). English spellings were used throughout.

Background

Name:

Interest

Begin by ticking only one of the following:
❒ I am really interested in science
❒ I am uncertain about my interest in science
❒ I am not interested in science

Instructions

The 30 statements below will help reveal how curious you are about science. This is not a test or an exam and there are no right or wrong answers. Simply indicate 'how you feel' about each statement by giving it a number as discussed.

5 = Strongly agree
4 = Agree
3 = Uncertain
2 = Disagree
1 = Strongly disagree

Curiosity

C1. Science magazines and stories are interesting. _____

C2. I like to watch television programmes about science. _____

C3. I enjoy collecting leaves or other things from the outdoors. _____

C4. I like to watch magic shows. _____

C5. It is boring to read about different kinds of animals. _____

C6. I don't want to know how rainbows are formed. _____

C7. I would like to listen to scientists talking about their jobs. _____

C8. I want to know what causes wind. _____

C9. I would like to experiment with gadgets inside the space shuttle. _____

C10. It is boring to visit scientists in their labs. _____

C11. It is fun to see inside toys to learn how they work. _____

C12. I like to talk about the planets and stars. _____

C13. Films and pictures about volcanoes are interesting. _____

C14. I like to watch the sky and the stars at night. _____

C15. I don't like looking at small objects through a magnifying lens. _____

C16. It is fun to walk and just look at plants and animals. _____

C17. I like to grow plants. _____

C18. I like to visit zoos to watch how animals behave _____

C19. I like to watch news reports about the space shuttle on television. _____

C20. I would like to visit a museum to see dinosaur bones. _____

C21. It is boring to hear other people talk about things astronauts have done. _____

C22. I like to ask questions about how animals live. _____

C23. I like to measure things to see how big they are. _____

C24. I like to search for answers to questions about space travel. _____

C25. It is boring to learn about new science words. _____

C26. I wonder what causes colourful sunsets. _____

C27. I like to watch clouds move across the sky. _____

C28. I don't like to do experiments with butterflies. _____

C29. It is boring to ask questions about how animals live. _____

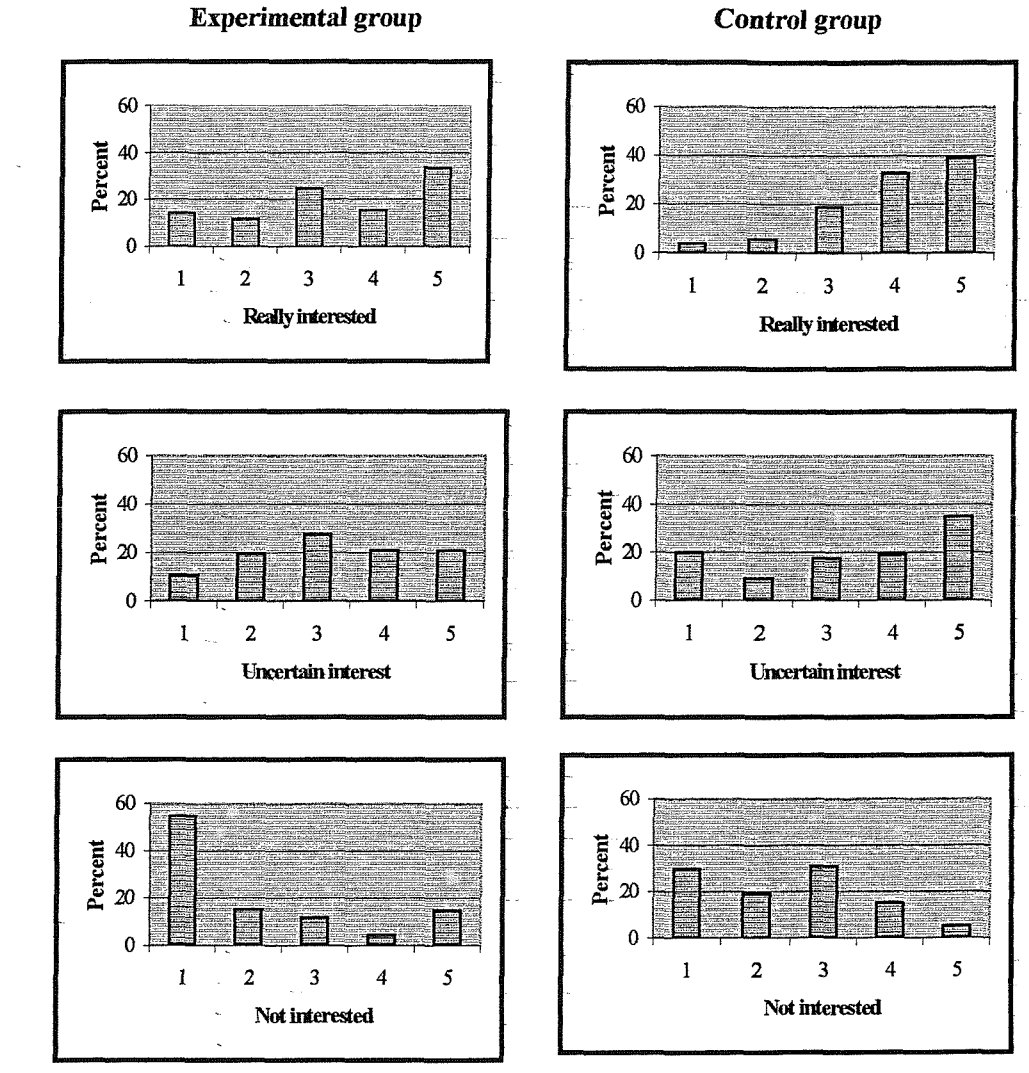
C30. I like to touch different things to learn more about them. _____

			Experimental group									Control group						
Name	Sex	Age	Interest	1s	2s	3s	4s	5s	Total	Name	Sex	Age	Interest	1s	2s	3s	4s	5s	Total
1. Adam	m	135	not	25	0	0	0	5	50	1. Andrew	m	132	uncertain	8	3	4	6	9	95
2. Brendan	m	134	uncertain	0	18	11	1	0	73	2. Ben	m	131	uncertain	14	1	2	1	12	86
3. Chris	m	133	uncertain	3	4	16	5	2	89	3. Charlie	m	128	not	5	12	11	2	0	70
4. David	m	133	really	3	5	9	10	3	95	4. Dominic	m	128	really	4	3	3	5	15	114
5. Edward	m	133	not	14	7	7	0	2	59	5. Eamon	m	127	really	2	0	1	1	26	139
6. Francis	m	132	not	15	1	3	1	10	80	6. Freddie	m	127	uncertain	4	5	1	8	12	109
7. Grant	m	131	really	4	1	6	12	7	107	7. George	m	127	really	1	0	7	17	5	115
8. Harry	m	128	uncertain	3	1	3	5	18	124	8. Hugh	m	126	really	0	4	6	10	10	116
9. Ian	m	128	really	2	11	8	7	2	86	9. Ivor	m	126	not	4	7	16	3	0	78
10. James	m	127	really	10	1	7	1	11	92	10. John	m	125	not	22	2	6	0	0	44
11. Keith	m	126	uncertain	3	8	12	6	1	84	11. Kevin	m	125	really	1	0	6	12	11	122
12. Liam	m	119	really	2	3	6	3	16	118	12. Lawrence	m	124	really	0	1	10	14	5	113
13. Matthew	m	119	really	4	4	9	4	9	100	13. Mark	m	124	not	7	2	11	7	3	87
14. Nigel	m	118	really	4	0	2	1	23	129	14. Neville	m	122	uncertain	0	0	5	13	12	127
15. Oliver	m	117	not	9	3	7	1	10	90	15. Oscar	m	120	uncertain	12	0	0	3	15	99
16. Peter	m	117	really	5	5	12	1	7	90	16. Paul	m	119	uncertain	3	3	10	6	8	103
17. Roger	m	117	uncertain	1	2	7	7	13	119	17. Richard	m	112	uncertain	5	4	10	4	7	94
18. Alice	f	131	uncertain	2	4	7	8	9	108	18. Anna	f	135	uncertain	8	3	7	1	11	94
19. Bethan	f	131	uncertain	0	5	15	5	5	100	19. Brianne	f	134	uncertain	0	3	9	10	8	113
20. Claire	f	130	uncertain	2	1	10	6	11	113	20. Carol	f	131	uncertain	1	6	4	16	3	104
21. Deirdre	f	130	not	18	4	0	2	6	64	21. Doreen	f	130	uncertain	3	2	8	3	14	113
22. Eve	f	126	uncertain	9	3	8	6	4	83	22. Eugenie	f	129	not	8	4	10	6	2	80
23. Faith	f	125	not	19	1	10	0	0	51	23. Felicity	f	127	not	4	9	12	3	2	80
24. Grace	f	124	not	21	7	1	1	0	42	24. Gemma	f	127	not	23	1	3	1	2	48
25. Hannah	f	122	uncertain	6	8	1	6	9	94	25. Harriet	f	124	uncertain	8	1	1	1	19	112
26. Imogen	f	122	uncertain	0	7	14	9	0	92	26. Isobel	f	119	uncertain	6	2	6	9	7	99
27. Jessica	f	122	uncertain	3	12	1	13	1	87	27. Joyce	f	116	not	1	8	10	9	2	93
28. Katy	f	119	uncertain	8	3	4	1	14	100	28. Karen	f	116	not	7	6	5	9	3	85
29. Lucy	f	117	uncertain	6	6	7	10	1	84	29. Larissa	f	113	uncertain	13	2	1	0	14	90
30. Monica	f	113	really	5	2	8	2	13	106	30. Maeve	f	112	uncertain	4	6	11	4	5	90
31. Nicky	f	112	not	10	13	0	5	2	66	31. Nuala	f	112	really	0	4	6	10	10	116

Science interest and curiosity at test (transformed responses: 1=strongly disagree; 2=disagree; 3=uncertain; 4=agree; 5=strongly agree)

			Experimental group									Control group						
Name	Sex	Age	Interest	1s	2s	3s	4s	5s	Total	Name	Sex	Age	Interest	1s	2s	3s	4s	5s	Total
1. Adam	m	138	not	18	0	2	3	7	71	1. Andrew	m	135	uncertain	9	1	5	7	8	94
2. Brendan	m	137	uncertain	10	6	9	5	0	69	2. Ben	m	134	uncertain	12	0	4	1	13	93
3. Chris	m	136	uncertain	2	2	13	6	7	104	3. Charlie	m	131	uncertain	17	0	1	0	12	80
4. David	m	136	not	15	0	3	3	9	81	4. Dominic	m	131	really	0	0	1	2	27	146
5. Edward	m	136	uncertain	4	3	8	10	5	99	5. Eamon	m	130	really	4	2	3	4	17	118
6. Francis	m	135	really	8	2	5	5	10	97	6. Freddie	m	130	really	3	4	6	9	8	105
7. Grant	m	134	really	2	2	5	1	20	125	7. George	m	130	really	0	0	5	11	14	129
8. Harry	m	131	not	10	3	3	2	12	93	8. Hugh	m	129	really	1	2	3	9	15	125
9. Ian	m	131	really	5	5	4	13	3	94	9. Ivor	m	129	not	3	3	11	6	7	101
10. James	m	130	really	4	3	8	7	8	102	10. John	m	128	not	14	2	4	3	7	77
11. Keith	m	129	uncertain	2	7	9	8	4	95	11. Kevin	m	128	uncertain	1	1	2	11	15	128
12. Liam	m	122	really	5	3	4	3	15	110	12. Lawrence	m	127	really	1	2	5	6	16	124
13. Matthew	m	122	really	4	4	9	4	9	100	13. Mark	m	127	not	7	2	11	7	3	87
14. Nigel	m	121	really	2	1	1	0	26	137	14. Neville	m	125	uncertain	0	1	7	14	8	119
15. Oliver	m	120	not	12	4	4	4	6	78	15. Oscar	m	123	really	14	1	0	1	14	90
16. Peter	m	120	not	15	1	4	2	8	77	16. Paul	m	122	not	6	2	10	4	8	96
17. Roger	m	120	uncertain	2	0	4	3	21	131	17. Richard	m	115	not	11	2	9	5	3	77
18. Alice	f	134	uncertain	1	4	9	9	7	107	18. Anna	f	138	uncertain	8	3	7	1	11	94
19. Bethan	f	134	uncertain	0	4	12	10	4	104	19. Brianne	f	137	uncertain	5	4	6	2	13	104
20. Claire	f	133	uncertain	0	3	5	15	7	116	20. Carol	f	134	uncertain	6	9	8	6	1	77
21. Deirdre	f	133	uncertain	3	13	5	4	5	85	21. Doreen	f	133	uncertain	5	2	5	9	9	105
22. Eve	f	129	uncertain	6	3	10	5	6	92	22. Eugenie	f	132	not	10	3	11	4	2	75
23. Faith	f	128	uncertain	7	7	7	3	6	84	23. Felicity	f	130	uncertain	7	9	7	5	2	76
24. Grace	f	127	not	11	6	6	4	3	72	24. Gemma	f	130	not	9	8	9	2	2	70
25. Hannah	f	125	not	13	1	0	0	16	95	25. Harriet	f	127	uncertain	4	3	3	3	17	116
26. Imogen	f	125	uncertain	0	12	6	12	0	90	26. Isobel	f	122	uncertain	2	5	8	10	5	101
27. Jessica	f	125	uncertain	1	8	12	5	4	93	27. Joyce	f	119	not	2	3	8	5	12	112
28. Katy	f	122	not	14	4	1	1	10	79	28. Karen	f	119	not	5	6	4	12	3	92
29. Lucy	f	120	uncertain	10	7	7	4	2	71	29. Larissa	f	116	uncertain	4	7	9	7	3	88
30. Monica	f	116	really	1	1	4	6	18	129	30. Maeve	f	115	uncertain	1	6	10	8	5	100
31. Nicky	f	115	uncertain	11	6	8	3	2	69	31. Nuala	f	115	uncertain	0	12	8	8	2	90

Science interest and curiosity at retest (transformed responses: 1=strongly disagree; 2=disagree; 3=uncertain; 4=agree; 5=strongly agree)



Curiosity response profiles by declared interest

Appendix VI: Summary of Experimental Treatment

The following notes outline the general activities which together comprised the experimental treatment. The activities themselves were drawn from a range of commercially available science schemes including Nuffield Primary Science (Nuffield-Chelsea Trust 1995) which was the science scheme of choice used throughout Big Town CPS. On most occasions, the astronomy lessons employed a three-phase structure: a whole class introduction; group or team work and work as individuals; a whole class plenary. In negotiation with Jack, the class teacher of the experimental group and the deputy head teacher of the school, it was agreed that the basic teaching strategies employed would include:

- productive questioning, elicitation and discussion;
- effective exposition;
- annotated drawings;
- sorting and classifying;
- using models;
- recording work in science workbooks and using multi-media technology;
- encouraging independence and team work.

Though not the immediate focus of the work undertaken here, the activities were carefully selected in order to provide children with opportunities to develop a wide range of skills including:

- asking questions;
- observing, exploring, researching, measuring and recording;
- making predictions and testing hypotheses;
- planning and carrying out scientific investigations including fair tests;
- making decisions;
- using a wide range of equipment and other resources;
- considering evidence;
- interpreting results and proposing explanations;
- communicating results and findings.

At all times the children were encouraged to be co-operative, open-minded, flexible and persistent.

Lesson 1: Introduction

Activities

Slide show presentation including views of the Sun, the planets, stars and galaxies, images from the Apollo Moon missions and images from Space Shuttle missions. Children encouraged to collect space images from magazines and newspapers at home to construct a wall display. Time line outlining major astronomical events from ancient times to the present day begun (to include the history of flight and space exploration). Children compose a letter to NASA education requesting information for their topic.

Supporting Video, reading and ICT

BBC Television Zig Zag Programme 1: 'Into space'. Atkinson (1994): 'Telescopes past and present'. pp.32-33. 'About astronomers'. pp.34-35. 'The history of astronomy'. pp.36-37. Dorling Kindersley's 'Space Encyclopedia' on CD-ROM.

Lesson 2: The Earth

Activities

Review Lesson 1. Discussion about the Earth including its size and shape. Exploration of evidence and other people's ideas (including legends involving the Earth). Introduction and development of key scientific vocabulary and use of language. Children draw into science workbooks images of the Earth from space in posters. Research and annotate features including land, water and atmosphere. Globes and atlases introduced and used to identify continents, oceans and seas. Shape reinforced by comparing with other 2D and 3Dshapes and tabulating sides, edges and vertices. Gravity as a pulling force introduced in terms of where people live. Work consolidated with end of week quiz involving key questions from intended learning outcomes.

Supporting Video, reading and ICT

Channel 4 Television selected extracts from Eureka Programme 2: 'The Earth, Sun and Moon'. Atkinson (1994): 'The Earth and Moon'. pp.12-13. Stannard (1996): 'Leaving home'. Ch. 4, pp.4-11. Dorling Kindersley's 'Space Encyclopedia' on CD-ROM.

Lesson 3: The Sun

Activities

Review Lesson 2. Discussion about the Sun including its size and shape. Exploration of evidence and other people's ideas (including legends involving the Sun). Introduction and development of key scientific vocabulary and use of language. Children draw into science workbooks images of the Sun from space in posters. Research and annotate features including sunspots, flares and prominences. Shape reinforced by comparing with other 2D and 3Dshapes and tabulating sides, edges and vertices. Source of the Sun's heat and light introduced. Dangers of looking at the Sun emphasized. Demonstration of sunspot activity by projecting the Sun's photosphere onto a piece of white card. Work consolidated with end of week quiz involving key questions from intended learning outcomes.

Supporting Video, reading and ICT

Channel 4 Television selected extracts from Eureka Programme 2: 'The Earth, Sun and Moon'. Atkinson (1994): 'The Sun'. pp.6-7. Stannard (1996): 'The Sun: a bomb that goes off slowly'. Ch. 3, pp.16-22. 'Birth of the Sun'. Ch.5, pp.32-36. Dorling Kindersley's 'Space Encyclopedia' on CD-ROM.

Lesson 4: The Moon

Activities

Review Lesson 3. Discussion about the Moon including its size and shape. Exploration of evidence and other people's ideas (including legends involving the Moon). Introduction and development of key scientific vocabulary and use of language. Children draw into science workbooks direct day and night-time homework observations of the Moon using telescopes and binoculars and compare with images of the Moon from space in posters and Moon maps.

Research and annotate features including craters and 'seas'. Children model crater formation using projectiles and sand. Shape reinforced by comparing with other 2D and 3Dshapes and tabulating sides, edges and vertices. Conditions on the Moon and the source of its light introduced. Children begin to observe and record periodic changes in the position of the Moon in the sky and its phases either directly or from diaries and newspapers. Work consolidated with end of week quiz involving key questions from intended learning outcomes.

Supporting Video, reading and ICT

BBC Television Zig Zag Programme 2: 'On the Moon'. Channel 4 Television selected extracts from Eureka Programme 2: 'The Earth, Sun and Moon'. Atkinson (1994): 'The Earth and Moon'. pp.12-13. Stannard (1996): 'First stop, the Moon'. Ch. 2, pp.12-15. Dorling Kindersley's 'Space Encyclopedia' on CD-ROM.

Lesson 5: Day and night

Activities

Review Lesson 4. Discussion about day and night and the day and night cycle. Exploration of evidence and other people's ideas. Introduction and development of key scientific vocabulary and use of language. Children observe and record the pattern of the Sun 'rising' in the east and 'setting' in the west. Children observe and record shadow position and length throughout one day. Children consider day and night in global context throughout the year (Arctic and Antarctic circles, tropics, equator). Children consider changes in daylight hours throughout the year. Children use a globe and an overhead projector to consider how observed patterns and changes can be modelled in other ways. Dynamics of complete Earth-Sun-Moon System introduced together with rotational and orbital periods. Relative and absolute size of the Earth, the Sun and the Moon reinforced by considering the effect of distance between the object and observer. Work consolidated with end of week quiz involving key questions from intended learning outcomes.

Supporting Video, reading and ICT

Channel 4 Television selected extracts from Eureka Programme 2: 'The Earth, Sun and Moon'. Stannard (1996): 'Leaving home'. Ch. 4, pp.10-11. Dorling Kindersley's 'Space Encyclopedia' on CD-ROM.

Lessons 6-8: The Solar System and wider Universe

Activities

Review Lessons 5 to 7. Discussion about the Solar System and the wider Universe. Exploration of evidence and other people's ideas. Introduction and development of key scientific vocabulary and use of language. Children break into research teams each with a planet to find out about. Solar System wall display produced (reminding children of problems associated with shapes, scales and dynamics). Children act out movements of planets around the Sun in playground. Children devise their own planetary mnemonics to remember the sequence and order of objects. Class data-base constructed and interrogated and multi-media software package developed. Homework includes looking for easy to identify constellations and visible planets. All work reinforced with 'postcards from the planets'. Work consolidated with end of week quiz involving key questions from intended learning outcomes.

Supporting Video, reading and ICT

BBC Television Zig Zag Programme 3: 'Planets'. Channel 4 Television Eureka Programme 1: 'The Universe and us'. Atkinson (1994): 'The Solar System'. pp.4-5. Planet chapters to 'The Story of the Universe'. pp.8-31. Stannard (1996): 'Visiting the neighbours'. Ch. 4, pp.23-31. 'Island worlds'. Ch.9, pp.53-58. 'The creation of the Universe'. Ch.11, pp.64-71. Dorling Kindersley's 'Space Encyclopedia' on CD-ROM.

Lesson 9: Seasonal change

Activities

Review Lesson 8. Discussion about the seasons and the cycle of seasonal change. Exploration of evidence and other people's ideas. Introduction and development of key

scientific vocabulary and use of language. Children consider seasonal change in global context throughout the year (northern and southern hemispheres, daylight hours). Children consider changes in daylight hours throughout the year. Children use a model of the Earth-Sun-Moon System to explore causal factors involved in seasonal change. Work consolidated with end of week quiz involving key questions from intended learning outcomes.

Supporting Video, reading and ICT

Channel 4 Television selected extracts from Eureka Programme 2: 'The Earth, Sun and Moon'. Stannard (1996): 'The Sun: a bomb that goes off slowly'. Ch. 3, pp.18-19. Dorling Kindersley's 'Space Encyclopedia' on CD-ROM.

Lesson 10: The Phases of the Moon

Activities

Review Lesson 9. Discussion about the Moon's phases and the Moon phase cycle. Exploration of evidence and other people's ideas. Introduction and development of key scientific vocabulary and use of language. Children use data collected on the phases of the Moon earlier. Children use a model of the Earth-Sun-Moon System to explore causal factors involved in the Moon's phases. Work consolidated with end of week quiz involving key questions from intended learning outcomes.

Supporting Video, reading and ICT

Channel 4 Television selected extracts from Eureka Programme 2: 'The Earth, Sun and Moon'. Atkinson (1994): 'The Earth and Moon'. pp.12-13. Dorling Kindersley's 'Space Encyclopedia' on CD-ROM.

Appendix VII: Responses, Mental Models, Score Profiles and Summated Scores

The tables which follow contain all summary details of the 'traditional' content areas of astronomy investigated here. They are identified as follows:

Children's ideas about the Earth (including inter-rater reliability)	Location code **E**
Children's ideas about the Sun	Location code **S**
Children's ideas about the Moon	Location code **M**
Children's ideas about what causes day and night	Location code **DN**
Children's ideas about what causes seasonal change	Location code **SC**
Children's ideas about what causes the phases of the Moon	Location code **MP**
Children's ideas about the Solar System	Location code **SOL**

[Note: the subscripts x and c have been used to denote the experimental and control groups throughout. The subscript r_2 has been used to denote the work of the second rater – Earth only.]

Name	Sex	Age	Shape (verbal/choice)	Drawing	Relative size	Gravity	Nature
1. Adam	m	135	spherical (sphere/sphere)	anglocentric (b)	Sun largest	'in' explicit (part. corr.)	planet
2. Brendan	m	134	spherical (round/sphere)	global (a)	S>E>M	'in' implicit	planet (orbits Sun)
3. Chris	m	133	spherical (oval/sphere)	global (a)	not sure	'in' explicit (part. corr.)	planet
4. David	m	133	spherical (round/sphere)	internal (smooth (e))	S>E>M	'in' implicit	planet (orbits Sun)
5. Edward	m	133	spherical (sphere/sphere)	global (a)	Moon largest	'in' explicit (corr.)	planet
6. Francis	m	132	spherical (round/sphere)	marginal (c)	Sun largest	'in' implicit	planet
7. Grant	m	131	spherical (round sphere)	global (a)	S>E>M	'in' explicit (corr.)	planet
8. Harry	m	128	spherical (sphere/sphere)	anglocentric (b)	S>E>M	'in' implicit	planet (orbits Sun)
9. Ian	m	128	spherical (sphere/sphere)	global (a)	S>E>M	'in' explicit (corr.)	planet (orbits Sun)
10. James	m	127	spherical (ball/sphere)	global (a)	S>E>M	'in' implicit	planet (orbits Sun)
11. Keith	m	126	spherical (sphere/sphere)	marginal (c)	Sun largest	'in' explicit (part. corr.)	planet
12. Liam	m	119	spherical (sphere/sphere)	global (a)	S>E>M	'in' explicit (part. corr.)	planet (orbits Sun)
13. Matthew	m	119	spherical (round/sphere)	marginal (c)	S>E>M	'in' explicit (part. corr.)	planet
14. Nigel	m	118	near-sphere (egg shaped/sphere)	anglocentric (b)	S>E>M	'in' explicit (part. corr.)	planet
15. Oliver	m	117	spherical (round/sphere)	anglocentric (b)	not sure	uncertain (not clear)	planet
16. Peter	m	117	spherical (round/sphere)	marginal (c)	Earth largest	'in' explicit (part. corr.)	not sure
17. Roger	m	117	near-sphere (egg shaped/sphere)	marginal (c)	Earth largest	'in' explicit (part. corr.)	planet
18. Alice	f	131	spherical (round/sphere)	marginal (c)	S>E>M	'in' explicit (part. corr.)	planet
19. Bethan	f	131	spherical (sphere/sphere)	global (a)	S>E>M	'in' explicit (corr.)	planet
20. Claire	f	130	non-spherical (round/disk)	marginal (c)	Moon largest	'in' implicit	planet
21. Deirdre	f	130	spherical (circle/sphere)	marginal (c)	Earth largest	uncertain (not clear)	world
22. Eve	f	126	spherical (round/sphere)	marginal (c)	equivalence	'in' implicit	planet
23. Faith	f	125	spherical (sphere/sphere)	marginal (c)	Moon largest	'in' implicit	planet
24. Grace	f	124	spherical (round/sphere)	marginal (c)	equivalence	'in' explicit (corr.)	not sure
25. Hannah	f	122	uncertain sphere (not sure/sphere)	marginal (c)	Sun largest	uncertain (not clear)	planet
26. Imogen	f	122	spherical (round sphere)	internal (irr. (d))	S>E>M	'in' implicit	planet
27. Jessica	f	122	spherical (cylinder/sphere)	internal (irr. (d))	S>E>M	'in' explicit (part. corr.)	planet
28. Katy	f	119	spherical (circle/sphere)	blank (f)	Earth largest	not sure	planet
29. Lucy	f	117	spherical (round/sphere)	internal (irr. (d))	equivalence	'in' implicit	planet
30. Monica	f	113	spherical (round/sphere)	marginal (c)	Earth largest	uncertain (not clear)	planet
31. Nicky	f	112	spherical (round/sphere)	internal (smooth (e))	S>E>M	uncertain (not clear)	not sure

Overview of Earth responses and models: experimental group at first interview and pre-experimental treatment

Ex

Name	Sex	Age	Shape (verbal/choice)	Drawing	Relative size	Gravity (response)	Nature
1. Adam	m	138	spherical (sphere/sphere)	anglocentric (b)	S>E>M	'in' explicit (corr.)	planet (orbits Sun)
2. Brendan	m	137	spherical (sphere/sphere)	global (a)	S>E>M	'in' implicit	planet (orbits Sun)
3. Chris	m	136	spherical (sphere/sphere)	anglocentric (b)	S>E>M (prop.)	'in' explicit (corr.)	planet (orbits Sun)
4. David	m	136	spherical (round/sphere)	marginal (c)	S>E>M	'in' explicit (corr.)	planet (orbits Sun)
5. Edward	m	136	spherical (sphere/sphere)	global (a)	S>E>M	'in' explicit (corr.)	planet (orbits Sun)
6. Francis	m	135	spherical (sphere/sphere)	internal (smooth (e))	S>E>M	'in' implicit	planet (orbits Sun)
7. Grant	m	134	spherical (round/sphere)	anglocentric (b)	S>E>M	'in' implicit	planet (orbits Sun)
8. Harry	m	131	spherical (sphere/sphere)	marginal (c)	S>E>M	uncertain (not clear)	planet (orbits Sun)
9. Ian	m	131	near-sphere (bulging sphere/sphere)	global (a)	S>E>M (prop.)	'in' explicit (corr.)	planet (orbits Sun)
10. James	m	130	spherical (sphere/sphere)	global (a)	S>E>M (prop.)	'in' implicit	planet (orbits Sun)
11. Keith	m	129	spherical (sphere/sphere)	anglocentric (b)	S>E>M	'in' explicit (corr.)	planet (orbits Sun)
12. Liam	m	122	spherical (sphere/sphere)	global (a)	S>E>M (prop.)	'in' explicit (corr.)	planet (orbits Sun)
13. Matthew	m	122	spherical (3D circle shape/sphere)	anglocentric (b)	Sun largest	'in' explicit (corr.)	planet (orbits Sun)
14. Nigel	m	121	near-sphere (egg shaped/sphere)	anglocentric (b)	S>E>M	'in' explicit (corr.)	planet (orbits Sun)
15. Oliver	m	120	spherical (sphere/sphere)	anglocentric (b)	S>E>M	'in' implicit	planet (orbits Sun)
16. Peter	m	120	spherical (sphere/sphere)	marginal (c)	Earth largest	uncertain (not clear)	planet (orbits Sun)
17. Roger	m	120	near-sphere (egg shaped/kind of sphere)	marginal (c)	S>E>M	'in' explicit (corr.)	planet (orbits Sun)
18. Alice	f	134	spherical (sphere/sphere)	marginal (c)	S>E>M	'in' explicit (corr.)	planet (orbits Sun)
19. Bethan	f	134	spherical (sphere/sphere)	global (a)	S>E>M	'in' explicit (corr.)	planet (orbits Sun)
20. Claire	f	133	spherical (round/sphere)	anglocentric (b)	S>E>M	'in' implicit	planet (orbits Sun)
21. Deirdre	f	133	spherical (round/sphere)	anglocentric (b)	S>E>M	'in' implicit	planet (orbits Sun)
22. Eve	f	129	spherical (round/sphere)	marginal (c)	S>E>M	'in' implicit	planet (orbits Sun)
23. Faith	f	128	spherical (sphere/sphere)	anglocentric (b)	S>E>M	'in' explicit (corr.)	planet (orbits Sun)
24. Grace	f	127	spherical (sphere/sphere)	marginal (c)	equivalence	'in' explicit (part. corr.)	planet (orbits Sun)
25. Hannah	f	125	spherical (circle/sphere)	marginal (c)	S>E>M	'in' implicit	planet (orbits Sun)
26. Imogen	f	125	spherical (round/sphere)	anglocentric (b)	S>E>M	uncertain (not clear)	planet (orbits Sun)
27. Jessica	f	125	spherical (round/sphere)	marginal (c)	S>E>M (prop.)	'in' implicit	planet (orbits Sun)
28. Katy	f	122	spherical (sphere/sphere)	marginal (c)	Earth largest	'in' implicit	planet (orbits Sun)
29. Lucy	f	120	spherical (round/sphere)	internal (irr. (d))	S>E>M	'in' implicit	planet (orbits Sun)
30. Monica	f	116	spherical (sphere/sphere)	marginal (c)	equivalence	not sure	planet
31. Nicky	f	115	spherical (round/sphere)	marginal (c)	Moon largest	down (people fall)	round thing

Overview of Earth responses and models: experimental group at second interview and post-experimental treatment

EX

Name	Sex	Age	Shape (verbal/choice)	Drawing	Relative size	Gravity (response)	Nature
1. Adam	m	141	spherical (sphere/sphere)	anglocentric (b)	S>E>M (prop.)	'in' explicit (corr.)	planet (orbits Sun)
2. Brendan	m	140	spherical (round/sphere)	anglocentric (b)	S>E>M	'in' explicit (part. corr.)	planet (orbits Sun)
3. Chris	m	139	spherical (sphere/sphere)	anglocentric (b)	S>E>M (prop.)	'in' explicit (part. corr.)	planet (orbits Sun)
4. David	m	139	spherical (round/sphere)	blank (f)	S>E>M	'in' explicit (corr.)	planet (orbits Sun)
5. Edward	m	139	spherical (sphere/sphere)	anglocentric (b)	S>E>M	'in' explicit (corr.)	planet (orbits Sun)
6. Francis	m	138	spherical (sphere/sphere)	internal (irr. (d))	S>E>M	'in' implicit	planet (orbits Sun)
7. Grant	m	137	spherical (round/sphere)	marginal (c)	S>E>M	'in' explicit (corr.)	planet (orbits Sun)
8. Harry	m	134	spherical (sphere/sphere)	marginal (c)	S>E>M	'in' implicit	planet (orbits Sun)
9. Ian	m	134	spherical (sphere/sphere)	marginal (c)	S>E>M	'in' explicit (corr.)	planet (orbits Sun)
10. James	m	133	spherical (sphere/sphere)	global (a)	S>E>M (prop.)	'in' implicit	planet (orbits Sun)
11. Keith	m	132	spherical (sphere/sphere)	anglocentric (b)	S>E>M	'in' explicit (part. corr.)	planet (orbits Sun)
12. Liam	m	125	spherical (sphere/sphere)	global (a)	S>E>M	'in' explicit (corr.)	planet (orbits Sun)
13. Matthew	m	125	spherical (sphere/sphere)	anglocentric (b)	S>E>M	'in' explicit (part. corr.)	planet (orbits Sun)
14. Nigel	m	124	spherical (round/sphere)	anglocentric (b)	S>E>M (prop.)	'in' explicit (part. corr.)	planet (orbits Sun)
15. Oliver	m	123	spherical (sphere/sphere)	anglocentric (b)	S>E>M	uncertain (not clear)	planet (orbits Sun)
16. Peter	m	123	spherical (circle/sphere)	marginal (c)	Earth largest	uncertain (not clear)	planet (orbits Sun)
17. Roger	m	123	near-sphere (egg shaped/sphere)	marginal (c)	Sun largest	'in' explicit (part. corr.)	planet (orbits Sun)
18. Alice	f	137	spherical (sphere/sphere)	marginal (c)	S>E>M	'in' explicit (part. corr.)	planet (orbits Sun)
19. Bethan	f	137	spherical (sphere/sphere)	anglocentric (b)	S>E>M	'in' explicit (corr.)	planet (orbits Sun)
20. Claire	f	136	spherical (sphere/sphere)	marginal (c)	S>E>M	'in' implicit	planet (orbits Sun)
21. Deirdre	f	136	spherical (round/sphere)	marginal (c)	S>E>M	'in' implicit	planet (orbits Sun)
22. Eve	f	132	spherical (round/sphere)	marginal (c)	S>E>M	'in' implicit	planet (orbits Sun)
23. Faith	f	131	spherical (sphere/sphere)	marginal (c)	S>E>M	'in' explicit (corr.)	planet (orbits Sun)
24. Grace	f	130	spherical (sphere/sphere)	marginal (c)	Earth largest	'in' explicit (part. corr.)	planet (orbits Sun)
25. Hannah	f	128	spherical (circle/sphere)	marginal (c)	S>E>M	uncertain (not clear)	not sure
26. Imogen	f	128	spherical (ball/sphere)	marginal (c)	S>E>M	'in' implicit	planet (orbits Sun)
27. Jessica	f	128	spherical (round/sphere)	marginal (c)	S>E>M	'in' explicit (corr.)	not sure
28. Katy	f	125	spherical (circle/sphere)	marginal (c)	Earth largest	uncertain (not clear)	not sure
29. Lucy	f	123	spherical (sphere/sphere)	marginal (c)	S>E>M	'in' implicit	planet (orbits Sun)
30. Monica	f	119	spherical (sphere/sphere)	marginal (c)	S>E>M	'in' implicit	planet (orbits Sun)
31. Nicky	f	118	spherical (round/sphere)	marginal (c)	Moon largest	uncertain (not clear)	planet

Overview of Earth responses and models: experimental group at third interview and delayed

Ex

Name	Sex	Age	Shape (verbal/choice)	Drawing	Relative size	Gravity	Nature
1. Andrew	m	132	spherical (circle/sphere)	marginal (c)	Earth largest	'in' implicit	planet (orbits Sun)
2. Ben	m	131	uncertain non-spherical (not sure/hemisphere)	marginal (c)	Sun largest	'in'explicit (part. corr.)	planet
3. Charlie	m	128	spherical (round/sphere)	marginal (c)	Earth largest	'in' explicit (corr.)	planet
4. Dominic	m	128	spherical (round/sphere)	marginal (c)	Earth largest	'in'explicit (part. corr.)	not sure
5. Eamon	m	127	spherical (ball/sphere)	global (a)	S>E>M	'in'explicit (part. corr.)	planet (orbits Sun)
6. Freddie	m	127	spherical (round/sphere)	marginal (c)	Moon largest	not sure	not sure
7. George	m	127	spherical (sphere/sphere)	global (a)	S>E>M	'in' explicit (corr.)	planet (orbits Sun)
8. Hugh	m	126	spherical (round/sphere)	marginal (c)	S>E>M	'in' explicit (corr.)	planet (orbits Sun)
9. Ivor	m	126	spherical (round/sphere)	marginal (c)	S>E>M	not sure	planet
10. John	m	125	spherical (round/sphere)	internal (smooth (e))	Earth largest	'in' implicit	planet
11. Kevin	m	125	spherical (sphere/sphere)	anglocentric (b)	S>E>M	'in' explicit (corr.)	planet
12. Lawrence	m	124	spherical (circle/sphere)	marginal (c)	equivalence	'in' implicit	planet
13. Mark	m	124	spherical (round/sphere)	internal (irr. (d))	Sun largest	'in'explicit (part. corr.)	not sure
14. Neville	m	122	spherical (cylinder/sphere)	marginal (c)	Earth largest	'in' explicit (corr.)	planet
15. Oscar	m	120	spherical (round/sphere)	anglocentric (b)	S>E>M	'in'explicit (part. corr.)	planet (orbits Sun)
16. Paul	m	119	spherical (circle/sphere)	internal (irr. (d))	Earth largest	'in' implicit	not sure
17. Richard	m	112	near-sphere (egg shaped/sphere)	marginal (c)	S>E>M	'in' implicit	planet
18. Anna	f	135	spherical (circle/sphere)	marginal (c)	Earth largest	'in' implicit	planet
19. Brianne	f	134	spherical (round/sphere)	marginal (c)	Moon largest	uncertain (not clear)	planet (orbits Sun)
20. Carol	f	131	spherical (round/sphere)	marginal (c)	S>E>M	'in' explicit (corr.)	planet (orbits Sun)
21. Doreen	f	130	spherical (sphere/sphere)	marginal (c)	S>E>M	'in'explicit (part. corr.)	planet
22. Eugenie	f	129	spherical (ball/sphere)	marginal (c)	S>E>M	'in' implicit	planet
23. Felicity	f	127	spherical (round/sphere)	marginal (c)	S>E>M	'in' implicit	planet (orbits Sun)
24. Gemma	f	127	spherical (circle/sphere)	marginal (c)	equivalence	'in' implicit	planet
25. Harriet	f	124	near-sphere (egg shaped/sphere)	marginal (c)	S>E>M	'in' implicit	ball
26. Isobel	f	119	near-sphere (egg shaped/sphere)	global (a)	S>E>M	'in'explicit (part. corr.)	sphere
27. Joyce	f	116	spherical (cylinder/sphere)	anglocentric (b)	equivalence	'in'explicit (part. corr.)	planet
28. Karen	f	116	spherical (round/sphere)	blank (f)	Earth largest	not sure	not sure
29. Larissa	f	113	spherical (circle/sphere)	marginal (c)	not sure	'in'explicit (part. corr.)	planet
30. Maeve	f	112	spherical (sphere/sphere)	marginal (c)	S>E>M	'in'explicit (part. corr.)	not sure
31. Nuala	f	112	spherical (circle/sphere)	marginal (c)	not sure	not sure	not sure

Overview of Earth responses and models: control group at first interview

Name	Sex	Age	Shape (verbal/choice)	Drawing	Relative size	Gravity	Nature
1. Andrew	m	135	spherical (round/sphere)	marginal (c)	Earth largest	'in' implicit	planet
2. Ben	m	134	spherical (sphere/sphere)	marginal (c)	Sun largest	'in' explicit (part. corr.)	planet (orbits Sun)
3. Charlie	m	131	spherical (round/sphere)	marginal (c)	S>E>M	'in' explicit (part. corr.)	planet
4. Dominic	m	131	spherical (round/sphere)	marginal (c)	Earth largest	'in' explicit (part. corr.)	planet (orbits Sun)
5. Eamon	m	130	spherical (ball/sphere)	global (a)	S>E>M	'in' explicit (corr.)	planet (orbits Sun)
6. Freddie	m	130	uncertain non-spherical (not sure/hemisphere)	marginal (c)	equivalence	not sure	not sure
7. George	m	130	spherical (sphere/sphere)	global (a)	S>E>M	'in' explicit (corr.)	planet (orbits Sun)
8. Hugh	m	129	spherical (sphere/sphere)	anglocentric (b)	S>E>M	'in' explicit (part. corr.)	planet (orbits Sun)
9. Ivor	m	129	spherical (round/sphere)	marginal (c)	S>E>M	'in' explicit (corr.)	planet
10. John	m	128	spherical (circle/sphere)	marginal (c)	not sure	not sure	planet
11. Kevin	m	128	spherical (round/sphere)	marginal (c)	S>E>M	'in' explicit (part. corr.)	planet
12. Lawrence	m	127	spherical (sphere/sphere)	marginal (c)	Sun largest	'in' implicit	planet (orbits Sun)
13. Mark	m	127	spherical (round/sphere)	marginal (c)	S>E>M	'in' explicit (part. corr.)	planet
14. Neville	m	125	spherical (sphere/sphere)	marginal (c)	S>E>M	'in' explicit (corr.)	planet (orbits Sun)
15. Oscar	m	123	spherical (round/sphere)	internal (irr. (d))	S>E>M	'in' explicit (part. corr.)	not sure
16. Paul	m	122	spherical (circle/sphere)	marginal (c)	Earth largest	'in' implicit	planet
17. Richard	m	115	spherical (round/sphere)	marginal (c)	Sun largest	'in' implicit	not sure
18. Anna	f	138	spherical (round/sphere)	marginal (c)	not sure	'in' implicit	planet
19. Brianne	f	137	spherical (round/sphere)	marginal (c)	Earth largest	'in' explicit (part. corr.)	planet
20. Carol	f	134	spherical (circle/sphere)	marginal (c)	S>E>M	'in' explicit (part. corr.)	planet
21. Doreen	f	133	spherical (sphere/sphere)	marginal (c)	S>E>M	'in' explicit (part. corr.)	planet (orbits Sun)
22. Eugenie	f	132	spherical (round/sphere)	marginal (c)	S>E>M	'in' implicit	planet (orbits Sun)
23. Felicity	f	130	spherical (round/sphere)	blank (f)	S>E>M	'in' implicit	planet
24. Gemma	f	130	spherical (round/sphere)	marginal (c)	S>E>M	'in' implicit	planet
25. Harriet	f	127	spherical (sphere/sphere)	marginal (c)	S>E>M	'in' implicit	planet
26. Isobel	f	122	spherical (sphere/sphere)	marginal (c)	S>E>M	'in' explicit (part. corr.)	planet
27. Joyce	f	119	spherical (cylinder/sphere)	marginal (c)	not sure	'in' explicit (part. corr.)	planet
28. Karen	f	119	spherical (round/sphere)	marginal (c)	Earth largest	'in' explicit (corr.)	planet
29. Larissa	f	116	spherical (circle/sphere)	anglocentric (b)	Earth largest	'in' explicit (corr.)	planet
30. Maeve	f	115	spherical (sphere/sphere)	marginal (c)	S>E>M	'in' implicit	not sure
31. Nuala	f	115	spherical (round/sphere)	marginal (c)	not sure	'in' implicit	not sure

Overview of Earth responses and models: control group at second interview

			Experimental group								Control group				
Name	Sex	Age	0s	1s	2s	3s	Score	Name	Sex	Age	0s	1s	2s	3s	Score
1. Adam	m	135	2	1	8	1	20	1. Andrew	m	132	3	2	6	1	17
2. Brendan	m	134	2	1	6	3	22	2. Ben	m	131	2	4	6	0	16
3. Chris	m	133	3	1	6	2	19	3. Charlie	m	128	3	2	6	1	17
4. David	m	133	2	1	8	1	20	4. Dominic	m	128	2	2	8	0	18
5. Edward	m	133	1	1	6	4	25	5. Eamon	m	127	1	0	8	3	25
6. Francis	m	132	1	2	8	1	21	6. Freddie	m	127	6	3	3	0	9
7. Grant	m	131	2	1	7	2	21	7. George	m	127	1	0	7	4	26
8. Harry	m	128	1	1	8	2	23	8. Hugh	m	126	1	1	7	3	24
9. Ian	m	128	1	0	6	5	27	9. Ivor	m	126	3	1	7	1	18
10. James	m	127	2	0	6	4	24	10. John	m	125	3	2	7	0	16
11. Keith	m	126	1	1	9	1	22	11. Kevin	m	125	1	0	8	3	25
12. Liam	m	119	1	2	6	3	23	12. Lawrence	m	124	2	2	8	0	18
13. Matthew	m	119	1	2	8	1	21	13. Mark	m	124	3	2	7	0	16
14. Nigel	m	118	1	1	8	2	23	14. Neville	m	122	1	2	8	1	21
15. Oliver	m	117	2	2	7	1	19	15. Oscar	m	120	2	1	6	3	22
16. Peter	m	117	2	2	8	0	18	16. Paul	m	119	3	2	6	1	17
17. Roger	m	117	2	1	7	2	21	17. Richard	m	112	1	0	9	2	24
18. Alice	f	131	2	1	9	0	19	18. Anna	f	135	3	2	6	1	17
19. Bethan	f	131	1	0	8	3	25	19. Brianne	f	134	2	3	6	1	18
20. Claire	f	130	2	4	6	0	16	20. Carol	f	131	1	1	8	2	23
21. Deirdre	f	130	2	5	5	0	15	21. Doreen	f	130	1	0	10	1	23
22. Eve	f	126	2	2	7	1	19	22. Eugenie	f	129	1	0	10	1	23
23. Faith	f	125	1	1	9	1	22	23. Felicity	f	127	1	1	8	2	23
24. Grace	f	124	3	2	6	1	17	24. Gemma	f	127	2	3	7	0	17
25. Hannah	f	122	3	2	7	0	16	25. Harriet	f	124	1	1	8	2	23
26. Imogen	f	122	1	1	9	1	22	26. Isobel	f	119	1	1	7	3	24
27. Jessica	f	122	1	1	9	1	22	27. Joyce	f	116	3	2	6	1	17
28. Katy	f	119	3	3	6	0	15	28. Karen	f	116	4	3	5	0	13
29. Lucy	f	117	1	3	8	0	19	29. Larissa	f	113	3	1	8	0	17
30. Monica	f	113	2	4	6	0	16	30. Maeve	f	112	3	0	9	0	18
31. Nicky	f	112	7	2	3	0	8	31. Nuala	f	112	6	1	5	0	11

Summated Earth scores by individual (first interview)

			Experimental group								Control group				
Name	Sex	Age	0s	1s	2s	3s	Score	Name	Sex	Age	0s	1s	2s	3s	Score
1. Adam	m	138	2	0	7	3	23	1. Andrew	m	135	3	3	6	0	15
2. Brendan	m	137	2	0	7	3	23	2. Ben	m	134	1	3	7	1	20
3. Chris	m	136	2	0	5	5	25	3. Charlie	m	131	2	1	9	0	19
4. David	m	136	1	1	7	3	24	4. Dominic	m	131	1	2	8	1	21
5. Edward	m	136	1	0	5	6	28	5. Eamon	m	130	0	2	7	3	25
6. Francis	m	135	1	0	9	2	24	6. Freddie	m	130	6	2	4	0	10
7. Grant	m	134	1	1	8	2	23	7. George	m	130	1	0	8	3	25
8. Harry	m	131	2	1	7	2	21	8. Hugh	m	129	1	0	9	2	24
9. Ian	m	131	1	0	5	6	28	9. Ivor	m	129	2	1	8	1	20
10. James	m	130	0	0	8	4	28	10. John	m	128	4	1	7	0	15
11. Keith	m	129	1	1	6	4	25	11. Kevin	m	128	1	1	10	0	21
12. Liam	m	122	0	0	5	7	31	12. Lawrence	m	127	0	2	8	1	21
13. Matthew	m	122	2	1	5	4	23	13. Mark	m	127	2	1	9	0	19
14. Nigel	m	121	1	0	5	6	28	14. Neville	m	125	1	0	9	2	24
15. Oliver	m	120	3	0	7	2	20	15. Oscar	m	123	2	3	7	0	17
16. Peter	m	120	2	3	6	1	18	16. Paul	m	122	2	3	7	0	17
17. Roger	m	120	2	1	4	5	24	17. Richard	m	115	2	2	8	0	18
18. Alice	f	134	1	1	7	3	24	18. Anna	f	138	4	1	7	0	15
19. Bethan	f	134	0	0	8	4	28	19. Brianne	f	137	2	2	8	0	18
20. Claire	f	133	1	1	7	3	24	20. Carol	f	134	2	1	9	0	19
21. Deirdre	f	133	1	1	7	3	24	21. Doreen	f	133	0	1	10	1	24
22. Eve	f	129	1	1	8	2	23	22. Eugenie	f	132	1	1	9	1	22
23. Faith	f	128	1	0	7	4	26	23. Felicity	f	130	1	2	9	0	20
24. Grace	f	127	3	1	7	1	18	24. Gemma	f	130	2	1	9	0	19
25. Hannah	f	125	3	1	7	1	18	25. Harriet	f	127	1	1	10	0	21
26. Imogen	f	125	1	2	6	3	23	26. Isobel	f	122	1	0	11	0	22
27. Jessica	f	125	2	1	7	2	21	27. Joyce	f	119	3	1	8	0	17
28. Katy	f	122	3	1	7	1	18	28. Karen	f	119	2	2	7	1	19
29. Lucy	f	120	2	1	7	2	21	29. Larissa	f	116	1	2	7	2	22
30. Monica	f	116	4	1	7	0	15	30. Maeve	f	115	4	0	8	0	16
31. Nicky	f	115	4	4	4	0	12	31. Nuala	f	115	5	1	6	0	13

Summated Earth scores by individual (second interview)

			Rater 1 (author)								Rater 2				
Name	Sex	Age	0s	1s	2s	3s	Score	Name	Sex	Age	0s	1s	2s	3s	Score
1. Adam	m	135	2	1	8	1	20	1. Adam	m	135	2	4	6	0	16
2. Brendan	m	134	2	1	6	3	22	2. Brendan	m	134	2	1	8	1	20
3. Chris	m	133	3	1	6	2	19	3. Chris	m	133	3	3	6	0	15
4. David	m	133	2	1	8	1	20	4. David	m	133	2	3	7	0	17
5. Edward	m	133	1	1	6	4	25	5. Edward	m	133	1	2	8	1	21
6. Francis	m	132	1	2	8	1	21	6. Francis	m	132	1	1	9	1	22
7. Grant	m	131	2	1	7	2	21	7. Grant	m	131	2	3	7	0	17
8. Harry	m	128	1	1	8	2	23	8. Harry	m	128	1	1	8	2	23
9. Ian	m	128	1	0	6	5	27	9. Ian	m	128	1	0	4	7	29
10. James	m	127	2	0	6	4	24	10. James	m	127	2	0	4	6	26
11. Keith	m	126	1	1	9	1	22	11. Keith	m	126	1	3	8	0	19
12. Liam	m	119	1	2	6	3	23	12. Liam	m	119	1	1	9	1	22
13. Matthew	m	119	1	2	8	1	21	13. Matthew	m	119	1	4	7	0	18
14. Nigel	m	118	1	1	8	2	23	14. Nigel	m	118	1	0	11	0	22
15. Oliver	m	117	2	2	7	1	19	15. Oliver	m	117	2	2	8	0	18
16. Peter	m	117	2	2	8	0	18	16. Peter	m	117	2	1	9	0	19
17. Roger	m	117	2	1	7	2	21	17. Roger	m	117	2	2	8	0	18
18. Alice	f	131	2	1	9	0	19	18. Alice	f	131	2	3	7	0	17
19. Bethan	f	131	1	0	8	3	25	19. Bethan	f	131	1	0	7	4	26
20. Claire	f	130	2	4	6	0	16	20. Claire	f	130	2	3	6	1	18
21. Deirdre	f	130	2	5	5	0	15	21. Deirdre	f	130	2	6	4	0	14
22. Eve	f	126	2	2	7	1	19	22. Eve	f	126	2	4	6	0	16
23. Faith	f	125	1	1	9	1	22	23. Faith	f	125	1	3	8	0	19
24. Grace	f	124	3	2	6	1	17	24. Grace	f	124	3	3	6	0	15
25. Hannah	f	122	3	2	7	0	16	25. Hannah	f	122	3	3	6	0	15
26. Imogen	f	122	1	1	9	1	22	26. Imogen	f	122	1	3	8	0	19
27. Jessica	f	122	1	1	9	1	22	27. Jessica	f	122	1	3	8	0	19
28. Katy	f	119	3	3	6	0	15	28. Katy	f	119	3	4	5	0	14
29. Lucy	f	117	1	3	8	0	19	29. Lucy	f	117	1	4	7	0	18
30. Monica	f	113	2	4	6	0	16	30. Monica	f	113	2	3	7	0	17
31. Nicky	f	112	7	2	3	0	8	31. Nicky	f	112	7	1	4	0	9

Inter-rater Earth item scores (experimental group at first interview)

Name	Sex	Age	Shape (verbal/choice)	Drawing	Relative size	Nature
1. Adam	m	135	spherical (circle/sphere)	blank (g)	Sun largest	planet
2. Brendan	m	134	spherical (ball/sphere)	fuzzy (c)	S>E>M	planet
3. Chris	m	133	spherical (oval/sphere)	blank (g)	not sure	planet
4. David	m	133	near-sphere (ball/kind of sphere)	halo (d)	S>E>M	star (ball of fire/burning gas)
5. Edward	m	133	spherical (sphere/sphere)	sunbeam (e)	Moon largest	planet
6. Francis	m	132	spherical (round/sphere)	halo (d)	Sun largest	planet
7. Grant	m	131	spherical (round/sphere)	sunbeam (e)	S>E>M	planet
8. Harry	m	128	spherical (ball/sphere)	irregular (b)	S>E>M	star (ball of fire/burning gas)
9. Ian	m	128	spherical (sphere/sphere)	blank (g)	S>E>M	star
10. James	m	127	spherical (ball/sphere)	featured (a)	S>E>M	star
11. Keith	m	126	spherical (sphere/sphere)	irregular (b)	Sun largest	planet
12. Liam	m	119	spherical (sphere/sphere)	halo (d)	S>E>M	star (ball of fire/burning gas)
13. Matthew	m	119	spherical (round/sphere)	blank (g)	S>E>M	heat
14. Nigel	m	118	spherical (round/sphere)	internal (f)	S>E>M	star (ball of fire/burning gas)
15. Oliver	m	117	spherical (round/sphere)	blank (g)	not sure	planet
16. Peter	m	117	spherical (round/sphere)	blank (g)	Earth largest	planet
17. Roger	m	117	uncertain sphere (not sure/sphere)	sunbeam (e)	Earth largest	fire
18. Alice	f	131	spherical (circle/sphere)	blank (g)	S>E>M	not sure
19. Bethan	f	131	near-sphere (no real shape/kind of sphere)	blank (g)	S>E>M	fire
20. Claire	f	130	spherical (circle/sphere)	sunbeam (e)	Moon largest	light
21. Deirdre	f	130	spherical (round/sphere)	irregular (b)	Earth largest	star (ball of fire/burning gas)
22. Eve	f	126	spherical (round/sphere)	featured (a)	equivalence	star (ball of fire/burning gas)
23. Faith	f	125	spherical (round/sphere)	blank (g)	Moon largest	planet
24. Grace	f	124	non-spherical (circle/disk)	sunbeam (e)	equivalence	fire
25. Hannah	f	122	non-spherical (half/hemisphere)	blank (g)	Sun largest	star
26. Imogen	f	122	spherical (round/sphere)	blank (g)	S>E>M	planet
27. Jessica	f	122	spherical (round/sphere)	blank (g)	S>E>M	star
28. Katy	f	119	non-spherical (circle/various)	sunbeam (e)	Earth largest	heat
29. Lucy	f	117	non-spherical (round/various)	featured (a)	equivalence	planet
30. Monica	f	113	spherical (circle/sphere)	blank (g)	Earth largest	not sure
31. Nicky	f	112	non-spherical (round/various)	sunbeam (e)	S>E>M	planet

Overview of Sun responses and models: experimental group at first interview and pre-experimental treatment

Name	Sex	Age	Shape (verbal/choice)	Drawing	Relative size	Nature
1. Adam	m	138	spherical (sphere/sphere)	featured (a)	S>E>M	star
2. Brendan	m	137	spherical (sphere/sphere)	featured (a)	S>E>M	star
3. Chris	m	136	spherical (sphere/sphere)	featured (a)	S>E>M (prop.)	star (ball of fire/burning gas)
4. David	m	136	near-sphere (ball/kind of sphere)	featured (a)	S>E>M	star (ball of fire/burning gas)
5. Edward	m	136	spherical (round/sphere)	sunbeam (e)	S>E>M	star
6. Francis	m	135	near-sphere (no real shape/sphere)	featured (a)	S>E>M	star (ball of fire/burning gas)
7. Grant	m	134	spherical (round/sphere)	halo (d)	S>E>M	star
8. Harry	m	131	near-sphere (no real shape/sphere)	irregular (b)	S>E>M	star (ball of fire/burning gas)
9. Ian	m	131	spherical (sphere/sphere)	featured (a)	S>E>M (prop.)	star (ball of fire/burning gas)
10. James	m	130	spherical (sphere/sphere)	featured (a)	S>E>M (prop.)	star (ball of fire/burning gas)
11. Keith	m	129	spherical (sphere/sphere)	featured (a)	S>E>M	star (ball of fire/burning gas)
12. Liam	m	122	spherical (sphere/sphere)	featured (a)	S>E>M (prop.)	star (ball of fire/burning gas)
13. Matthew	m	122	spherical (circle/sphere)	featured (a)	Sun largest	star
14. Nigel	m	121	spherical (circle/sphere)	featured (a)	S>E>M	star
15. Oliver	m	120	spherical (sphere/sphere)	halo (d)	S>E>M	star
16. Peter	m	120	near-sphere (sphere/kind of sphere)	featured (a)	Earth largest	not sure
17. Roger	m	120	near-sphere (no real shape/sphere)	irregular (b)	S>E>M	star (ball of fire/burning gas)
18. Alice	f	134	spherical (round/sphere)	featured (a)	S>E>M	star
19. Bethan	f	134	spherical (sphere/sphere)	halo (d)	S>E>M	star (ball of fire/burning gas)
20. Claire	f	133	spherical (round/sphere)	blank (g)	S>E>M	star
21. Deirdre	f	133	spherical (round/sphere)	featured (a)	S>E>M	star (ball of fire/burning gas)
22. Eve	f	129	spherical (round/sphere)	featured (a)	S>E>M	star (ball of fire/burning gas)
23. Faith	f	128	spherical (sphere/sphere)	featured (a)	S>E>M	star (ball of fire/burning gas)
24. Grace	f	127	spherical (sphere/sphere)	sunbeam (e)	equivalence	star (ball of fire/burning gas)
25. Hannah	f	125	non-spherical (circle/disk)	blank (g)	S>E>M	star
26. Imogen	f	125	spherical (round/sphere)	blank (g)	S>E>M	star (ball of fire/burning gas)
27. Jessica	f	125	spherical (round/sphere)	featured (a)	S>E>M (prop.)	star
28. Katy	f	122	non-spherical (sort of ... /hemisphere)	sunbeam (e)	Earth largest	star (ball of fire/burning gas)
29. Lucy	f	120	spherical (sphere/sphere)	sunbeam (e)	S>E>M	star
30. Monica	f	116	uncertain non-spherical (not sure/disk)	blank (g)	equivalence	star
31. Nicky	f	115	spherical (sphere/sphere)	halo (d)	Moon largest	not sure

Overview of Sun responses and models: experimental group at second interview and post-experimental treatment

Name	Sex	Age	Shape (verbal/choice)	Drawing	Relative size	Nature
1. Adam	m	141	spherical (sphere/sphere)	featured (a)	S>E>M (prop.)	star
2. Brendan	m	140	spherical (round/sphere)	featured (a)	S>E>M	star
3. Chris	m	139	spherical (sphere/sphere)	featured (a)	S>E>M (prop.)	star (ball of fire/burning gas)
4. David	m	139	spherical (sphere/sphere)	featured (a)	S>E>M	star (ball of fire/burning gas)
5. Edward	m	139	spherical (round/sphere)	featured (a)	S>E>M	star
6. Francis	m	138	spherical (circle/sphere)	halo (d)	S>E>M	star (ball of fire/burning gas)
7. Grant	m	137	spherical (round/sphere)	halo (d)	S>E>M	star
8. Harry	m	134	near-sphere (no real shape/sphere)	featured (a)	S>E>M	star (ball of fire/burning gas)
9. Ian	m	134	spherical (like a globe/sphere)	featured (a)	S>E>M	star (ball of fire/burning gas)
10. James	m	133	near-sphere (no real shape/sphere)	featured (a)	S>E>M (prop.)	star (ball of fire/burning gas)
11. Keith	m	132	spherical (sphere/sphere)	featured (a)	S>E>M	star
12. Liam	m	125	spherical (sphere/sphere)	featured (a)	S>E>M	star
13. Matthew	m	125	spherical (sphere/sphere)	featured (a)	S>E>M	star
14. Nigel	m	124	spherical (round/sphere)	featured (a)	S>E>M (prop.)	star
15. Oliver	m	123	spherical (sphere/sphere)	halo (d)	S>E>M	star
16. Peter	m	123	spherical (round/sphere)	blank (g)	Earth largest	planet
17. Roger	m	123	near-sphere (no real shape/sphere)	featured (a)	Sun largest	star
18. Alice	f	137	spherical (sphere/sphere)	featured (a)	S>E>M	star (ball of fire/burning gas)
19. Bethan	f	137	spherical (sphere/sphere)	halo (d)	S>E>M	star (ball of fire/burning gas)
20. Claire	f	136	spherical (circle/sphere)	sunbeam (e)	S>E>M	star (ball of fire/burning gas)
21. Deirdre	f	136	spherical (round/sphere)	featured (a)	S>E>M	star (ball of fire/burning gas)
22. Eve	f	132	spherical (round/sphere)	featured (a)	S>E>M	star
23. Faith	f	131	spherical (sphere/sphere)	featured (a)	S>E>M	star
24. Grace	f	130	spherical (sphere/sphere)	sunbeam (e)	Earth largest	star
25. Hannah	f	128	not determined (star/not sure)	star (h)	S>E>M	star (ball of fire/burning gas)
26. Imogen	f	128	spherical (ball/sphere)	blank (g)	S>E>M	star
27. Jessica	f	128	spherical (round/sphere)	featured (a)	S>E>M	star (ball of fire/burning gas)
28. Katy	f	125	uncertain non-spherical (not sure/hemisphere)	blank (g)	Earth largest	heat
29. Lucy	f	123	spherical (sphere/sphere)	blank (g)	S>E>M	planet
30. Monica	f	119	spherical (sphere/sphere)	blank (g)	S>E>M	star
31. Nicky	f	118	spherical (ball/sphere)	blank (g)	Moon largest	star (ball of fire/burning gas)

Overview of Sun responses and models: experimental group at third interview and delayed

Name	Sex	Age	Shape (verbal/choice)	Drawing	Relative size	Nature
1. Andrew	m	132	non-spherical (circle/various)	blank (g)	Earth largest	not sure
2. Ben	m	131	non-spherical (ball/hemisphere)	sunbeam (e)	Sun largest	fire
3. Charlie	m	128	spherical (ball/sphere)	sunbeam (e)	Earth largest	star
4. Dominic	m	128	spherical (round/sphere)	blank (g)	Earth largest	planet
5. Eamon	m	127	near-sphere (no real shape/kind of sphere)	irregular (b)	S>E>M	star (ball of fire/burning gas)
6. Freddie	m	127	spherical (round/sphere)	blank (g)	Moon largest	star
7. George	m	127	spherical (sphere/sphere)	featured (a)	S>E>M	star (ball of fire/burning gas)
8. Hugh	m	126	spherical (round/sphere)	featured (a)	S>E>M	star (ball of fire/burning gas)
9. Ivor	m	126	spherical (round/sphere)	blank (g)	S>E>M	planet
10. John	m	125	non-spherical (round/cylinder)	blank (g)	Earth largest	not sure
11. Kevin	m	125	spherical (sphere/sphere)	halo (d)	S>E>M	star (ball of fire/burning gas)
12. Lawrence	m	124	spherical (round/sphere)	sunbeam (e)	equivalence	planet
13. Mark	m	124	spherical (round/sphere)	sunbeam (e)	Sun largest	star (ball of fire/burning gas)
14. Neville	m	122	spherical (round/sphere)	blank (g)	Earth largest	star
15. Oscar	m	120	spherical (round/sphere)	blank (g)	S>E>M	star
16. Paul	m	119	spherical (circle/sphere)	sunbeam (e)	Earth largest	not sure
17. Richard	m	112	spherical (round/sphere)	halo (d)	S>E>M	star
18. Anna	f	135	non-spherical (circle/disk)	sunbeam (e)	Earth largest	not sure
19. Brianne	f	134	near-sphere (no real shape/sort of sphere)	irregular (b)	Moon largest	not sure
20. Carol	f	131	not determined (not sure/not sure)	sunbeam (e)	S>E>M	star (ball of fire/burning gas)
21. Doreen	f	130	near-sphere (no real shape/sort of sphere)	halo (d)	S>E>M	star
22. Eugenie	f	129	spherical (round/sphere)	halo (d)	S>E>M	star (ball of fire/burning gas)
23. Felicity	f	127	spherical (round/sphere)	blank (g)	S>E>M	star (ball of fire/burning gas)
24. Gemma	f	127	spherical (round/sphere)	sunbeam (e)	equivalence	star
25. Harriet	f	124	uncertain non-spherical (not sure/hemisphere)	semicircle (h)	S>E>M	not sure
26. Isobel	f	119	spherical (ball/sphere)	internal (f)	S>E>M	star (ball of fire/burning gas)
27. Joyce	f	116	spherical (round/sphere)	blank (g)	equivalence	planet
28. Karen	f	116	non-spherical (round/hemisphere)	blank (g)	Earth largest	planet
29. Larissa	f	113	spherical (circle/sphere)	blank (g)	not sure	fire
30. Maeve	f	112	uncertain non-spherical (not sure/hemisphere)	blank (g)	S>E>M	planet
31. Nuala	f	112	spherical (ball/sphere)	sunbeam (e)	not sure	fire

Overview of Sun responses and models: control group at first interview

Name	Sex	Age	Shape (verbal/choice)	Drawing	Relative size	Nature
1. Andrew	m	135	non-spherical (round/disk)	blank (g)	Earth largest	not sure
2. Ben	m	134	spherical (ball/sphere)	blank (g)	Sun largest	not sure
3. Charlie	m	131	spherical (round/sphere)	sunbeam (e)	S>E>M	star
4. Dominic	m	131	spherical (round/sphere)	blank (g)	Earth largest	star
5. Eamon	m	130	spherical (round/sphere)	irregular (b)	S>E>M	star (ball of fire/burning gas)
6. Freddie	m	130	non-spherical (round/cylinder)	halo (d)	equivalence	star
7. George	m	130	spherical (sphere/sphere)	featured (a)	S>E>M	star (ball of fire/burning gas)
8. Hugh	m	129	spherical (sphere/sphere)	featured (a)	S>E>M	star
9. Ivor	m	129	spherical (round/sphere)	irregular (b)	S>E>M	star
10. John	m	128	spherical (round/sphere)	blank (g)	not sure	star
11. Kevin	m	128	spherical (ball/sphere)	sunbeam (e)	S>E>M	star (ball of fire/burning gas)
12. Lawrence	m	127	spherical (sphere/sphere)	sunbeam (e)	Sun largest	planet
13. Mark	m	127	spherical (round/sphere)	halo (d)	S>E>M	star (ball of fire/burning gas)
14. Neville	m	125	spherical (sphere/sphere)	halo (d)	S>E>M	star
15. Oscar	m	123	spherical (round/sphere)	internal (f)	S>E>M	star
16. Paul	m	122	spherical (circle/sphere)	sunbeam (e)	Earth largest	not sure
17. Richard	m	115	spherical (round/sphere)	blank (g)	Sun largest	not sure
18. Anna	f	138	spherical (round/sphere)	sunbeam (e)	not sure	star
19. Brianne	f	137	not determined (round/not sure)	halo (d)	Earth largest	light
20. Carol	f	134	not determined (not sure/not sure)	sunbeam (e)	S>E>M	star (ball of fire/burning gas)
21. Doreen	f	133	spherical (sphere/sphere)	blank (g)	S>E>M	star
22. Eugenie	f	132	spherical (round/sphere)	featured (a)	S>E>M	star
23. Felicity	f	130	spherical (round/sphere)	blank (g)	S>E>M	star
24. Gemma	f	130	spherical (round/sphere)	sunbeam (e)	S>E>M	star
25. Harriet	f	127	spherical (sphere/sphere)	blank (g)	S>E>M	planet
26. Isobel	f	122	spherical (ball/sphere)	blank (g)	S>E>M	not sure
27. Joyce	f	119	spherical (round/sphere)	blank (g)	not sure	planet
28. Karen	f	119	spherical (round/sphere)	sunbeam (e)	Earth largest	planet
29. Larissa	f	116	spherical (round/sphere)	sunbeam (e)	Earth largest	star
30. Maeve	f	115	non-spherical (ball/cylinder)	rectangle (h)	S>E>M	star
31. Nuala	f	115	spherical (ball/sphere)	sunbeam (e)	not sure	not sure

Overview of Sun responses and models: control group at second interview

			Experimental group								Control group				
Name	Sex	Age	0s	1s	2s	3s	Score	Name	Sex	Age	0s	1s	2s	3s	Score
1. Adam	m	135	3	5	4	0	13	1. Andrew	m	132	4	5	3	0	11
2. Brendan	m	134	3	1	8	0	17	2. Ben	m	131	2	5	5	0	15
3. Chris	m	133	4	3	5	0	13	3. Charlie	m	128	2	2	7	1	19
4. David	m	133	2	0	8	2	22	4. Dominic	m	128	3	5	4	0	13
5. Edward	m	133	3	2	6	1	17	5. Eamon	m	127	3	0	5	4	22
6. Francis	m	132	3	3	5	1	16	6. Freddie	m	127	4	4	4	0	12
7. Grant	m	131	3	2	6	1	17	7. George	m	127	2	0	7	3	23
8. Harry	m	128	3	0	8	1	19	8. Hugh	m	126	2	1	6	3	22
9. Ian	m	128	2	3	7	0	17	9. Ivor	m	126	2	4	5	1	17
10. James	m	127	3	1	7	1	18	10. John	m	125	5	4	3	0	10
11. Keith	m	126	2	3	7	0	17	11. Kevin	m	125	2	1	7	2	21
12. Liam	m	119	2	0	9	1	21	12. Lawrence	m	124	3	3	6	0	15
13. Matthew	m	119	2	4	6	0	16	13. Mark	m	124	3	2	6	1	17
14. Nigel	m	118	2	1	8	1	20	14. Neville	m	122	4	3	5	0	13
15. Oliver	m	117	5	4	3	0	10	15. Oscar	m	120	4	2	6	0	14
16. Peter	m	117	3	5	4	0	13	16. Paul	m	119	4	3	5	0	13
17. Roger	m	117	3	3	6	0	15	17. Richard	m	112	3	1	8	0	17
18. Alice	f	131	4	3	5	0	13	18. Anna	f	135	5	3	4	0	11
19. Bethan	f	131	4	2	4	2	16	19. Brianne	f	134	6	1	3	2	13
20. Claire	f	130	2	5	5	0	15	20. Carol	f	131	7	0	4	1	11
21. Deirdre	f	130	2	4	5	1	17	21. Doreen	f	130	3	0	7	2	20
22. Eve	f	126	2	3	4	3	20	22. Eugenie	f	129	3	1	6	2	19
23. Faith	f	125	3	4	5	0	14	23. Felicity	f	127	2	2	5	3	21
24. Grace	f	124	3	5	4	0	13	24. Gemma	f	127	3	2	7	0	16
25. Hannah	f	122	3	6	3	0	12	25. Harriet	f	124	4	4	4	0	12
26. Imogen	f	122	3	4	5	0	14	26. Isobel	f	119	4	0	7	1	17
27. Jessica	f	122	2	4	6	0	16	27. Joyce	f	116	2	5	4	1	16
28. Katy	f	119	5	5	2	0	9	28. Karen	f	116	3	6	3	0	12
29. Lucy	f	117	3	5	3	1	14	29. Larissa	f	113	4	4	4	0	12
30. Monica	f	113	5	3	4	0	11	30. Maeve	f	112	4	4	4	0	12
31. Nicky	f	112	4	4	4	0	12	31. Nuala	f	112	4	2	6	0	14

Summated Sun scores by individual (first interview)

			Experimental group								Control group				
Name	Sex	Age	0s	1s	2s	3s	Score	Name	Sex	Age	0s	1s	2s	3s	Score
1. Adam	m	138	0	2	8	2	24	1. Andrew	m	135	4	5	3	0	11
2. Brendan	m	137	2	0	8	2	22	2. Ben	m	134	5	2	5	0	12
3. Chris	m	136	4	0	5	3	19	3. Charlie	m	131	3	2	7	0	16
4. David	m	136	2	0	4	6	26	4. Dominic	m	131	3	4	5	0	14
5. Edward	m	136	2	2	7	1	19	5. Eamon	m	130	1	2	7	2	22
6. Francis	m	135	2	0	6	4	24	6. Freddie	m	130	4	3	5	0	13
7. Grant	m	134	1	2	9	0	20	7. George	m	130	2	0	7	3	23
8. Harry	m	131	3	0	5	4	22	8. Hugh	m	129	3	0	7	2	20
9. Ian	m	131	1	0	5	6	28	9. Ivor	m	129	3	2	6	1	17
10. James	m	130	1	0	4	7	29	10. John	m	128	5	2	5	0	12
11. Keith	m	129	1	1	7	3	24	11. Kevin	m	128	4	0	7	1	17
12. Liam	m	122	2	0	5	5	25	12. Lawrence	m	127	3	3	6	0	15
13. Matthew	m	122	2	4	4	2	18	13. Mark	m	127	3	1	7	1	18
14. Nigel	m	121	1	2	7	2	22	14. Neville	m	125	3	0	9	0	18
15. Oliver	m	120	4	0	8	0	16	15. Oscar	m	123	2	3	7	0	17
16. Peter	m	120	5	1	4	2	15	16. Paul	m	122	4	2	6	0	14
17. Roger	m	120	2	1	6	3	22	17. Richard	m	115	4	4	4	0	12
18. Alice	f	134	4	1	6	1	16	18. Anna	f	138	4	2	6	0	14
19. Bethan	f	134	1	1	7	3	24	19. Brianne	f	137	4	4	4	0	12
20. Claire	f	133	3	3	6	0	15	20. Carol	f	134	6	0	5	1	13
21. Deirdre	f	133	3	1	5	3	20	21. Doreen	f	133	3	1	8	0	17
22. Eve	f	129	2	1	6	3	22	22. Eugenie	f	132	3	1	7	1	18
23. Faith	f	128	3	0	6	3	21	23. Felicity	f	130	3	2	6	1	17
24. Grace	f	127	4	1	6	1	16	24. Gemma	f	130	4	1	7	0	15
25. Hannah	f	125	2	4	6	0	16	25. Harriet	f	127	2	3	6	1	18
26. Imogen	f	125	2	4	5	1	17	26. Isobel	f	122	5	1	6	0	13
27. Jessica	f	125	4	1	5	2	17	27. Joyce	f	119	3	4	5	0	14
28. Katy	f	122	2	4	5	1	17	28. Karen	f	119	4	3	5	0	13
29. Lucy	f	120	2	0	9	1	21	29. Larissa	f	116	3	1	8	0	17
30. Monica	f	116	5	3	4	0	11	30. Maeve	f	115	5	2	5	0	12
31. Nicky	f	115	4	2	6	0	14	31. Nuala	f	115	5	0	7	0	14

Summated Sun scores by individual (second interview)

Name	Sex	Age	Shape (verbal/choice)	Drawing	Relative size	Nature
1. Adam	m	135	spherical (circle/sphere)	e	Sun largest	'comes out at night'
2. Brendan	m	134	spherical (bumpy/sphere)	e	S>E>M	planet
3. Chris	m	133	spherical (round/sphere)	f	not sure	planet
4. David	m	133	spherical (ball/sphere)	e	S>E>M	ball of dust/rock
5. Edward	m	133	spherical (sphere/sphere)	c	Moon largest	planet
6. Francis	m	132	non-spherical (round/various)	e	Sun largest	planet
7. Grant	m	131	spherical (round/sphere)	b	S>E>M	planet
8. Harry	m	128	spherical (ball/sphere)	c	S>E>M	planet
9. Ian	m	128	spherical (sphere/sphere)	e	S>E>M	ball of dust/rock
10. James	m	127	spherical (ball/sphere)	e	S>E>M	planet
11. Keith	m	126	spherical (sphere/sphere)	e	Sun largest	'between a star and a planet'
12. Liam	m	119	spherical (sphere/sphere)	d	S>E>M	'between a star and a planet'
13. Matthew	m	119	spherical (round/sphere)	c	S>E>M	planet
14. Nigel	m	118	spherical (round/sphere)	d	S>E>M	ball of dust/rock
15. Oliver	m	117	spherical (circle/sphere)	f	not sure	not sure
16. Peter	m	117	uncertain non-spherical (banana/not sure)	g	Earth largest	'Moon is the Moon'
17. Roger	m	117	non-spherical (circle/disk)	e	Earth largest	planet
18. Alice	f	131	spherical (sphere/sphere)	e	S>E>M	not sure
19. Bethan	f	131	uncertain non-spherical (banana/not sure)	f	S>E>M	planet
20. Claire	f	130	non-spherical (circle/various)	e	Moon largest	star
21. Deirdre	f	130	spherical (round/sphere)	e	Earth largest	'shines at night'
22. Eve	f	126	spherical (round/sphere)	b	equivalence	star
23. Faith	f	125	spherical (round/sphere)	e	Moon largest	'comes out at night'
24. Grace	f	124	uncertain non-spherical (round/not sure)	e	equivalence	'soft stuff'
25. Hannah	f	122	uncertain non-spherical (not sure/semicircle)	g	Sun largest	not sure
26. Imogen	f	122	spherical (round/sphere)	e	S>E>M	'comes out at night'
27. Jessica	f	122	spherical (round/sphere)	e	S>E>M	ball of dust/rock
28. Katy	f	119	uncertain non-spherical (banana/not sure)	f	Earth largest	'comes out at night'
29. Lucy	f	117	non-spherical (round/various)	e	equivalence	planet
30. Monica	f	113	non-spherical (half/semicircle)	g	Earth largest	not sure
31. Nicky	f	112	uncertain non-spherical (not sure/various)	g	S>E>M	not sure

Overview of Moon responses and models: experimental group at first interview and pre-experimental treatment

Name	Sex	Age	Shape (verbal/choice)	Drawing	Relative size	Nature
1. Adam	m	138	spherical (sphere/sphere)	f	S>E>M	ball of dust/rock
2. Brendan	m	137	spherical (sphere/sphere)	d	S>E>M	ball of dust/rock
3. Chris	m	136	uncertain sphere (not sure/sphere)	e	S>E>M (prop.)	planet
4. David	m	136	spherical (sphere/sphere)	a	S>E>M	ball of dust/rock
5. Edward	m	136	spherical (round/sphere)	b	S>E>M	satellite
6. Francis	m	135	spherical (sphere/sphere)	a	S>E>M	ball of dust/rock
7. Grant	m	134	spherical (round/sphere)	b	S>E>M	satellite
8. Harry	m	131	spherical (sphere/sphere)	c	S>E>M	ball of dust/rock
9. Ian	m	131	spherical (sphere/sphere)	a	S>E>M (prop.)	planet
10. James	m	130	spherical (round/sphere)	e	S>E>M (prop.)	planet
11. Keith	m	129	spherical (sphere/sphere)	a	S>E>M	ball of dust/rock
12. Liam	m	122	spherical (sphere/sphere)	a	S>E>M (prop.)	satellite
13. Matthew	m	122	spherical (round/sphere)	c	Sun largest	ball of dust/rock
14. Nigel	m	121	spherical (round/sphere)	a	S>E>M	ball of dust/rock
15. Oliver	m	120	uncertain non-spherical (not sure/hemisphere)	g	S>E>M	not sure
16. Peter	m	120	spherical (round/sphere)	e	Earth largest	star
17. Roger	m	120	spherical (round/sphere)	a	S>E>M	planet
18. Alice	f	134	spherical (sphere/sphere)	e	S>E>M	not sure
19. Bethan	f	134	spherical (sphere/sphere)	a	S>E>M	ball of dust/rock
20. Claire	f	133	non-spherical (depends/sphere and disk)	e	S>E>M	planet
21. Deirdre	f	133	spherical (round/sphere)	d	S>E>M	ball of dust/rock
22. Eve	f	129	spherical (round/sphere)	a	S>E>M	ball of dust/rock
23. Faith	f	128	spherical (sphere/sphere)	e	S>E>M	ball of dust/rock
24. Grace	f	127	spherical (sphere/sphere)	e	equivalence	not sure
25. Hannah	f	125	non-spherical (depends/disk and semicircle)	e	S>E>M	star
26. Imogen	f	125	spherical (round/sphere)	e	S>E>M	'Moon is the Moon'
27. Jessica	f	125	spherical (round/sphere)	e	S>E>M (prop.)	ball of dust/rock
28. Katy	f	122	uncertain non-spherical (not sure/semicircle)	e	Earth largest	not sure
29. Lucy	f	120	spherical (sphere/sphere)	e	S>E>M	'Moon is the Moon'
30. Monica	f	116	spherical (sphere/sphere)	e	equivalence	not sure
31. Nicky	f	115	spherical (sphere/sphere)	f	Moon largest	'Moon is the Moon'

Overview of Moon responses and models: experimental group at second interview and post-experimental treatment

Name	Sex	Age	Shape (verbal/choice)	Drawing	Relative size	Nature
1. Adam	m	141	spherical (sphere/sphere)	f	S>E>M (prop.)	not sure
2. Brendan	m	140	spherical (circle/sphere)	d	S>E>M	not sure
3. Chris	m	139	spherical (sphere/sphere)	e	S>E>M (prop.)	'magnet ... moves the sea'
4. David	m	139	spherical (round/sphere)	e	S>E>M	ball of dust/rock
5. Edward	m	139	spherical (round/sphere)	b	S>E>M	ball of dust/rock
6. Francis	m	138	spherical (round/sphere)	b	S>E>M	'Moon is the Moon'
7. Grant	m	137	spherical (round/sphere)	b	S>E>M	satellite
8. Harry	m	134	spherical (sphere/sphere)	c	S>E>M	ball of dust/rock
9. Ian	m	134	spherical (sphere/sphere)	f	S>E>M	satellite
10. James	m	133	spherical (sphere/sphere)	e	S>E>M (prop.)	planet
11. Keith	m	132	spherical (sphere/sphere)	a	S>E>M	ball of dust/rock
12. Liam	m	125	spherical (sphere/sphere)	a	S>E>M	satellite
13. Matthew	m	125	spherical (sphere/sphere)	c	S>E>M	satellite
14. Nigel	m	124	spherical (round/sphere)	d	S>E>M (prop.)	planet
15. Oliver	m	123	spherical (sphere/sphere)	e	S>E>M	not sure
16. Peter	m	123	non-spherical (round/hemisphere)	e	Earth largest	'Moon is the Moon'
17. Roger	m	123	spherical (circle/sphere)	e	Sun largest	planet
18. Alice	f	137	spherical (sphere/sphere)	e	S>E>M	'Moon is the Moon'
19. Bethan	f	137	spherical (sphere/sphere)	a	S>E>M	satellite
20. Claire	f	136	non-spherical (round/hemisphere)	e	S>E>M	planet
21. Deirdre	f	136	spherical (round/sphere)	a	S>E>M	ball of dust/rock
22. Eve	f	132	spherical (round/sphere)	e	S>E>M	not sure
23. Faith	f	131	spherical (sphere/sphere)	e	S>E>M	satellite
24. Grace	f	130	spherical (round/sphere)	e	Earth largest	not sure
25. Hannah	f	128	non-spherical (circle/disk))	f	S>E>M	not sure
26. Imogen	f	128	spherical (ball/sphere)	f	S>E>M	planet
27. Jessica	f	128	spherical (round/sphere)	a	S>E>M	ball of dust/rock
28. Katy	f	125	uncertain non-spherical (not sure/hemisphere)	f	Earth largest	not sure
29. Lucy	f	123	spherical (sphere/sphere)	e	S>E>M	not sure
30. Monica	f	119	spherical (sphere/sphere)	e	S>E>M	not sure
31. Nicky	f	118	spherical (round/sphere)	f	Moon largest	not sure

Overview of Moon responses and models: experimental group at third interview and delayed

Name	Sex	Age	Shape (verbal/choice)	Drawing	Relative size	Nature
1. Andrew	m	132	spherical (ball/sphere)	e	Earth largest	not sure
2. Ben	m	131	spherical (sphere/sphere)	e	Sun largest	ball of dust/rock
3. Charlie	m	128	spherical (round/sphere)	e	Earth largest	planet
4. Dominic	m	128	uncertain non-spherical (not sure/various)	g	Earth largest	not sure
5. Eamon	m	127	spherical (circle/sphere)	d	S>E>M	ball of dust/rock
6. Freddie	m	127	uncertain non-spherical (not sure/various)	f	Moon largest	not sure
7. George	m	127	spherical (sphere/sphere)	b	S>E>M	planet
8. Hugh	m	126	spherical (round/sphere)	e	S>E>M	planet
9. Ivor	m	126	spherical (circle/sphere)	b	S>E>M	planet
10. John	m	125	non-spherical (round/hemisphere)	g	Earth largest	not sure
11. Kevin	m	125	spherical (round/sphere)	f	S>E>M	ball of dust/rock
12. Lawrence	m	124	spherical (round/sphere)	e	equivalence	planet
13. Mark	m	124	spherical (round/sphere)	c	Sun largest	planet
14. Neville	m	122	spherical (round/sphere)	e	Earth largest	planet
15. Oscar	m	120	spherical (round/sphere)	e	S>E>M	ball of dust/rock
16. Paul	m	119	spherical (circle/sphere)	c	Earth largest	planet
17. Richard	m	112	spherical (round/sphere)	e	S>E>M	not sure
18. Anna	f	135	spherical (circle/sphere)	f	Earth largest	not sure
19. Brianne	f	134	non-spherical (round/various)	e	Moon largest	not sure
20. Carol	f	131	not sure	g	S>E>M	not sure
21. Doreen	f	130	spherical (sphere/sphere)	e	S>E>M	planet
22. Eugenie	f	129	spherical (round/sphere)	f	S>E>M	not sure
23. Felicity	f	127	spherical (round/sphere)	e	S>E>M	ball of dust/rock
24. Gemma	f	127	spherical (circle/sphere)	b	equivalence	planet
25. Harriet	f	124	non-spherical (round/semicircle)	e	S>E>M	not sure
26. Isobel	f	119	spherical (round/sphere)	a	S>E>M	not sure
27. Joyce	f	116	spherical (sphere/sphere)	e	equivalence	planet
28. Karen	f	116	spherical (round/sphere)	f	Earth largest	'shines at night'
29. Larissa	f	113	spherical (circle/sphere)	c	not sure	planet
30. Maeve	f	112	non-spherical (round/disk)	c	S>E>M	ball of dust/rock
31. Nuala	f	112	spherical (round/sphere)	e	not sure	ball of dust/rock

Overview of Moon responses and models: control group at first interview

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Name	Sex	Age	Shape (verbal/choice)	Drawing	Relative size	Nature
1. Andrew	m	135	uncertain non-spherical (not sure/hemisphere)	g	Earth largest	not sure
2. Ben	m	134	non-spherical (round/hemisphere)	f	Sun largest	planet
3. Charlie	m	131	spherical (round/sphere)	f	S>E>M	planet
4. Dominic	m	131	spherical (round/sphere)	c	Earth largest	not sure
5. Eamon	m	130	spherical (round/sphere)	a	S>E>M	asteroid
6. Freddie	m	130	uncertain non-spherical (not sure/hemisphere)	g	equivalence	not sure
7. George	m	130	spherical (round/sphere)	a	S>E>M	planet
8. Hugh	m	129	spherical (round/sphere)	d	S>E>M	ball of dust/rock
9. Ivor	m	129	spherical (round/sphere)	b	S>E>M	planet
10. John	m	128	spherical (round/sphere)	e	not sure	planet
11. Kevin	m	128	spherical (round/sphere)	f	S>E>M	asteroid
12. Lawrence	m	127	spherical (sphere/sphere)	g	Sun largest	not sure
13. Mark	m	127	spherical (round/sphere)	b	S>E>M	planet
14. Neville	m	125	spherical (sphere/sphere)	c	S>E>M	planet
15. Oscar	m	123	spherical (round/sphere)	e	S>E>M	ball of dust/rock
16. Paul	m	122	spherical (circle/sphere)	e	Earth largest	planet
17. Richard	m	115	spherical (round/sphere)	f	Sun largest	not sure
18. Anna	f	138	non-spherical (round/hemisphere)	f	not sure	not sure
19. Brianne	f	137	non-spherical (round/disk)	e	Earth largest	star
20. Carol	f	134	non-spherical (round/hemisphere)	f	S>E>M	not sure
21. Doreen	f	133	spherical (sphere/sphere)	e	S>E>M	planet
22. Eugenie	f	132	spherical (round/sphere)	b	S>E>M	planet
23. Felicity	f	130	spherical (round/sphere)	f	S>E>M	ball of dust/rock
24. Gemma	f	130	spherical (round/sphere)	b	S>E>M	planet
25. Harriet	f	127	spherical (round/sphere)	f	S>E>M	planet
26. Isobel	f	122	spherical (round/sphere)	a	S>E>M	not sure
27. Joyce	f	119	spherical (sphere/sphere)	e	not sure	planet
28. Karen	f	119	spherical (round/sphere)	e	Earth largest	planet
29. Larissa	f	116	spherical (circle/sphere)	d	Earth largest	planet
30. Maeve	f	115	non-spherical (round/hemisphere)	g	S>E>M	planet
31. Nuala	f	115	spherical (round/sphere)	e	not sure	planet

Overview of Moon responses and models: control group at second interview

			Experimental group								Control group				
Name	Sex	Age	0s	1s	2s	3s	Score	Name	Sex	Age	0s	1s	2s	3s	Score
1. Adam	m	135	3	6	3	0	12	1. Andrew	m	132	3	4	4	1	15
2. Brendan	m	134	2	4	5	1	17	2. Ben	m	131	1	4	7	0	18
3. Chris	m	133	3	5	4	0	13	3. Charlie	m	128	1	6	5	0	16
4. David	m	133	2	4	6	0	16	4. Dominic	m	128	4	7	1	0	9
5. Edward	m	133	2	5	4	1	16	5. Eamon	m	127	2	3	7	0	17
6. Francis	m	132	0	8	3	0	14	6. Freddie	m	127	6	6	0	0	6
7. Grant	m	131	3	3	5	1	16	7. George	m	127	1	4	7	0	18
8. Harry	m	128	2	4	6	0	16	8. Hugh	m	126	1	5	5	1	18
9. Ian	m	128	1	2	8	1	21	9. Ivor	m	126	1	5	6	0	17
10. James	m	127	3	3	5	1	16	10. John	m	125	4	8	0	0	8
11. Keith	m	126	1	5	5	1	18	11. Kevin	m	125	2	3	6	1	18
12. Liam	m	119	1	4	6	1	19	12. Lawrence	m	124	3	7	2	0	11
13. Matthew	m	119	3	4	5	0	14	13. Mark	m	124	1	8	3	0	14
14. Nigel	m	118	2	2	8	0	18	14. Neville	m	122	1	7	3	1	16
15. Oliver	m	117	7	4	1	0	6	15. Oscar	m	120	1	4	6	1	19
16. Peter	m	117	5	7	0	0	7	16. Paul	m	119	2	4	5	1	17
17. Roger	m	117	3	8	1	0	10	17. Richard	m	112	2	5	4	1	16
18. Alice	f	131	4	2	6	0	14	18. Anna	f	135	3	7	2	0	11
19. Bethan	f	131	5	5	2	0	9	19. Brianne	f	134	2	6	3	1	15
20. Claire	f	130	1	9	2	0	13	20. Carol	f	131	7	4	1	0	6
21. Deirdre	f	130	5	5	2	0	9	21. Doreen	f	130	1	4	6	1	19
22. Eve	f	126	1	8	3	0	14	22. Eugenie	f	129	3	4	4	1	15
23. Faith	f	125	3	5	3	1	14	23. Felicity	f	127	2	4	5	1	17
24. Grace	f	124	2	7	3	0	13	24. Gemma	f	127	2	6	4	0	14
25. Hannah	f	122	4	7	1	0	9	25. Harriet	f	124	5	4	3	0	10
26. Imogen	f	122	1	5	6	0	17	26. Isobel	f	119	3	3	5	1	16
27. Jessica	f	122	2	3	6	1	18	27. Joyce	f	116	2	5	4	1	16
28. Katy	f	119	5	7	0	0	7	28. Karen	f	116	6	5	1	0	7
29. Lucy	f	117	4	6	2	0	10	29. Larissa	f	113	4	5	2	1	12
30. Monica	f	113	5	7	0	0	7	30. Maeve	f	112	1	6	5	0	16
31. Nicky	f	112	6	4	2	0	8	31. Nuala	f	112	5	3	4	0	11

Summated Moon scores by individual (first interview)

			Experimental group								Control group				
Name	Sex	Age	0s	1s	2s	3s	Score	Name	Sex	Age	0s	1s	2s	3s	Score
1. Adam	m	138	1	4	7	0	18	1. Andrew	m	135	5	6	1	0	8
2. Brendan	m	137	1	1	9	1	22	2. Ben	m	134	3	7	2	0	11
3. Chris	m	136	2	1	7	2	21	3. Charlie	m	131	2	5	5	0	15
4. David	m	136	2	1	7	2	21	4. Dominic	m	131	3	5	4	0	13
5. Edward	m	136	2	2	6	2	20	5. Eamon	m	130	2	5	3	2	17
6. Francis	m	135	1	1	7	3	24	6. Freddie	m	130	4	7	1	0	9
7. Grant	m	134	1	1	8	2	23	7. George	m	130	2	2	6	2	20
8. Harry	m	131	1	0	10	1	23	8. Hugh	m	129	1	3	7	1	20
9. Ian	m	131	1	1	6	4	25	9. Ivor	m	129	1	5	5	1	18
10. James	m	130	1	4	5	2	20	10. John	m	128	4	5	3	0	11
11. Keith	m	129	1	0	8	3	25	11. Kevin	m	128	2	5	4	1	16
12. Liam	m	122	0	1	7	4	27	12. Lawrence	m	127	4	6	2	0	10
13. Matthew	m	122	2	4	5	1	17	13. Mark	m	127	1	7	4	0	15
14. Nigel	m	121	1	1	7	3	24	14. Neville	m	125	3	2	6	1	17
15. Oliver	m	120	5	2	4	1	13	15. Oscar	m	123	2	3	6	1	18
16. Peter	m	120	4	5	3	0	11	16. Paul	m	122	1	6	4	1	17
17. Roger	m	120	2	3	4	3	20	17. Richard	m	115	3	7	2	0	11
18. Alice	f	134	3	1	7	1	18	18. Anna	f	138	5	6	1	0	8
19. Bethan	f	134	1	2	6	3	23	19. Brianne	f	137	1	8	3	0	14
20. Claire	f	133	3	4	5	0	14	20. Carol	f	134	4	7	1	0	9
21. Deirdre	f	133	1	1	8	2	23	21. Doreen	f	133	1	4	7	0	18
22. Eve	f	129	1	3	6	2	21	22. Eugenie	f	132	1	5	6	0	17
23. Faith	f	128	2	2	7	1	19	23. Felicity	f	130	2	5	5	0	15
24. Grace	f	127	4	2	5	1	15	24. Gemma	f	130	1	6	4	1	17
25. Hannah	f	125	3	6	3	0	12	25. Harriet	f	127	3	6	3	0	12
26. Imogen	f	125	1	3	6	2	21	26. Isobel	f	122	3	3	5	1	16
27. Jessica	f	125	2	1	7	2	21	27. Joyce	f	119	3	4	5	0	14
28. Katy	f	122	7	4	1	0	6	28. Karen	f	119	4	5	2	1	12
29. Lucy	f	120	1	4	6	1	19	29. Larissa	f	116	3	7	2	0	11
30. Monica	f	116	4	3	3	2	15	30. Maeve	f	115	1	9	2	0	13
31. Nicky	f	115	3	6	3	0	12	31. Nuala	f	115	4	6	2	0	10

Summated Moon scores by individual (second interview)

			Experimental group				Control group
Name	Sex	Age	Model	Name	Sex	Age	Model
1. Adam	m	135	Earth orbits the Moon	1. Andrew	m	132	not sure
2. Brendan	m	134	Earth rotates (variable period)	2. Ben	m	131	Earth rotates once every 24 hours
3. Chris	m	133	Earth rotates (variable period)	3. Charlie	m	128	Sun and Moon orbit the Earth
4. David	m	133	Earth rotates (variable period)	4. Dominic	m	128	Earth rotates once every 24 hours
5. Edward	m	133	Sun and Moon orbit the Earth	5. Eamon	m	127	Earth rotates once every 24 hours
6. Francis	m	132	Sun and Moon orbit the Earth	6. Freddie	m	127	not sure
7. Grant	m	131	Earth orbits the Sun	7. George	m	127	Earth rotates once every 24 hours
8. Harry	m	128	Earth rotates once every 24 hours	8. Hugh	m	126	Earth rotates once every 24 hours
9. Ian	m	128	Earth rotates once every 24 hours	9. Ivor	m	126	Earth rotates once every 24 hours
10. James	m	127	Sun and Moon orbit the Earth	10. John	m	125	Sun orbits the Moon
11. Keith	m	126	Earth rotates (variable period)	11. Kevin	m	125	Earth rotates once every 24 hours
12. Liam	m	119	Earth rotates once every 24 hours	12. Lawrence	m	124	Sun and Moon orbit the Earth
13. Matthew	m	119	Earth rotates once every 24 hours	13. Mark	m	124	'Sun goes down when tired'
14. Nigel	m	118	Earth rotates once every 24 hours	14. Neville	m	122	Earth rotates once every 24 hours
15. Oliver	m	117	not sure	15. Oscar	m	120	not sure
16. Peter	m	117	not sure	16. Paul	m	119	Sun and Moon orbit the Earth
17. Roger	m	117	Earth rotates once every 24 hours	17. Richard	m	112	Earth rotates (variable period)
18. Alice	f	131	Earth rotates once every 24 hours	18. Anna	f	135	Earth rotates (variable period)
19. Bethan	f	131	Earth rotates once every 24 hours	19. Brianne	f	134	Earth rotates once every 24 hours
20. Claire	f	130	not sure	20. Carol	f	131	Sun and Moon orbit the Earth
21. Deirdre	f	130	Sun and Moon orbit the Earth	21. Doreen	f	130	Earth rotates once every 24 hours
22. Eve	f	126	Sun and Moon orbit the Earth	22. Eugenie	f	129	Earth rotates once every 24 hours
23. Faith	f	125	Earth rotates once every 24 hours	23. Felicity	f	127	Earth rotates once every 24 hours
24. Grace	f	124	Earth rotates once every 24 hours	24. Gemma	f	127	'God'
25. Hannah	f	122	'so people can sleep'	25. Harriet	f	124	Sun and Moon orbit the Earth
26. Imogen	f	122	Sun and Moon orbit the Earth	26. Isobel	f	119	not sure
27. Jessica	f	122	Earth rotates once every 24 hours	27. Joyce	f	116	Moon orbits the Earth
28. Katy	f	119	not sure	28. Karen	f	116	Earth rotates once every 24 hours
29. Lucy	f	117	Sun and Moon orbit the Earth	29. Larissa	f	113	not sure
30. Monica	f	113	not sure	30. Maeve	f	112	Sun and Moon orbit the Earth
31. Nicky	f	112	not sure	31. Nuala	f	112	Sun and Moon orbit the Earth

Overview of mental models of day and night: experimental and control groups at first interview

DNX/C

			Experimental group				Control group			Experimental group (delayed)	
Name	Sex	Age	Model	Name	Sex	Age	Model	Name	Sex	Age	Model
1. Adam	m	138	Earth rotates once every 24 hours	1. Andrew	m	135	not sure	1. Adam	m	141	Earth rotates once every 24 hours
2. Brendan	m	137	Earth rotates once every 24 hours	2. Ben	m	134	Earth rotates once every 24 hours	2. Brendan	m	140	Earth rotates once every 24 hours
3. Chris	m	136	Earth rotates once every 24 hours	3. Charlie	m	131	Earth rotates once every 24 hours	3. Chris	m	139	Earth rotates once every 24 hours
4. David	m	136	Earth rotates once every 24 hours	4. Dominic	m	131	Earth orbits the Sun	4. David	m	139	Earth rotates once every 24 hours
5. Edward	m	136	Earth rotates once every 24 hours	5. Eamon	m	130	Earth rotates (variable period)	5. Edward	m	139	Earth rotates once every 24 hours
6. Francis	m	135	Earth rotates once every 24 hours	6. Freddie	m	130	not sure	6. Francis	m	138	Earth rotates once every 24 hours
7. Grant	m	134	Earth rotates once every 24 hours	7. George	m	130	Earth rotates once every 24 hours	7. Grant	m	137	Earth rotates once every 24 hours
8. Harry	m	131	Earth rotates once every 24 hours	8. Hugh	m	129	Sun and Moon orbit the Earth	8. Harry	m	134	Earth rotates once every 24 hours
9. Ian	m	131	Earth rotates once every 24 hours	9. Ivor	m	129	Earth rotates once every 24 hours	9. Ian	m	134	Earth rotates once every 24 hours
10. James	m	130	Earth rotates once every 24 hours	10. John	m	128	Earth rotates once every 24 hours	10. James	m	133	Earth rotates once every 24 hours
11. Keith	m	129	Earth rotates once every 24 hours	11. Kevin	m	128	Earth rotates once every 24 hours	11. Keith	m	132	Earth rotates once every 24 hours
12. Liam	m	122	Earth rotates once every 24 hours	12. Lawrence	m	127	Sun and Moon orbit the Earth	12. Liam	m	125	Earth rotates once every 24 hours
13. Matthew	m	122	Earth orbits the Sun	13. Mark	m	127	Earth rotates once every 24 hours	13. Matthew	m	125	Earth rotates once every 24 hours
14. Nigel	m	121	Earth rotates once every 24 hours	14. Neville	m	125	Earth rotates once every 24 hours	14. Nigel	m	124	Earth rotates once every 24 hours
15. Oliver	m	120	not sure	15. Oscar	m	123	Earth rotates once every 24 hours	15. Oliver	m	123	Earth orbits the Sun
16. Peter	m	120	Sun and Moon orbit the Earth	16. Paul	m	122	Sun and Moon orbit the Earth	16. Peter	m	123	Sun and Moon orbit the Earth
17. Roger	m	120	Earth rotates once every 24 hours	17. Richard	m	115	Earth rotates (variable period)	17. Roger	m	123	Earth rotates once every 24 hours
18. Alice	f	134	Earth rotates once every 24 hours	18. Anna	f	138	Earth rotates (variable period)	18. Alice	f	137	Earth rotates once every 24 hours
19. Bethan	f	134	Earth rotates once every 24 hours	19. Brianne	f	137	Sun and Moon orbit the Earth	19. Bethan	f	137	Earth rotates once every 24 hours
20. Claire	f	133	Earth rotates once every 24 hours	20. Carol	f	134	Sun and Moon orbit the Earth	20. Claire	f	136	Sun and Moon orbit the Earth
21. Deirdre	f	133	Earth rotates (variable period)	21. Doreen	f	133	Earth rotates once every 24 hours	21. Deirdre	f	136	Earth rotates once every 24 hours
22. Eve	f	129	Earth rotates once every 24 hours	22. Eugenie	f	132	Earth rotates once every 24 hours	22. Eve	f	132	Sun and Moon orbit the Earth
23. Faith	f	128	Earth rotates once every 24 hours	23. Felicity	f	130	Earth rotates (variable period)	23. Faith	f	131	Earth rotates once every 24 hours
24. Grace	f	127	Earth rotates once every 24 hours	24. Gemma	f	130	Earth rotates (variable period)	24. Grace	f	130	Earth rotates once every 24 hours
25. Hannah	f	125	not sure	25. Harriet	f	127	not sure	25. Hannah	f	128	clouds cover the Sun'
26. Imogen	f	125	Earth rotates once every 24 hours	26. Isobel	f	122	Earth rotates (variable period)	26. Imogen	f	128	Earth rotates once every 24 hours
27. Jessica	f	125	Earth rotates once every 24 hours	27. Joyce	f	119	not sure	27. Jessica	f	128	Earth rotates once every 24 hours
28. Katy	f	122	Satellites	28. Karen	f	119	Sun and Moon orbit the Earth	28. Katy	f	125	not sure
29. Lucy	f	120	Earth rotates once every 24 hours	29. Larissa	f	116	not sure	29. Lucy	f	123	Sun and Moon orbit the Earth
30. Monica	f	116	Sun rotates	30. Maeve	f	115	Earth rotates (variable period)	30. Monica	f	119	Earth rotates once every 24 hours
31. Nicky	f	115	Earth rotates once every 24 hours	31. Nuala	f	115	Sun and Moon orbit the Earth	31. Nicky	f	118	not sure

Overview of mental models of day and night: experimental and control groups at second and third interviews

DNx/c

			Experimental group								Control group				
Name	Sex	Age	0s	1s	2s	3s	Score	Name	Sex	Age	0s	1s	2s	3s	Score
1. Adam	m	135	2	2	2	0	6	1. Andrew	m	132	5	0	1	0	2
2. Brendan	m	134	2	0	4	0	8	2. Ben	m	131	1	0	5	0	10
3. Chris	m	133	1	1	4	0	9	3. Charlie	m	128	1	4	1	0	6
4. David	m	133	1	2	3	0	8	4. Dominic	m	128	2	0	4	0	8
5. Edward	m	133	0	4	2	0	8	5. Eamon	m	127	0	0	4	2	14
6. Francis	m	132	3	2	1	0	4	6. Freddie	m	127	5	0	1	0	2
7. Grant	m	131	1	3	2	0	7	7. George	m	127	0	0	4	2	14
8. Harry	m	128	1	0	4	1	11	8. Hugh	m	126	1	0	3	2	12
9. Ian	m	128	0	1	4	1	12	9. Ivor	m	126	2	0	3	1	9
10. James	m	127	0	4	2	0	8	10. John	m	125	1	4	1	0	6
11. Keith	m	126	1	2	3	0	8	11. Kevin	m	125	0	1	5	0	11
12. Liam	m	119	0	0	5	1	13	12. Lawrence	m	124	0	4	2	0	8
13. Matthew	m	119	1	1	4	0	9	13. Mark	m	124	2	2	2	0	6
14. Nigel	m	118	0	0	6	0	12	14. Neville	m	122	0	0	5	1	13
15. Oliver	m	117	5	0	1	0	2	15. Oscar	m	120	5	0	1	0	2
16. Peter	m	117	5	0	1	0	2	16. Paul	m	119	2	3	1	0	5
17. Roger	m	117	0	0	6	0	12	17. Richard	m	112	3	2	1	0	4
18. Alice	f	131	1	0	5	0	10	18. Anna	f	135	3	0	3	0	6
19. Bethan	f	131	0	0	5	1	13	19. Brianne	f	134	0	2	4	0	10
20. Claire	f	130	5	0	1	0	2	20. Carol	f	131	2	4	0	0	4
21. Deirdre	f	130	2	4	0	0	4	21. Doreen	f	130	0	0	5	1	13
22. Eve	f	126	1	3	2	0	7	22. Eugenie	f	129	0	1	4	1	12
23. Faith	f	125	1	1	4	0	9	23. Felicity	f	127	0	0	6	0	12
24. Grace	f	124	0	1	5	0	11	24. Gemma	f	127	4	1	1	0	3
25. Hannah	f	122	3	2	1	0	4	25. Harriet	f	124	1	3	2	0	7
26. Imogen	f	122	2	3	1	0	5	26. Isobel	f	119	5	0	1	0	2
27. Jessica	f	122	1	0	4	1	11	27. Joyce	f	116	3	2	1	0	4
28. Katy	f	119	5	0	1	0	2	28. Karen	f	116	2	0	3	1	9
29. Lucy	f	117	3	2	1	0	4	29. Larissa	f	113	5	0	1	0	2
30. Monica	f	113	5	0	1	0	2	30. Maeve	f	112	2	3	1	0	5
31. Nicky	f	112	5	0	1	0	2	31. Nuala	f	112	1	4	1	0	6

Summated day and night scores by individual (first interview)

			Experimental group								Control group				
Name	Sex	Age	0s	1s	2s	3s	Score	Name	Sex	Age	0s	1s	2s	3s	Score
1. Adam	m	138	0	1	5	0	11	1. Andrew	m	135	4	1	1	0	3
2. Brendan	m	137	0	0	4	2	14	2. Ben	m	134	2	0	4	0	8
3. Chris	m	136	0	0	5	1	13	3. Charlie	m	131	1	1	4	0	9
4. David	m	136	0	1	4	1	12	4. Dominic	m	131	1	3	2	0	7
5. Edward	m	136	0	0	5	1	13	5. Eamon	m	130	0	3	3	0	9
6. Francis	m	135	0	0	6	0	12	6. Freddie	m	130	6	0	0	0	0
7. Grant	m	134	0	1	5	0	11	7. George	m	130	0	0	5	1	13
8. Harry	m	131	0	0	5	1	13	8. Hugh	m	129	1	4	1	0	6
9. Ian	m	131	0	0	3	3	15	9. Ivor	m	129	1	0	5	0	10
10. James	m	130	0	0	5	1	13	10. John	m	128	1	0	5	0	10
11. Keith	m	129	0	0	6	0	12	11. Kevin	m	128	0	0	6	0	12
12. Liam	m	122	0	0	5	1	13	12. Lawrence	m	127	1	4	1	0	6
13. Matthew	m	122	1	3	2	0	7	13. Mark	m	127	2	0	4	0	8
14. Nigel	m	121	0	2	3	1	11	14. Neville	m	125	0	1	5	0	11
15. Oliver	m	120	5	1	0	0	1	15. Oscar	m	123	2	0	4	0	8
16. Peter	m	120	1	4	1	0	6	16. Paul	m	122	1	4	1	0	6
17. Roger	m	120	1	0	3	2	12	17. Richard	m	115	3	0	3	0	6
18. Alice	f	134	1	0	3	2	12	18. Anna	f	138	3	0	3	0	6
19. Bethan	f	134	0	0	4	2	14	19. Brianne	f	137	1	4	1	0	6
20. Claire	f	133	1	1	4	0	9	20. Carol	f	134	2	1	3	0	7
21. Deirdre	f	133	0	2	4	0	10	21. Doreen	f	133	0	0	6	0	12
22. Eve	f	129	1	2	3	0	8	22. Eugenie	f	132	1	0	5	0	10
23. Faith	f	128	0	0	4	2	14	23. Felicity	f	130	1	0	4	1	11
24. Grace	f	127	1	0	5	0	10	24. Gemma	f	130	3	0	3	0	6
25. Hannah	f	125	4	1	1	0	3	25. Harriet	f	127	5	0	1	0	2
26. Imogen	f	125	1	0	3	2	12	26. Isobel	f	122	2	0	4	0	8
27. Jessica	f	125	1	0	5	0	10	27. Joyce	f	119	5	0	1	0	2
28. Katy	f	122	1	3	2	0	7	28. Karen	f	119	1	4	1	0	6
29. Lucy	f	120	2	0	3	1	9	29. Larissa	f	116	4	0	2	0	4
30. Monica	f	116	1	4	1	0	6	30. Maeve	f	115	2	1	3	0	7
31. Nicky	f	115	1	0	5	0	10	31. Nuala	f	115	2	3	1	0	5

Summated day and night scores by individual (second interview)

Experimental group				Control group			
Name	Sex	Age	Model	Name	Sex	Age	Model
1. Adam	m	135	not sure	1. Andrew	m	132	not sure
2. Brendan	m	134	not sure	2. Ben	m	131	not sure
3. Chris	m	133	not sure	3. Charlie	m	128	not sure
4. David	m	133	Sun heats up and cools down	4. Dominic	m	128	not sure
5. Edward	m	133	Sun orbits the Earth (at different speeds)	5. Eamon	m	127	Earth orbits the Sun ('flowers grow in spring')
6. Francis	m	132	Sun orbits the Earth (stops at times)	6. Freddie	m	127	not sure
7. Grant	m	131	rotation of the Earth (day/night confusion)	7. George	m	127	tilt of Earth's axis as Earth orbits the Sun
8. Harry	m	128	rotation of the Earth (day/night confusion)	8. Hugh	m	126	not sure
9. Ian	m	128	Earth orbits the Sun (some parts closer than others)	9. Ivor	m	126	Moon gets in the way
10. James	m	127	not sure	10. John	m	125	not sure
11. Keith	m	126	not sure	11. Kevin	m	125	Earth and Sun closer (Earth moves to Sun - summer)
12. Liam	m	119	Earth orbits the Sun (not clear)	12. Lawrence	m	124	not sure
13. Matthew	m	119	Earth and Sun closer (Earth moves to Sun - summer)	13. Mark	m	124	rotation of the Earth (day/night confusion)
14. Nigel	m	118	Earth and Sun closer (Sun moves to Earth - summer)	14. Neville	m	122	Earth orbits the Sun ('Sun shines lower and lower')
15. Oliver	m	117	not sure	15. Oscar	m	120	not sure
16. Peter	m	117	not sure	16. Paul	m	119	'leaves falling'
17. Roger	m	117	not sure	17. Richard	m	112	not sure
18. Alice	f	131	Sun orbits the Earth (stops at times)	18. Anna	f	135	'cold air comes'
19. Bethan	f	131	not sure	19. Brianne	f	134	not sure
20. Claire	f	130	'it's to do with the Moon'	20. Carol	f	131	not sure
21. Deirdre	f	130	not sure	21. Doreen	f	130	rotation of the Earth (day/night confusion)
22. Eve	f	126	Earth and Sun closer (Earth moves to Sun - summer)	22. Eugenie	f	129	not sure
23. Faith	f	125	not sure	23. Felicity	f	127	tilt of Earth's axis as Earth orbits the Sun
24. Grace	f	124	not sure	24. Gemma	f	127	not sure
25. Hannah	f	122	'flowers ... they grow and die'	25. Harriet	f	124	Sun heats up and cools down
26. Imogen	f	122	Sun orbits the Earth (stops at times)	26. Isobel	f	119	'weather'
27. Jessica	f	122	not sure	27. Joyce	f	116	Sun heats up and cools down
28. Katy	f	119	not sure	28. Karen	f	116	not sure
29. Lucy	f	117	not sure	29. Larissa	f	113	not sure
30. Monica	f	113	not sure	30. Maeve	f	112	'days get shorter'
31. Nicky	f	112	not sure	31. Nuala	f	112	not sure

Overview of mental models of seasonal change: experimental and control groups at first interview

Name	Sex	Age	Experimental group Model	Name	Sex	Age	Control group Model	Name	Sex	Age	Experimental group (delayed) Model
1. Adam	m	138	tilt of Earth's axis as Earth orbits the Sun	1. Andrew	m	135	not sure	1. Adam	m	141	not sure
2. Brendan	m	137	Earth orbits the Sun	2. Ben	m	134	'weather'	2. Brendan	m	140	Earth orbits the Sun
3. Chris	m	136	not sure	3. Charlie	m	131	not sure	3. Chris	m	139	tilt of Earth's axis as Earth orbits the Sun
4. David	m	136	tilt of Earth's axis as Earth orbits the Sun	4. Dominic	m	131	not sure	4. David	m	139	not sure
5. Edward	m	136	tilt of Earth's axis as Earth orbits the Sun	5. Eamon	m	130	rotation of the Earth (day/night confusion)	5. Edward	m	139	rotation of the Earth (day/night confusion)
6. Francis	m	135	tilt of Earth's axis as Earth orbits the Sun	6. Freddie	m	130	not sure	6. Francis	m	138	Earth orbits the Sun (clouds)
7. Grant	m	134	tilt of Earth's axis as Earth orbits the Sun	7. George	m	130	tilt of Earth's axis as Earth orbits the Sun	7. Grant	m	137	tilt of Earth's axis as Earth orbits the Sun
8. Harry	m	131	not sure	8. Hugh	m	129	Sun heats up and cools down	8. Harry	m	134	not sure
9. Ian	m	131	tilt of Earth's axis as Earth orbits the Sun	9. Ivor	m	129	not sure	9. Ian	m	134	tilt of Earth's axis as Earth orbits the Sun
10. James	m	130	tilt of Earth's axis as Earth orbits the Sun	10. John	m	128	not sure	10. James	m	133	tilt of Earth's axis as Earth orbits the Sun
11. Keith	m	129	tilt of Earth's axis as Earth orbits the Sun	11. Kevin	m	128	tilt of Earth's axis as Earth orbits the Sun	11. Keith	m	132	tilt of Earth's axis as Earth orbits the Sun
12. Liam	m	122	tilt of Earth's axis as Earth orbits the Sun	12. Lawrence	m	127	'weather'	12. Liam	m	125	tilt of Earth's axis as Earth orbits the Sun
13. Matthew	m	122	Sun moves up and down	13. Mark	m	127	not sure	13. Matthew	m	125	Earth orbits the Sun
14. Nigel	m	121	tilt of Earth's axis as Earth orbits the Sun	14. Neville	m	125	Sun moves up and down	14. Nigel	m	124	tilt of Earth's axis as Earth orbits the Sun
15. Oliver	m	120	not sure	15. Oscar	m	123	Sun moves up and down	15. Oliver	m	123	not sure
16. Peter	m	120	Sun orbits the Earth (at different speeds)	16. Paul	m	122	not sure	16. Peter	m	123	rotation of the Earth (day/night confusion)
17. Roger	m	120	tilt of Earth's axis as Earth orbits the Sun	17. Richard	m	115	Earth and Sun closer (Sun moves - summer)	17. Roger	m	123	not sure
18. Alice	f	134	tilt of Earth's axis as Earth orbits the Sun	18. Anna	f	138	not sure	18. Alice	f	137	Sun orbits the Earth (stops at times)
19. Bethan	f	134	tilt of Earth's axis as Earth orbits the Sun	19. Brianne	f	137	not sure	19. Bethan	f	137	tilt of Earth's axis as Earth orbits the Sun
20. Claire	f	133	Earth orbits the Sun (stops in places)	20. Carol	f	134	not sure	20. Claire	f	136	'shadow over the Earth'
21. Deirdre	f	133	Sun orbits the Earth (at different speeds)	21. Doreen	f	133	Earth orbits the Sun (faces Sun/Moon)	21. Deirdre	f	136	Earth orbits the Sun
22. Eve	f	129	rotation of the Earth (day/night confusion)	22. Eugenie	f	132	not sure	22. Eve	f	132	Sun orbits the Earth (stops at times)
23. Faith	f	128	Earth orbits the Sun (closer in summer)	23. Felicity	f	130	tilt of Earth's axis as Earth orbits the Sun	23. Faith	f	131	not sure
24. Grace	f	127	Earth orbits the Sun (closer in summer)	24. Gemma	f	130	not sure	24. Grace	f	130	not sure
25. Hannah	f	125	not sure	25. Harriet	f	127	'Sun gets cold'	25. Hannah	f	128	not sure
26. Imogen	f	125	tilt of Earth's axis as Earth orbits the Sun	26. Isobel	f	122	not sure	26. Imogen	f	128	tilt of Earth's axis as Earth orbits the Sun
27. Jessica	f	125	not sure	27. Joyce	f	119	not sure	27. Jessica	f	128	not sure
28. Katy	f	122	not sure	28. Karen	f	119	'weather'	28. Katy	f	125	not sure
29. Lucy	f	120	tilt of Earth's axis as Earth orbits the Sun	29. Larissa	f	116	not sure	29. Lucy	f	123	not sure
30. Monica	f	116	Sun's dark side	30. Maeve	f	115	'weather'	30. Monica	f	119	not sure
31. Nicky	f	115	Earth orbits the Sun (stops at times)	31. Nuala	f	115	not sure	31. Nicky	f	118	not sure

Overview of mental models of seasonal change: experimental and control groups at second and third interviews

SCx/c

			Experimental group								Control group				
Name	Sex	Age	0s	1s	2s	3s	Score	Name	Sex	Age	0s	1s	2s	3s	Score
1. Adam	m	135	4	1	1	0	3	1. Andrew	m	132	4	1	1	0	3
2. Brendan	m	134	5	0	1	0	2	2. Ben	m	131	4	1	1	0	3
3. Chris	m	133	5	0	1	0	2	3. Charlie	m	128	3	3	0	0	3
4. David	m	133	2	4	0	0	4	4. Dominic	m	128	4	1	1	0	3
5. Edward	m	133	2	3	1	0	5	5. Eamon	m	127	1	4	1	0	6
6. Francis	m	132	2	3	1	0	5	6. Freddie	m	127	5	0	1	0	2
7. Grant	m	131	2	2	2	0	6	7. George	m	127	1	0	5	0	10
8. Harry	m	128	4	2	0	0	2	8. Hugh	m	126	5	0	1	0	2
9. Ian	m	128	1	5	0	0	5	9. Ivor	m	126	3	2	1	0	4
10. James	m	127	4	0	2	0	4	10. John	m	125	6	0	0	0	0
11. Keith	m	126	4	0	2	0	4	11. Kevin	m	125	0	4	2	0	8
12. Liam	m	119	1	3	2	0	7	12. Lawrence	m	124	4	0	2	0	4
13. Matthew	m	119	2	2	2	0	6	13. Mark	m	124	2	3	1	0	5
14. Nigel	m	118	1	4	1	0	6	14. Neville	m	122	2	2	1	1	7
15. Oliver	m	117	4	1	1	0	3	15. Oscar	m	120	5	1	0	0	1
16. Peter	m	117	4	2	0	0	2	16. Paul	m	119	3	3	0	0	3
17. Roger	m	117	5	1	0	0	1	17. Richard	m	112	4	0	2	0	4
18. Alice	f	131	3	2	1	0	4	18. Anna	f	135	3	3	0	0	3
19. Bethan	f	131	4	0	2	0	4	19. Brianne	f	134	4	0	2	0	4
20. Claire	f	130	3	2	1	0	4	20. Carol	f	131	4	0	2	0	4
21. Deirdre	f	130	6	0	0	0	0	21. Doreen	f	130	1	3	2	0	7
22. Eve	f	126	2	4	0	0	4	22. Eugenie	f	129	5	0	1	0	2
23. Faith	f	125	4	2	0	0	2	23. Felicity	f	127	1	1	4	0	9
24. Grace	f	124	5	1	0	0	1	24. Gemma	f	127	5	0	1	0	2
25. Hannah	f	122	4	2	0	0	2	25. Harriet	f	124	3	2	1	0	4
26. Imogen	f	122	2	3	1	0	5	26. Isobel	f	119	4	1	1	0	3
27. Jessica	f	122	5	0	1	0	2	27. Joyce	f	116	3	2	1	0	4
28. Katy	f	119	5	0	1	0	2	28. Karen	f	116	5	1	0	0	1
29. Lucy	f	117	4	2	0	0	2	29. Larissa	f	113	6	0	0	0	0
30. Monica	f	113	5	0	1	0	2	30. Maeve	f	112	3	2	1	0	4
31. Nicky	f	112	6	0	0	0	0	31. Nuala	f	112	5	0	1	0	2

Summated seasonal change scores by individual (first interview)

			Experimental group								Control group				
Name	Sex	Age	0s	1s	2s	3s	Score	Name	Sex	Age	0s	1s	2s	3s	Score
1. Adam	m	138	0	1	4	1	12	1. Andrew	m	135	4	1	1	0	3
2. Brendan	m	137	1	4	1	0	6	2. Ben	m	134	2	2	2	0	6
3. Chris	m	136	2	1	1	2	9	3. Charlie	m	131	5	1	0	0	1
4. David	m	136	0	1	2	3	14	4. Dominic	m	131	4	1	1	0	3
5. Edward	m	136	0	0	5	1	13	5. Eamon	m	130	2	3	1	0	5
6. Francis	m	135	1	1	2	2	11	6. Freddie	m	130	4	1	1	0	3
7. Grant	m	134	0	0	3	3	15	7. George	m	130	0	0	4	2	14
8. Harry	m	131	5	0	1	0	2	8. Hugh	m	129	3	2	1	0	4
9. Ian	m	131	0	0	2	4	16	9. Ivor	m	129	6	0	0	0	0
10. James	m	130	0	0	4	2	14	10. John	m	128	6	0	0	0	0
11. Keith	m	129	0	0	4	2	14	11. Kevin	m	128	0	1	5	0	11
12. Liam	m	122	0	0	3	3	15	12. Lawrence	m	127	2	1	3	0	7
13. Matthew	m	122	2	3	1	0	5	13. Mark	m	127	4	1	1	0	3
14. Nigel	m	121	0	0	3	3	15	14. Neville	m	125	1	4	1	0	6
15. Oliver	m	120	6	0	0	0	0	15. Oscar	m	123	3	3	0	0	3
16. Peter	m	120	1	5	0	0	5	16. Paul	m	122	5	1	0	0	1
17. Roger	m	120	1	2	3	0	8	17. Richard	m	115	2	2	2	0	6
18. Alice	f	134	0	1	3	2	13	18. Anna	f	138	5	1	0	0	1
19. Bethan	f	134	0	0	3	3	15	19. Brianne	f	137	4	0	2	0	4
20. Claire	f	133	2	4	0	0	4	20. Carol	f	134	4	0	2	0	4
21. Deirdre	f	133	1	3	2	0	7	21. Doreen	f	133	0	2	4	0	10
22. Eve	f	129	1	4	1	0	6	22. Eugenie	f	132	5	0	1	0	2
23. Faith	f	128	1	1	4	0	9	23. Felicity	f	130	0	1	5	0	11
24. Grace	f	127	2	4	0	0	4	24. Gemma	f	130	5	0	1	0	2
25. Hannah	f	125	5	1	0	0	1	25. Harriet	f	127	4	1	1	0	3
26. Imogen	f	125	0	0	3	3	15	26. Isobel	f	122	5	1	0	0	1
27. Jessica	f	125	4	0	2	0	4	27. Joyce	f	119	5	0	1	0	2
28. Katy	f	122	4	1	1	0	3	28. Karen	f	119	4	2	0	0	2
29. Lucy	f	120	0	0	3	3	15	29. Larissa	f	116	5	1	0	0	1
30. Monica	f	116	1	4	1	0	6	30. Maeve	f	115	4	1	1	0	3
31. Nicky	f	115	2	4	0	0	4	31. Nuala	f	115	5	1	0	0	1

Summated seasonal change scores by individual (second interview)

Experimental group				Control group			
Name	Sex	Age	Model	Name	Sex	Age	Model
1. Adam	m	135	clouds	1. Andrew	m	132	not sure
2. Brendan	m	134	not sure	2. Ben	m	131	amount of lit side seen as Earth rotates
3. Chris	m	133	clouds	3. Charlie	m	128	amount of lit side seen as Earth rotates
4. David	m	133	Earth shadow (eclipse)	4. Dominic	m	128	not sure
5. Edward	m	133	planets get in the way	5. Eamon	m	127	Earth shadow (eclipse)
6. Francis	m	132	amount of lit side seen as Earth rotates	6. Freddie	m	127	not sure
7. Grant	m	131	Earth shadow (eclipse)	7. George	m	127	amount of lit side seen as the Moon orbits the Earth
8. Harry	m	128	not sure	8. Hugh	m	126	Earth shadow (eclipse)
9. Ian	m	128	Earth shadow (eclipse)	9. Ivor	m	126	amount of lit side seen as Earth rotates
10. James	m	127	'Moon's dark side'	10. John	m	125	not sure
11. Keith	m	126	'Moon's dark side'	11. Kevin	m	125	not sure
12. Liam	m	119	planets get in the way	12. Lawrence	m	124	Moon goes behind the Sun
13. Matthew	m	119	'Moon gets covered in darkness'	13. Mark	m	124	not sure
14. Nigel	m	118	'Moon's dark side'	14. Neville	m	122	clouds
15. Oliver	m	117	not sure	15. Oscar	m	120	planets get in the way
16. Peter	m	117	'something to do with the sky'	16. Paul	m	119	'darkness falls on the Moon'
17. Roger	m	117	clouds	17. Richard	m	112	Earth shadow (eclipse)
18. Alice	f	131	not sure	18. Anna	f	135	clouds
19. Bethan	f	131	not sure	19. Brianne	f	134	clouds
20. Claire	f	130	clouds	20. Carol	f	131	not sure
21. Deirdre	f	130	not sure	21. Doreen	f	130	amount of lit side seen as Earth rotates
22. Eve	f	126	clouds	22. Eugenie	f	129	not sure
23. Faith	f	125	not sure	23. Felicity	f	127	clouds
24. Grace	f	124	clouds	24. Gemma	f	127	'the Moon gets cold'
25. Hannah	f	122	not sure	25. Harriet	f	124	Earth shadow (eclipse)
26. Imogen	f	122	not sure	26. Isobel	f	119	clouds
27. Jessica	f	122	not sure	27. Joyce	f	116	'the seasons'
28. Katy	f	119	'Hallowe'en'	28. Karen	f	116	'coldness ... the time of day'
29. Lucy	f	117	not sure	29. Larissa	f	113	not sure
30. Monica	f	113	not sure	30. Maeve	f	112	'darkness'
31. Nicky	f	112	'something to do with darkness'	31. Nuala	f	112	'each day a bit of it fades away'

Overview of mental models of the Moon's phases: experimental and control groups at first interview

			Experimental group				Control group				Experimental group (delayed)
Name	Sex	Age	Model	Name	Sex	Age	Model	Name	Sex	Age	Model
1. Adam	m	138	lit side seen as Moon orbits Earth	1. Andrew	m	135	not sure	1. Adam	m	141	not sure
2. Brendan	m	137	lit side seen as Moon orbits Earth	2. Ben	m	134	clouds	2. Brendan	m	140	Earth shadow (eclipse)
3. Chris	m	136	lit side seen as Moon orbits Earth	3. Charlie	m	131	lit side seen as Earth rotates	3. Chris	m	139	lit side seen as Earth rotates
4. David	m	136	lit side seen as Moon orbits Earth	4. Dominic	m	131	clouds	4. David	m	139	lit side seen as Moon orbits Earth
5. Edward	m	136	Earth shadow (eclipse)	5. Eamon	m	130	Moon goes behind the Sun	5. Edward	m	139	Earth shadow (eclipse)
6. Francis	m	135	lit side seen as Moon orbits Earth	6. Freddie	m	130	not sure	6. Francis	m	138	lit side seen as Earth rotates
7. Grant	m	134	lit side seen as Moon orbits Earth	7. George	m	130	lit side seen as Moon orbits Earth	7. Grant	m	137	lit side seen as Moon orbits Earth
8. Harry	m	131	lit side seen as Moon orbits Earth	8. Hugh	m	129	Moon goes behind the Sun	8. Harry	m	134	'it spins ... hard to explain'
9. Ian	m	131	lit side seen as Moon orbits Earth	9. Ivor	m	129	lit side seen as Moon orbits Earth	9. Ian	m	134	lit side seen as Moon orbits Earth
10. James	m	130	Earth shadow (eclipse)	10. John	m	128	clouds	10. James	m	133	Earth shadow (eclipse)
11. Keith	m	129	lit side seen as Moon orbits Earth	11. Kevin	m	128	Earth shadow (eclipse)	11. Keith	m	132	lit side seen as Moon orbits Earth
12. Liam	m	122	lit side seen as Moon orbits Earth	12. Lawrence	m	127	Moon goes behind the Sun	12. Liam	m	125	Earth shadow (eclipse)
13. Matthew	m	122	lit side seen as Earth rotates	13. Mark	m	127	clouds	13. Matthew	m	125	Earth shadow (eclipse)
14. Nigel	m	121	Earth shadow (eclipse)	14. Neville	m	125	Moon goes behind the Sun	14. Nigel	m	124	lit side seen as Earth rotates
15. Oliver	m	120	not sure	15. Oscar	m	123	clouds	15. Oliver	m	123	not sure
16. Peter	m	120	not sure	16. Paul	m	122	'sky covers the Moon'	16. Peter	m	123	not sure
17. Roger	m	120	clouds	17. Richard	m	115	not sure	17. Roger	m	123	clouds
18. Alice	f	134	lit side seen as Moon orbits Earth	18. Anna	f	138	'sky moves'	18. Alice	f	137	Earth shadow (eclipse)
19. Bethan	f	134	lit side seen as Moon orbits Earth	19. Brianne	f	137	clouds	19. Bethan	f	137	lit side seen as Moon orbits Earth
20. Claire	f	133	clouds	20. Carol	f	134	lit side seen as Earth rotates	20. Claire	f	136	clouds
21. Deirdre	f	133	lit side seen as Moon orbits Earth	21. Doreen	f	133	lit side seen as Earth rotates	21. Deirdre	f	136	Moon goes behind the Sun
22. Eve	f	129	lit side seen as Moon orbits Earth	22. Eugenie	f	132	not sure	22. Eve	f	132	Moon goes behind the Sun
23. Faith	f	128	lit side seen as Moon orbits Earth	23. Felicity	f	130	not sure	23. Faith	f	131	lit side seen as Moon orbits Earth
24. Grace	f	127	clouds	24. Gemma	f	130	Earth shadow (eclipse)	24. Grace	f	130	lit side seen as Moon orbits Earth
25. Hannah	f	125	Moon goes behind the Sun	25. Harriet	f	127	clouds	25. Hannah	f	128	planets get in the way
26. Imogen	f	125	not sure	26. Isobel	f	122	clouds	26. Imogen	f	128	not sure
27. Jessica	f	125	not sure	27. Joyce	f	119	'seasons'	27. Jessica	f	128	not sure
28. Katy	f	122	'Sun reflects on it'	28. Karen	f	119	not sure	28. Katy	f	125	not sure
29. Lucy	f	120	Moon goes behind the Sun	29. Larissa	f	116	clouds	29. Lucy	f	123	'when it [Sun] gets nearer to the Moon'
30. Monica	f	116	not sure	30. Maeve	f	115	not sure	30. Monica	f	119	not sure
31. Nicky	f	115	not sure	31. Nuala	f	115	clouds	31. Nicky	f	118	not sure

Overview of mental models of the Moon's phases: experimental and control groups at second and third interviews

			Experimental group								Control group				
Name	Sex	Age	0s	1s	2s	3s	Score	Name	Sex	Age	0s	1s	2s	3s	Score
1. Adam	m	135	1	5	0	0	5	1. Andrew	m	132	4	1	1	0	3
2. Brendan	m	134	4	0	2	0	4	2. Ben	m	131	2	3	0	1	6
3. Chris	m	133	2	3	1	0	5	3. Charlie	m	128	2	3	1	0	5
4. David	m	133	2	3	1	0	5	4. Dominic	m	128	5	0	1	0	2
5. Edward	m	133	1	3	2	0	7	5. Eamon	m	127	1	4	1	0	6
6. Francis	m	132	1	3	2	0	7	6. Freddie	m	127	5	1	0	0	1
7. Grant	m	131	2	3	1	0	5	7. George	m	127	0	1	5	0	11
8. Harry	m	128	4	0	2	0	4	8. Hugh	m	126	2	3	0	1	6
9. Ian	m	128	1	4	1	0	6	9. Ivor	m	126	3	3	0	0	3
10. James	m	127	4	2	0	0	2	10. John	m	125	6	0	0	0	0
11. Keith	m	126	3	2	1	0	4	11. Kevin	m	125	4	0	2	0	4
12. Liam	m	119	2	3	1	0	5	12. Lawrence	m	124	2	3	1	0	5
13. Matthew	m	119	4	1	1	0	3	13. Mark	m	124	5	0	1	0	2
14. Nigel	m	118	3	3	0	0	3	14. Neville	m	122	2	2	1	1	7
15. Oliver	m	117	5	0	1	0	2	15. Oscar	m	120	4	2	0	0	2
16. Peter	m	117	4	1	1	0	3	16. Paul	m	119	4	1	1	0	3
17. Roger	m	117	2	4	0	0	4	17. Richard	m	112	4	2	0	0	2
18. Alice	f	131	5	0	1	0	2	18. Anna	f	135	3	3	0	0	3
19. Bethan	f	131	6	0	0	0	0	19. Brianne	f	134	3	2	0	1	5
20. Claire	f	130	1	4	1	0	6	20. Carol	f	131	5	0	1	0	2
21. Deirdre	f	130	5	0	1	0	2	21. Doreen	f	130	1	3	1	1	8
22. Eve	f	126	2	3	1	0	5	22. Eugenie	f	129	5	0	0	1	3
23. Faith	f	125	4	0	2	0	4	23. Felicity	f	127	2	2	1	1	7
24. Grace	f	124	2	3	1	0	5	24. Gemma	f	127	4	1	1	0	3
25. Hannah	f	122	6	0	0	0	0	25. Harriet	f	124	2	3	1	0	5
26. Imogen	f	122	5	0	1	0	2	26. Isobel	f	119	3	2	1	0	4
27. Jessica	f	122	6	0	0	0	0	27. Joyce	f	116	4	1	1	0	3
28. Katy	f	119	4	1	1	0	3	28. Karen	f	116	4	1	1	0	3
29. Lucy	f	117	5	0	1	0	2	29. Larissa	f	113	5	0	1	0	2
30. Monica	f	113	5	0	1	0	2	30. Maeve	f	112	3	2	1	0	4
31. Nicky	f	112	5	1	0	0	1	31. Nuala	f	112	4	2	0	0	2

Summated Moon phase scores by individual (first interview)

			Experimental group								Control group				
Name	Sex	Age	0s	1s	2s	3s	Score	Name	Sex	Age	0s	1s	2s	3s	Score
1. Adam	m	138	0	1	5	0	11	1. Andrew	m	135	5	0	0	1	3
2. Brendan	m	137	0	0	6	0	12	2. Ben	m	134	4	2	0	0	2
3. Chris	m	136	0	1	5	0	11	3. Charlie	m	131	2	3	1	0	5
4. David	m	136	0	2	4	0	10	4. Dominic	m	131	4	1	0	1	4
5. Edward	m	136	1	4	1	0	6	5. Eamon	m	130	2	3	0	1	6
6. Francis	m	135	0	3	3	0	9	6. Freddie	m	130	6	0	0	0	0
7. Grant	m	134	0	2	3	1	11	7. George	m	130	2	1	1	2	9
8. Harry	m	131	1	1	3	1	10	8. Hugh	m	129	2	3	1	0	5
9. Ian	m	131	0	0	2	4	16	9. Ivor	m	129	2	1	3	0	7
10. James	m	130	1	4	1	0	6	10. John	m	128	4	2	0	0	2
11. Keith	m	129	0	1	5	0	11	11. Kevin	m	128	2	3	1	0	5
12. Liam	m	122	0	1	3	2	13	12. Lawrence	m	127	2	3	1	0	5
13. Matthew	m	122	3	1	2	0	5	13. Mark	m	127	2	3	1	0	5
14. Nigel	m	121	0	3	2	1	10	14. Neville	m	125	2	3	0	1	6
15. Oliver	m	120	5	1	0	0	1	15. Oscar	m	123	5	1	0	0	1
16. Peter	m	120	4	1	1	0	3	16. Paul	m	122	3	3	0	0	3
17. Roger	m	120	1	3	2	0	7	17. Richard	m	115	6	0	0	0	0
18. Alice	f	134	1	2	3	0	8	18. Anna	f	138	4	1	1	0	3
19. Bethan	f	134	0	0	4	2	14	19. Brianne	f	137	3	2	1	0	4
20. Claire	f	133	2	3	1	0	5	20. Carol	f	134	5	1	0	0	1
21. Deirdre	f	133	1	0	3	2	12	21. Doreen	f	133	2	3	1	0	5
22. Eve	f	129	0	1	5	0	11	22. Eugenie	f	132	6	0	0	0	0
23. Faith	f	128	1	2	3	0	8	23. Felicity	f	130	5	1	0	0	1
24. Grace	f	127	3	2	1	0	4	24. Gemma	f	130	3	2	1	0	4
25. Hannah	f	125	3	2	1	0	4	25. Harriet	f	127	3	2	1	0	4
26. Imogen	f	125	4	0	2	0	4	26. Isobel	f	122	4	1	1	0	3
27. Jessica	f	125	4	1	1	0	3	27. Joyce	f	119	4	1	1	0	3
28. Katy	f	122	3	1	2	0	5	28. Karen	f	119	6	0	0	0	0
29. Lucy	f	120	1	3	2	0	7	29. Larissa	f	116	4	1	1	0	3
30. Monica	f	116	5	1	0	0	1	30. Maeve	f	115	6	0	0	0	0
31. Nicky	f	115	5	0	1	0	2	31. Nuala	f	115	5	1	0	0	1

Summated Moon phase scores by individual (second interview)

Name	Sex	Age	Map	Movements	Forces	Age	Origin
1. Adam	m	135	random	not sure	not sure	not sure	not sure
2. Brendan	m	134	heliocentric (complete/correct)	orbit Sun together	not sure	50 million years	not sure
3. Chris	m	133	heliocentric (incomplete/incorrect)	Earth orbits Sun	not sure	not sure	not sure
4. David	m	133	heliocentric (incomplete/incorrect)	orbit Sun	not sure	not sure	Big Bang
5. Edward	m	133	heliocentric (incomplete/incorrect)	stationary	not sure	'old'	Big Bang
6. Francis	m	132	Earth, Sun and Moon	Earth orbits Moon	not sure	not sure	'scientists don't know'
7. Grant	m	131	random	stationary	not sure	not sure	not sure
8. Harry	m	128	heliocentric (complete/incorrect)	orbit Sun	not sure	not sure	'from pitch black'
9. Ian	m	128	random	orbit Sun	Sun's gravity	'since Earth created'	'gas clouds'
10. James	m	127	heliocentric (incomplete/incorrect)	orbit Sun together	'need light'	500 million years	not sure
11. Keith	m	126	random	stationary	not sure	not sure	not sure
12. Liam	m	119	heliocentric (incomplete/incorrect)	orbit Sun	not sure	'before Christ'	'crashes'
13. Matthew	m	119	random	Earth orbits Sun	not sure	not sure	not sure
14. Nigel	m	118	heliocentric (incomplete/incorrect)	stationary	not sure	not sure	Big Bang
15. Oliver	m	117	processional (Earth-centred)	orbit Earth in procession	not sure	not sure	not sure
16. Peter	m	117	processional (Earth-centred)	orbit Earth in procession	not sure	not sure	not sure
17. Roger	m	117	random	stationary	not sure	not sure	not sure
18. Alice	f	131	random	Earth orbits Sun	not sure	not sure	not sure
19. Bethan	f	131	heliocentric (incomplete/incorrect)	Earth orbits Sun	not sure	not sure	not sure
20. Claire	f	130	random	not sure	not sure	thousands of years	not sure
21. Deirdre	f	130	Earth, Sun and Moon	orbit Earth	not sure	not sure	not sure
22. Eve	f	126	processional (Earth-centred)	orbit Earth in procession	not sure	'old'	not sure
23. Faith	f	125	random	orbit Sun together	'need light'	not sure	not sure
24. Grace	f	124	Earth, Sun and Moon	orbit Earth	not sure	not sure	not sure
25. Hannah	f	122	not sure	not sure	not sure	not sure	not sure
26. Imogen	f	122	random	stationary	not sure	not sure	not sure
27. Jessica	f	122	heliocentric (incomplete/incorrect)	stationary	not sure	not sure	not sure
28. Katy	f	119	not sure	not sure	not sure	not sure	not sure
29. Lucy	f	117	processional (Earth-centred)	not sure	not sure	not sure	not sure
30. Monica	f	113	not sure	not sure	not sure	not sure	not sure
31. Nicky	f	112	not sure	not sure	not sure	not sure	not sure

Overview of Solar System responses and models: experimental group at first interview and pre-experimental treatment

Name	Sex	Age	Map	Movements	Forces	Age	Origin
1. Adam	m	138	heliocentric (complete/correct)	orbit Sun	not sure	billions of years	not sure
2. Brendan	m	137	heliocentric (complete/correct)	orbit Sun	not sure	billions of years	not sure
3. Chris	m	136	heliocentric (complete/correct)	orbit Sun	not sure	'very old'	Big Bang
4. David	m	136	heliocentric (complete/correct)	orbit Sun	Sun's gravity	not sure	Big Bang
5. Edward	m	136	heliocentric (complete/correct)	orbit Sun together	Sun's gravity	millions of years	Big Bang
6. Francis	m	135	heliocentric (complete/incorrect)	orbit Sun	not sure	'1997 so older'	Big Bang
7. Grant	m	134	heliocentric (complete/correct)	orbit Sun	Sun's gravity	'all different'	Big Bang
8. Harry	m	131	heliocentric (complete/correct)	orbit Sun	not sure	not sure	Big Bang
9. Ian	m	131	heliocentric (complete/correct)	orbit Sun	Sun's gravity	billions of years	Big Bang
10. James	m	130	heliocentric (complete/correct)	orbit Sun	Sun's gravity	10 million years	Big Bang
11. Keith	m	129	heliocentric (complete/correct)	orbit Sun	Sun's gravity	thousands of years	Big Bang
12. Liam	m	122	heliocentric (complete/correct)	orbit Sun	Sun's gravity	billions of years	Big Bang
13. Matthew	m	122	heliocentric (incomplete/incorrect)	not sure	Sun's gravity	'very old'	Big Bang
14. Nigel	m	121	heliocentric (complete/correct)	orbit Sun	Sun's gravity	2 million years	Big Bang
15. Oliver	m	120	spiral	not sure	not sure	not sure	not sure
16. Peter	m	120	processional (Earth-centred)	not sure	not sure	not sure	God
17. Roger	m	120	heliocentric (complete/incorrect)	stationary	not sure	millions of years	not sure
18. Alice	f	134	heliocentric (complete/correct)	orbit Sun	not sure	not sure	not sure
19. Bethan	f	134	heliocentric (complete/correct)	orbit Sun	Sun's gravity	millions of years	Big Bang
20. Claire	f	133	heliocentric (complete/correct)	orbit Sun	not sure	not sure	Big Bang
21. Deirdre	f	133	heliocentric (complete/correct)	orbit Sun	Sun's gravity	millions of years	Big Bang
22. Eve	f	129	processional (Sun-centred)	orbit Sun in procession	Sun's gravity	not sure	Big Bang
23. Faith	f	128	heliocentric (complete/correct)	orbit Sun	not sure	not sure	Big Bang
24. Grace	f	127	random	stationary	not sure	not sure	Big Bang
25. Hannah	f	125	heliocentric (incomplete/incorrect)	orbit Sun together	not sure	not sure	Big Bang
26. Imogen	f	125	heliocentric (complete/correct)	orbit Sun	not sure	billions of years	Big Bang
27. Jessica	f	125	heliocentric (complete/correct)	orbit Sun	Sun's gravity	billions of years	Big Bang
28. Katy	f	122	heliocentric (complete/correct)	not sure	not sure	not sure	not sure
29. Lucy	f	120	heliocentric (complete/correct)	orbit Sun	Sun's gravity	not sure	not sure
30. Monica	f	116	random	not sure	not sure	not sure	not sure
31. Nicky	f	115	heliocentric (complete/correct)	Earth orbits Sun	not sure	millions of years	not sure

Overview of Solar System responses and models: experimental group at second interview and post-experimental treatment

Name	Sex	Age	Map	Movements	Forces	Age	Origin
1. Adam	m	141	heliocentric (complete/correct)	orbit Sun	not sure	millions of years	not sure
2. Brendan	m	140	heliocentric (complete/correct)	orbit Sun	not sure	billions of years	not sure
3. Chris	m	139	heliocentric (complete/correct)	orbit Sun	not sure	not sure	Big Bang
4. David	m	139	heliocentric (complete/incorrect)	orbit Sun	Sun's gravity	not sure	Big Bang
5. Edward	m	139	heliocentric (complete/correct)	orbit Sun	Sun's gravity	millions of years	not sure
6. Francis	m	138	heliocentric (complete/correct)	orbit Sun	'Sun's warmth'	'very old'	Big Bang
7. Grant	m	137	heliocentric (complete/correct)	orbit Sun	Sun's gravity	'all different'	Big Bang
8. Harry	m	134	heliocentric (complete/correct)	orbit Sun	not sure	not sure	Big Bang
9. Ian	m	134	heliocentric (complete/correct)	orbit Sun	Sun's gravity	billions of years	Big Bang
10. James	m	133	heliocentric (complete/correct)	orbit Sun	Sun's gravity	million of years	Big Bang
11. Keith	m	132	heliocentric (complete/correct)	orbit Sun	Sun's gravity	thousands of years	Big Bang
12. Liam	m	125	heliocentric (complete/correct)	orbit Sun	Sun's gravity	billions of years	Big Bang
13. Matthew	m	125	heliocentric (incomplete/incorrect)	orbit Sun	Sun's gravity	not sure	Big Bang
14. Nigel	m	124	heliocentric (complete/correct)	orbit Sun	Sun's gravity	millions of years	Big Bang
15. Oliver	m	123	heliocentric (complete/correct)	orbit Sun	not sure	not sure	not sure
16. Peter	m	123	heliocentric (incomplete/incorrect)	not sure	'so don't fall down'	not sure	not sure
17. Roger	m	123	heliocentric (incomplete/incorrect)	orbit Sun	not sure	millions of years	not sure
18. Alice	f	137	heliocentric (incomplete/incorrect)	orbit Sun	not sure	not sure	not sure
19. Bethan	f	137	heliocentric (complete/correct)	orbit Sun	Sun's gravity	millions of years	Big Bang
20. Claire	f	136	geocentric (complete/correct)	orbit Earth	not sure	not sure	Big Bang
21. Deirdre	f	136	heliocentric (complete/incorrect)	orbit Sun	'the force'	millions of years	Big Bang
22. Eve	f	132	heliocentric (complete/correct)	orbit Sun	Sun's gravity	not sure	Big Bang
23. Faith	f	131	heliocentric (complete/correct)	orbit Sun	not sure	not sure	Big Bang
24. Grace	f	130	random	not sure	not sure	not sure	Big Bang
25. Hannah	f	128	heliocentric (incomplete/incorrect)	orbit Sun	not sure	not sure	Big Bang
26. Imogen	f	128	heliocentric (complete/correct)	orbit Sun	not sure	billions of years	God
27. Jessica	f	128	heliocentric (complete/correct)	orbit Sun	not sure	billions of years	Big Bang
28. Katy	f	125	Earth, Sun and Moon	not sure	not sure	not sure	not sure
29. Lucy	f	123	heliocentric (complete/correct)	orbit Sun	Sun's gravity	not sure	not sure
30. Monica	f	119	not sure	not sure	not sure	not sure	not sure
31. Nicky	f	118	not sure	not sure	not sure	millions of years	not sure

Overview of Solar System responses and models: experimental group at third interview and delayed

Name	Sex	Age	Map	Movements	Forces	Age	Origin
1. Andrew	m	132	heliocentric (incomplete/incorrect)	orbit Sun	not sure	not sure	not sure
2. Ben	m	131	random	not sure	not sure	not sure	not sure
3. Charlie	m	128	random	random	not sure	billions of years	not sure
4. Dominic	m	128	geocentric (incomplete/incorrect)	Sun moves	not sure	not sure	God
5. Eamon	m	127	heliocentric (incomplete/incorrect)	orbit Sun	Sun's gravity	billions of years	Big Bang
6. Freddie	m	127	random	not sure	not sure	not sure	not sure
7. George	m	127	heliocentric (complete/incorrect)	orbit Sun	Sun's gravity	not sure	not sure
8. Hugh	m	126	heliocentric (incomplete/incorrect)	orbit Sun	not sure	65 million years	Big Bang
9. Ivor	m	126	heliocentric (incomplete/incorrect)	Earth orbits Sun	not sure	not sure	not sure
10. John	m	125	random	stationary	not sure	not sure	not sure
11. Kevin	m	125	heliocentric (complete/incorrect)	orbit Sun	Sun's gravity	not sure	not sure
12. Lawrence	m	124	heliocentric (complete/incorrect)	orbit Sun	not sure	not sure	God
13. Mark	m	124	random	orbit Sun	Sun's gravity	not sure	not sure
14. Neville	m	122	random	orbit Sun together	Sun's gravity	not sure	'planet exploded'
15. Oscar	m	120	heliocentric (incomplete/incorrect)	orbit Sun	not sure	'all different'	'from a star'
16. Paul	m	119	random	Sun moves	not sure	not sure	God
17. Richard	m	112	random	Earth orbits Sun	not sure	5000 years	'star got bigger'
18. Anna	f	135	Earth, Sun and Moon	not sure	not sure	not sure	not sure
19. Brianne	f	134	random	not sure	not sure	not sure	not sure
20. Carol	f	131	heliocentric (incomplete/incorrect)	not sure	not sure	not sure	not sure
21. Doreen	f	130	random	orbit Sun together	Sun pushes around	billions of years	Big Bang
22. Eugenie	f	129	heliocentric (incomplete/incorrect)	not sure	not sure	not sure	Big Bang
23. Felicity	f	127	heliocentric (incomplete/incorrect)	orbit Sun together	not sure	not sure	not sure
24. Gemma	f	127	Earth, Sun and Moon	not sure	not sure	not sure	not sure
25. Harriet	f	124	random	not sure	not sure	not sure	not sure
26. Isobel	f	119	heliocentric (incomplete/incorrect)	not sure	not sure	not sure	God
27. Joyce	f	116	random	not sure	not sure	2000 years	not sure
28. Karen	f	116	random	not sure	not sure	thousands of years	not sure
29. Larissa	f	113	random	not sure	not sure	not sure	not sure
30. Maeve	f	112	random	not sure	not sure	not sure	not sure
31. Nuala	f	112	Earth, Sun and Moon	not sure	not sure	not sure	not sure

Overview of Solar System responses and models: control group at first interview

Name	Sex	Age	Map	Movements	Forces	Age	Origin
1. Andrew	m	135	heliocentric (incomplete/incorrect)	orbit Sun	not sure	not sure	not sure
2. Ben	m	134	random	not sure	not sure	billions of years	not sure
3. Charlie	m	131	random	not sure	not sure	not sure	not sure
4. Dominic	m	131	random	orbit Sun	not sure	not sure	not sure
5. Eamon	m	130	heliocentric (incomplete/incorrect)	orbit Sun	Sun's gravity	trillions of years	Big Bang
6. Freddie	m	130	random	not sure	not sure	not sure	not sure
7. George	m	130	heliocentric (complete/correct)	orbit Sun	not sure	not sure	'started as a flame'
8. Hugh	m	129	heliocentric (incomplete/incorrect)	not sure	not sure	not sure	Big Bang
9. Ivor	m	129	heliocentric (incomplete/incorrect)	not sure	not sure	not sure	not sure
10. John	m	128	random	not sure	not sure	not sure	not sure
11. Kevin	m	128	heliocentric (incomplete/incorrect)	not sure	not sure	not sure	not sure
12. Lawrence	m	127	heliocentric (incomplete/incorrect)	orbit Sun	not sure	not sure	not sure
13. Mark	m	127	Earth, Sun and Moon	stationary	not sure	not sure	not sure
14. Neville	m	125	heliocentric (incomplete/incorrect)	orbit Sun	not sure	not sure	'thing broke up'
15. Oscar	m	123	random	random	not sure	not sure	not sure
16. Paul	m	122	random	stationary	not sure	not sure	not sure
17. Richard	m	115	random	not sure	not sure	not sure	not sure
18. Anna	f	138	Earth, Sun and Moon	not sure	not sure	not sure	not sure
19. Brianne	f	137	not sure	not sure	not sure	not sure	not sure
20. Carol	f	134	Earth, Sun and Moon	not sure	not sure	not sure	not sure
21. Doreen	f	133	Earth, Sun and Moon	orbit Sun together	not sure	not sure	not sure
22. Eugenie	f	132	Earth, Sun and Moon	not sure	not sure	not sure	not sure
23. Felicity	f	130	heliocentric (incomplete/incorrect)	not sure	not sure	not sure	not sure
24. Gemma	f	130	Earth, Sun and Moon	not sure	not sure	not sure	not sure
25. Harriet	f	127	heliocentric (incomplete/incorrect)	not sure	not sure	not sure	not sure
26. Isobel	f	122	random	not sure	not sure	not sure	not sure
27. Joyce	f	119	Earth, Sun and Moon	not sure	not sure	not sure	not sure
28. Karen	f	119	random	not sure	not sure	not sure	not sure
29. Larissa	f	116	random	not sure	not sure	not sure	not sure
30. Maeve	f	115	random	not sure	not sure	not sure	not sure
31. Nuala	f	115	Earth, Sun and Moon	not sure	not sure	not sure	not sure

Overview of Solar System responses and models: control group at second interview

			Experimental group								Control group				
Name	Sex	Age	0s	1s	2s	3s	Score	Name	Sex	Age	0s	1s	2s	3s	Score
1. Adam	m	135	5	6	1	0	8	1. Andrew	m	132	4	6	2	0	10
2. Brendan	m	134	2	5	5	0	15	2. Ben	m	131	7	4	1	0	6
3. Chris	m	133	3	6	3	0	12	3. Charlie	m	128	3	6	3	0	12
4. David	m	133	2	6	4	0	14	4. Dominic	m	128	4	7	1	0	9
5. Edward	m	133	1	9	2	0	13	5. Eamon	m	127	0	7	5	0	17
6. Francis	m	132	3	7	2	0	11	6. Freddie	m	127	8	3	1	0	5
7. Grant	m	131	4	6	2	0	10	7. George	m	127	3	3	5	1	16
8. Harry	m	128	1	6	5	0	16	8. Hugh	m	126	2	6	4	0	14
9. Ian	m	128	1	6	5	0	16	9. Ivor	m	126	4	7	1	0	9
10. James	m	127	0	9	3	0	15	10. John	m	125	6	5	1	0	7
11. Keith	m	126	3	6	3	0	12	11. Kevin	m	125	3	5	4	0	13
12. Liam	m	119	1	7	4	0	15	12. Lawrence	m	124	3	6	3	0	12
13. Matthew	m	119	4	7	1	0	9	13. Mark	m	124	4	5	3	0	11
14. Nigel	m	118	2	8	2	0	12	14. Neville	m	122	2	7	3	0	13
15. Oliver	m	117	5	6	1	0	8	15. Oscar	m	120	1	8	3	0	14
16. Peter	m	117	6	5	1	0	7	16. Paul	m	119	4	7	1	0	9
17. Roger	m	117	4	7	1	0	9	17. Richard	m	112	3	8	1	0	10
18. Alice	f	131	4	6	2	0	10	18. Anna	f	135	7	4	1	0	6
19. Bethan	f	131	3	6	3	0	12	19. Brianne	f	134	5	6	1	0	8
20. Claire	f	130	4	7	1	0	9	20. Carol	f	131	6	5	1	0	7
21. Deirdre	f	130	5	6	1	0	8	21. Doreen	f	130	1	8	3	0	14
22. Eve	f	126	3	8	1	0	10	22. Eugenie	f	129	5	4	3	0	10
23. Faith	f	125	4	7	1	0	9	23. Felicity	f	127	4	6	2	0	10
24. Grace	f	124	5	6	1	0	8	24. Gemma	f	127	7	4	1	0	6
25. Hannah	f	122	9	2	1	0	4	25. Harriet	f	124	6	5	1	0	7
26. Imogen	f	122	4	6	2	0	10	26. Isobel	f	119	5	6	1	0	8
27. Jessica	f	122	3	6	3	0	12	27. Joyce	f	116	5	6	1	0	8
28. Katy	f	119	8	3	1	0	5	28. Karen	f	116	4	7	1	0	9
29. Lucy	f	117	5	5	2	0	9	29. Larissa	f	113	6	5	1	0	7
30. Monica	f	113	9	2	1	0	4	30. Maeve	f	112	7	3	2	0	7
31. Nicky	f	112	12	0	0	0	0	31. Nuala	f	112	9	2	1	0	4

Summated Solar System scores by individual (first interview)

			Experimental group								Control group				
Name	Sex	Age	0s	1s	2s	3s	Score	Name	Sex	Age	0s	1s	2s	3s	Score
1. Adam	m	138	2	2	7	1	19	1. Andrew	m	135	5	5	2	0	9
2. Brendan	m	137	2	2	7	1	19	2. Ben	m	134	6	3	3	0	9
3. Chris	m	136	1	3	7	1	20	3. Charlie	m	131	8	3	1	0	5
4. David	m	136	1	3	7	1	20	4. Dominic	m	131	6	4	2	0	8
5. Edward	m	136	0	3	9	0	21	5. Eamon	m	130	1	3	8	0	19
6. Francis	m	135	1	5	6	0	17	6. Freddie	m	130	6	4	2	0	8
7. Grant	m	134	0	3	8	1	22	7. George	m	130	3	3	5	1	16
8. Harry	m	131	2	3	7	0	17	8. Hugh	m	129	4	5	3	0	11
9. Ian	m	131	0	1	4	7	30	9. Ivor	m	129	4	6	2	0	10
10. James	m	130	0	1	9	2	25	10. John	m	128	6	5	1	0	7
11. Keith	m	129	0	1	9	2	25	11. Kevin	m	128	5	5	2	0	9
12. Liam	m	122	0	1	6	5	28	12. Lawrence	m	127	3	6	3	0	12
13. Matthew	m	122	1	7	3	1	16	13. Mark	m	127	6	4	2	0	8
14. Nigel	m	121	0	3	7	2	23	14. Neville	m	125	2	7	3	0	13
15. Oliver	m	120	4	5	3	0	11	15. Oscar	m	123	5	6	1	0	8
16. Peter	m	120	3	6	3	0	12	16. Paul	m	122	4	7	1	0	9
17. Roger	m	120	2	7	3	0	13	17. Richard	m	115	5	6	1	0	8
18. Alice	f	134	3	3	6	0	15	18. Anna	f	138	7	4	1	0	6
19. Bethan	f	134	0	2	8	2	24	19. Brianne	f	137	9	2	1	0	4
20. Claire	f	133	2	4	6	0	16	20. Carol	f	134	7	4	1	0	6
21. Deirdre	f	133	0	4	8	0	20	21. Doreen	f	133	4	5	3	0	11
22. Eve	f	129	1	6	4	1	17	22. Eugenie	f	132	7	4	1	0	6
23. Faith	f	128	2	1	8	1	20	23. Felicity	f	130	4	6	2	0	10
24. Grace	f	127	2	6	4	0	14	24. Gemma	f	130	7	4	1	0	6
25. Hannah	f	125	2	7	3	0	13	25. Harriet	f	127	5	6	1	0	8
26. Imogen	f	125	1	3	8	0	19	26. Isobel	f	122	7	4	1	0	6
27. Jessica	f	125	0	1	10	1	24	27. Joyce	f	119	6	5	1	0	7
28. Katy	f	122	4	3	5	0	13	28. Karen	f	119	6	5	1	0	7
29. Lucy	f	120	2	3	7	0	17	29. Larissa	f	116	5	6	1	0	8
30. Monica	f	116	4	4	4	0	12	30. Maeve	f	115	5	5	2	0	9
31. Nicky	f	115	2	6	4	0	14	31. Nuala	f	115	7	4	1	0	6

Summated Solar System scores by individual (second interview)

Appendix VIII: Detailed Inferential Analyses of Quantitative Data

1. Age

(i) Experimental group

At first interview, ages in the experimental group ranged from 112 to 135 months (9 years 4 months to 11 years 3 months) with a mean of 124.9 months (10 years 5 months). The 23 month difference between the youngest and oldest child in the group reflected the vertically grouped age structure described. While the boys in the experimental group appeared older than the girls overall, the observed difference in their mean ages, 126.3 months (10 years 6 months) and 123.1 months (10 years 3 months), was not significant ($t=1.31$, $df=29$, $p=0.20$; normality for boys $D_{xb}=0.178$, $p>0.15$; normality for girls $D_{xg}=0.112$, $p>0.15$; F-ratio=1.21).

At second interview, ages in the experimental group ranged from 115 to 138 months (9 years 7 months to 11 years 6 months) with a mean of 127.9 months (10 years 8 months). The analysis of age differences within the experimental group between first and second interviews using a matched t-test was not possible (matched t-tests involved a consistent difference in pairs of results of 3 months). The observed difference in mean ages at first and second interviews, 124.9 and 127.9 months (10 years 5 months and 10 years 8 months), using a two-sample t-test was not significant ($t=-1.76$, $p=0.084$, $df=60$; normality for the experimental group at first and second interviews $D_x=0.116$, $p>0.15$; F-ratio=1.00).

At first interview, the median age of the experimental group was 126.0 months (10 years 6 months). As defined by the lower and upper quartiles (Q1 and Q3), half of the children in the group were between 119.0 and 131.0 months old (9 years 11 months and 10 years 11 months). While the boys in the experimental group appeared older than the girls overall, the observed difference in their median ages, 128.0 months (10 years 8 months) and 123.0 months (10 years 3 months), was not significant ($W_{xb}=307.0$, $W_{xg}=189.0$, $p=0.170$).

At second interview, the median age of the experimental group was 129.0 months (10 years 9 months). The observed differences in the median ages of the experimental group at first and second interview, 126.0 months (10 years 6 months) and 129.0 months (10 years 9 months), was not significant ($W_{xf}=851.5$, $W_{xs}=1101.5$, $p=0.079$).

(ii) Control group

At first interview, ages in the control group also ranged from 112 to 135 months (9 years 4 months to 11 years 3 months) but presented a mean of 124.1 months (10 years 4 months). Like the experimental group, the 23 month difference between the youngest and oldest child in the group reflected the vertically grouped age structure described. Similarly, while the boys in the control group appeared older than the girls overall, the observed difference in their mean ages, 124.9 months (10 years 5 months) and 123.2 months (10 years 3 months), was not significant ($t=0.67$, $df=19$, $p=0.51$; normality for boys $D_{cb}=0.161$, $p>0.15$; normality for girls $D_{cg}=0.140$, $p>0.15$; F-ratio=3.10 which is significant at $\alpha=0.05$).

At second interview, ages in the control group ranged from 115 to 138 months (9 years 7 months to 11 years 6 months) with a mean of 127.1 months (10 years 7 months). The analysis of age differences within the control group between first and second interviews using a matched t-test was also not possible. The observed difference in mean ages at first and second interviews, 124.1 and 127.1 months (10 years 4 months and 10 years 7 months), using a two-sample t-test was not significant ($t=-1.81$, $p=0.076$, $df=60$; normality for the control group at first and second interviews $D_c=0.137$, $p=0.140$; F-ratio=1.00).

At first interview, the median age of the control group was also 126.0 months (10 years 6 months). As defined by the lower and upper quartiles (Q1 and Q3), half of the children in the group were between 119.0 and 128.0 months old (9 years 11 months and 10 years 8 months). While the boys in the control group appeared fractionally older than the girls overall, the observed difference in their median ages, 126.0 months (10 years 6 months) and 125.5 months (10 years 6 months), was not significant ($W_{cb}=278.0$, $W_{cg}=218.0$, $p=0.827$).

At second interview, the median age of the control group was 129.0 months (10 years 9 months). The observed differences in the median ages of the control group at first and second interview, 126.0 months (10 years 6 months) and 129.0 months (10 years 9 months), was not significant ($W_{cf}=839.0$, $W_{cs}=1114.0$, $p=0.053$).

(iii) Experimental and control groups compared

The observed difference in the mean ages of the experimental and control groups at first interview, 124.9 months (10 years 5 months) and 124.1 months (10 years 4 months), was not significant (t=0.44, df=60, p=0.66; normality for experimental group D_x=0.116, p>0.15; normality for control group D_c=0.137, p=0.140; F-ratio=1.06). The observed differences in mean ages of the experimental and control groups at first and second interviews were not significant (one-way ANOVA F=2.24, df=3, p=0.087).

There were no observed or significant differences in the median ages of the experimental and control groups, 126.0 months (10 years 6 months) and 126.0 months (10 years 6 months), at first interview (W_x=1011.0, W_c=942.0, p=0.632).

2. Intellectual maturity

(a) Point scale measurement

(i) Experimental group

At test, class intellectual maturity point scores in the experimental group ranged from 83 to 122 with a mean of 100.2. One child exceeded a score of 115 (Liam 122, percentile rank 93) and three scored 85 or less (Adam 83, percentile rank 13; David 84, percentile rank 14; Imogen 83, percentile rank 13). While boys in the experimental group appeared to have a higher intellectual maturity score than the girls overall, the observed difference in their mean scores, 100.5 and 99.9, was not significant (t=0.16, df=29, p=0.87; normality for boys D_{xb}=0.107, p>0.15; normality for girls D_{xg}=0.187, p>0.15; F-ratio=1.72).

At retest, class intellectual maturity point scores in the experimental group ranged from 87 to 115 with a mean of 100.7. Test- retest reliability was acceptable. The observed difference in mean scores of the experimental group at test and retest, 100.2 and 100.7, was not significant (matched t=-0.38, p=0.709; normality of differences between the experimental group at test and retest D_{xd}=0.063, p>0.15; F-ratio=1.74). Correlation coefficient analysis for pairs of data was significant (Pearson's r=0.724, p=0.000).

(ii) Control group

At test, class intellectual maturity point scores in the control group ranged from 80 to 117 with a mean of 98.9. Two children met or exceeded a score of 115 (Hugh 117, percentile rank 87; Isobel 115, percentile rank 84) and four scored 85 or less (Dominic 85, percentile rank 16; Freddie 80, percentile rank 9; Anna 83, percentile rank 13; Harriet 81, percentile rank10). While girls in the control group appeared to have a higher intellectual maturity score than the boys overall, the observed difference in their mean scores, 99.3 and 98.6, was not significant ($t=-0.20$, $df=29$, $p=0.84$; normality for boys $D_{cb}=0.115$, $p>0.15$; normality for girls $D_{cg}=0.131$, $p>0.15$; F-ratio=1.12).

At retest, class intellectual maturity point scores in the control group ranged from 82 to 115 with a mean of 98.2. Test-retest reliability was acceptable. The observed difference in mean scores of the control group at test and retest, 98.9 and 98.2, was not significant (matched $t=0.69$, $p=0.498$; normality of differences between the control group at test and retest $D_{cd}=0.099$, $p>0.15$; F-ratio=1.24). Correlation coefficient analysis for pairs of data was significant (Pearson's $r=0.802$, $p=0.000$).

(iii) Experimental and control groups compared

The observed difference in the mean class intellectual maturity point scores of the experimental and control groups at test, 100.2 and 98.9, was not significant ($t=0.56$, $df=60$, $p=0.58$; normality for the experimental group $D_x=0.064$, $p>0.15$; normality for the control group $D_c=0.117$, $p>0.15$; F-ratio=1.13). The observed differences in all mean intellectual maturity scores of the experimental and control groups at test and retest were not significant (one-way ANOVA $F=0.56$, $df=3$, $p=0.645$).

(b) Quality scale measurement

(i) Experimental group

Inter-rater reliability was acceptable. The observed differences in mean intellectual maturity quality scores of the experimental group between Rater 1 and Rater 2, 98.0 and 97.1, was not significant (matched $t=1.92$, $p=0.065$; normality of differences between experimental group

and rater D_{xd}=0.123, p>0.15; F-ratio=1.04). Correlation coefficient analysis for pairs of data was significant (Pearson's r=0.946, p=0.000).

The observed differences in all mean intellectual maturity point and quality scores of the experimental group, including Rater 2, at test were not significant (one-way ANOVA F=1.13, df=2, p=0.326). Correlation coefficient analyses for pairs of data were significant (Pearson's r for point and Rater 1 quality scores =0.908, p=0.000; Pearson's r for point and Rater 2 quality scores =0.897, p=0.000).

(ii) Control group

Inter-rater reliability was acceptable. The observed differences in mean intellectual maturity quality scores of the control group between Rater 1 and Rater 2, 96.8 and 97.3, is not significant (matched t=-0.95, p=0.348; normality of differences between control group and rater D_{cd}=0.058, p>0.15; F-ratio=1.07). Correlation coefficient analysis for pairs of data was significant (Pearson's r=0.938, p=0.000).

The observed differences in all mean intellectual maturity point and quality scores of the control group, including Rater 2, at test were not significant (one-way ANOVA F=0.51, df=2, p=0.600). Correlation coefficient analyses for pairs of data were significant (Pearson's r for point and Rater 1 quality scores =0.947, p=0.000; Pearson's r for point and Rater 2 quality scores =0.915, p=0.000).

3. Science interest and curiosity

(a) Declared interest

(i) Experimental group

At test, only 9 (29%) of the children in the experimental group declared a real interest in science (8 boys and 1 girl), 14 (45%) were uncertain (5 boys and 9 girls) and 8 (26%) indicated that they were not interested in science at all (4 boys and 4 girls). While boys in the experimental group appeared more interested in science overall, the observed difference in

profile was not significant (test statistic D_{xbg}=0.400, critical value K_D=0.491 for α=0.05). χ^2 testing for gender association revealed 4 of the 6 cells with expected counts of less than 5.

At retest, 8 (26%) of the children in the experimental group declared a real interest in science (7 boys and 1 girl), 15 (48%) were uncertain (5 boys and 10 girls) and 8 (26%) indicated that they were not interested in science at all (5 boys and 3 girls). Test-retest reliability was acceptable. Observed differences in class profiles were not significant (test statistic D_{xtr}=0.032, critical value K_D=0.345 for α=0.05). However, it should be noted that despite profile similarity, 10 (32%) children (5 boys and 5 girls) changed their minds and indicated a different interest in science at retest to that stated previously.

(ii) Control group

At test, only 7 (23%) of the children in the control group declared a real interest in science (6 boys and 1 girl), 15 (48%) were uncertain (7 boys and 8 girls) and 9 (29%) indicated that they were not interested in science at all (4 boys and 5 girls). While boys in the control group appeared more interested in science overall, the observed difference in profile was not significant (test statistic D_{cbg}=0.282, critical value K_D=0.491 for α=0.05). χ^2 testing for gender association revealed 4 of the 6 cells with expected counts of less than 5.

At retest, the class interest profile was identical but the numbers of boys and girls within each declaration changed slightly. 7 (23%) of the children in the control group declared a real interest in science (7 boys and 0 girls), 15 (48%) were uncertain (5 boys and 10 girls) and 9 (29%) indicated that they were not interested in science at all (5 boys and 4 girls). Test-retest reliability was acceptable. Observed differences at class level, as expected, were not significant (test statistic D_{ctr}=0.000, critical value K_D=0.345 for α=0.05). However, it should be noted that despite identical profiles, 8 (26%) children (6 boys and 2 girls) changed their minds and indicated a different interest in science at retest to that stated previously.

(iii) Experimental and control groups compared

Observed differences in interest profiles of the experimental and control groups at test was not significant (test statistic D_{xc}=0.064, critical value K_D=0.345 for α=0.05). Statistical

analysis also revealed no significant association between experimental or control group and declared interest (χ^2=0.343, df=2, p=0.842).

(b) Curiosity score

(i) Experimental group

At test, class curiosity scores in the experimental group ranged from 42 to 129 with a mean of 89.5. The curiosity range of 87 reflected the differences in expressed interest, lower scores generally obtained from children with no declared interest in science (mean 62.8), higher scores from children who declared a real interest in science (mean 102.6). While boys in the experimental group appeared more curious than the girls overall, the observed difference in their mean scores, 93.2 and 85.0, was not significant (t=1.05, df=29, p=0.30; normality for boys D_{xb}=0.115, p>0.15; normality for girls D_{xg}=0.178, p>0.15; F-ratio=1.00).

At retest, class curiosity scores in the experimental group ranged from 69 to 137 with a mean of 95.1. Test-retest reliability was acceptable. The observed differences in mean scores of the experimental group at test and retest, 89.5 and 95.1, was not significant (matched t=-1.95, p=0.06; normality of differences between experimental group at test and retest D_{dx}=0.059, p>0.15; F-ratio=1.35). Correlation coefficient analysis for pairs of data was significant (Pearson's r=0.698, p=0.000).

(ii) Control group

At test, class curiosity scores in the control group ranged from 44 to 139 with a mean of 97.7. Again, the curiosity range of 95 reflected the differences in expressed interest, lower scores generally obtained from children with no declared interest in science (mean 73.9), higher scores from children who declared a real interest in science (mean 119.3). While boys in the control group appeared more curious than the girls overall, the observed difference in their mean scores, 100.7 and 94.1, was not significant (t=0.86, df=29, p=0.39; normality for boys D_{cb}=0.115, p>0.15; normality for girls D_{cg}=0.124, p>0.15; F-ratio=1.64).

At retest, class curiosity scores in the control group ranged from 70 to 146 with a mean of 99.7. Test-retest reliability was acceptable. The observed differences in mean scores of the control group at test and retest, 97.7 and 99.7, was not significant (matched t=-0.74, p=0.47; normality of differences between control group at test and retest D_{cd}= 0.086, p>0.15; F-ratio=1.21). Correlation coefficient analysis for pairs of data was significant (Pearson's r=0.727, p=0.000).

(iii) Experimental and control groups compared

The observed differences in the mean scores of the experimental and control groups at test, 89.5 and 97.7, was not significant (t=-1.50, df=60, p=0.14; normality for the experimental group D_x=0.124, p>0.15; normality for the control group D_c=0.107, p>0.15; F-ratio=1.08). The observed differences in all mean curiosity scores of the experimental and control groups at test and retest were not significant (one-way ANOVA F=1.47, df=3, p=0.227).

While low sample sizes excluded the use of inferential statistics to compare response profiles by declared interest, these were nevertheless useful. As might be expected, responses to curiosity statements obtained from children who declared a real interest in science were positively skewed towards the 'strongly agree' part of the scale (5), while those responses to curiosity statements obtained from children who declared no interest in science were negatively skewed towards the 'strongly disagree' part of the scale (1). Response profiles from the experimental and control groups were broadly similar in appearance. Profiles reflect the mean scores arranged by interest in Table 5.14 (see Appendix V).

4. Informal science experiences

(i) Experimental group

79 sources were received from the 31 children in total (mean 2.5 sources per child, boys higher at 3.1 and girls lower at 1.9). The commonest source of information was TV (all 17 boys and 10 girls) which provided about one third (34%) of all responses. In all but one case (film and video), the percentage of sources indicated by boys was greater than that by girls: notably so in the 'other' category where boys were found to mention playing more space

games than girls. χ^2 testing for gender associations revealed too many cells with expected counts less than 5.

(ii) Control group

82 sources were received from the 31 children in total (mean 2.6 sources per child, boys higher at 3.1 and girls lower at 2.1). The commonest source of information was TV (14 boys and 7 girls) which provided about one quarter (26%) of all responses. In all cases, the percentage of sources indicated by boys was greater than that by girls, again, notably so in the 'other' category where boys were found to play more space games than girls. χ^2 testing for gender associations revealed too many cells with expected counts less than 5.

(iii) Experimental and control groups compared

Statistical analyses suggested no significant associations between the experimental group, control group and informal sources of information (TV χ^2=3.321, df=1, p=0.068; film and video χ^2=0.295, df=1, p=0.587; literature χ^2=0.313, df=1, p=0.576; computer χ^2=2.345, df=1, p=0.126; holiday χ^2=0.081, df=1, p=0.776; other χ^2=0.272, df=1, p=0.60).

5. The Earth

Pre-experimental treatment

A summary of Earth item scores by group and gender from children in the experimental group and control group are presented as shown (Table 1).

		Experimental group				Control group			
		n	Mean	Range	SD	n	Mean	Range	SD
Pre-treatment	Class	31	20.0	8 – 27	3.77	31	19.2	9 – 26	4.27
	Boys	17	21.7	18 – 27	2.31	17	19.4	9 – 26	4.50
	Girls	14	17.9	8 - 25	4.21	14	19.1	11 - 24	4.14

Table 1 Earth scores

(i) Experimental group

At first interview (pre-experimental treatment), overall scores in the experimental group ranged from 8 to 27 with a mean of 20.0. 1 child scored between 0 and 11 (3%), 26 children between 12 and 23 (84%) and 4 children between 24 and 36 (13%). The boys in the experimental group appeared to score more highly than the girls overall and the observed difference in their mean scores, 21.7 and 17.9, was significant ($t=3.00$, $df=19$, $p=0.007$; normality for boys $D_{xb}=0.067$, $p>0.15$; normality for girls $D_{xg}=0.136$, $p>0.15$; F-ratio=3.32 which is significant at $\alpha=0.05$). Overall score profile percentages included 15.6% 0s, 13.7% 1s, 59.1% 2s and 11.6% 3s. Interestingly, analysis of the score profile percentages of boys and girls suggested that the observed differences were not significant (test statistic $D_{xbg}=0.140$, critical value $K_D=0.142$ for $\alpha=0.05$). In those areas of children's ideas about the Earth which received most attention earlier (E1, E2, E4, E10 and E11), observed differences in median scores between boys and girls were significant in items E1 (shape verbal: $W_{xb}=324.0$, $W_{xg}=156.5$, $p=0.018$), E4 (drawing: $W_{xb}=343.5$, $W_{xg}=152.5$, $p=0.001$) and E11 (nature: $W_{xb}=323.0$, $W_{xg}=173.0$, $p=0.015$).

(ii) Control group

At first interview (pre-experimental treatment), overall scores in the control group ranged from 9 to 26 with a mean of 19.2. 2 children scored between 0 and 11 (6%), 23 children between 12 and 23 (74%) and 6 children between 24 and 36 (19%). While the boys in the control group appeared to score more highly than the girls, the observed difference in their mean scores, 19.4 and 19.1, was not significant ($t=0.18$, $df=29$, $p=0.86$; normality for boys $D_{cb}=0.148$, $p>0.15$; normality for girls $D_{cg}=0.138$, $p>0.15$; F-ratio=1.18). Overall score profile percentages included 18.8% 0s, 12.1% 1s, 59.1% 2s and 9.9% 3s. Analysis of the score profile percentages of boys and girls suggested that the observed differences were not significant (test statistic $D_{cbg}=0.030$, critical value $K_D=0.142$ for $\alpha=0.05$). In those areas of children's ideas about the Earth which received most attention earlier (E1, E2, E4, E10 and E11), observed differences in median scores between boys and girls were not significant.

(iii) Experimental and control groups compared

The observed difference in overall mean scores of the experimental group and control group at first interview (pre-experimental treatment), 20.0 and 19.2, was not significant (t=0.76, df=60, p=0.45; normality of the experimental group D_x=0.073, p>0.15; normality of the control group D_c=0.129, p>0.15; F=1.28). Analysis of the score profile percentages of the experimental group and the control group suggested that the observed differences were not significant (test statistic D_{xc}=0.032, critical value K_D=0.100 for α=0.05). In those areas of children's ideas about the Earth which received most attention earlier (E1, E2, E4, E10 and E11), observed differences in median scores between the experimental group and the control group were not significant.

Post-experimental treatment

As with the pre-experimental data, a summary of Earth item scores by group and gender from children in the experimental group and control group are presented as shown (Table 2).

		Experimental group				Control group			
		n	Mean	Range	SD	n	Mean	Range	SD
Post-treatment	Class	31	22.9	12 – 31	4.16	31	19.3	10 – 25	3.55
	Boys	17	24.5	18 – 31	3.32	17	19.5	10 – 25	3.99
	Girls	14	21.1	12 - 28	4.41	14	19.1	13 - 24	3.08

Table 2 Earth scores

(i) Experimental group

At second interview (post-experimental treatment), overall scores in the experimental group ranged from 12 to 31 with a mean of 22.9. No children scored between 0 and 11 (0%), 16 children between 12 and 23 (52%) and 15 children between 24 and 36 (48%). The boys in the experimental group appeared to score more highly than the girls overall and the observed difference in their mean scores, 24.5 and 21.1, was significant (t=2.45, df=29, p=0.021; normality for boys D_{xb}=0.113, p>0.15; normality for girls D_{xg}=0.133, p>0.15; F-ratio=1.76). Overall score profile percentages included 13.7% 0s, 6.7% 1s, 54.3% 2s and 25.3% 3s. Analysis of the score profile percentages of boys and girls suggested that the observed

differences were not significant (test statistic D_{xbg}=0.049, critical value K_D=0.142 for α=0.05). In those areas of children's ideas about the Earth which received most attention earlier (E1, E2, E4, E10 and E11), observed differences in median scores between boys and girls were significant in item E1 (shape verbal: W_{xb}=335.0, W_{xg}=161.0, p=0.005).

The observed difference in mean scores of the experimental group between first and second interviews (pre- and post experimental treatment), 20.0 and 22.9, was significant (matched t=-6.36, p=0.000, normality of differences in experimental scores D_{dx}=0.081, p>0.15; F-ratio=1.22). Correlation coefficient analysis for pairs of data was significant (Pearson's r=0.794, p=0.000). Analysis of the score profile percentages of the experimental group at first and second interview suggested that observed differences were significant (test statistic D_x=0.137, critical value K_D=0.120 for α=0.01). In those areas of children's ideas about the Earth which received most attention earlier (E1, E2, E4, E10 and E11), observed differences in median scores between first and second interviews were significant for items E1 (shape verbal: W_{x1}=821.0, W_{x2}=1132.0, p=0.016) and E11 (nature: W_{x1}=627.0, W_{x2}=1326.0, p=0.000).

(ii) Control group

At second interview (post-experimental treatment), overall scores in the control group ranged from 10 to 25 with a mean of 19.3. 1 child scored between 0 and 11 (3%), 25 children between 12 and 23 (81%) and 5 children between 24 and 36 (16%). While the boys in the control group appeared to score more highly than the girls, the observed difference in their mean scores, 19.5 and 19.1, was not significant (t=0.31, df=29, p=0.76; normality for boys D_{cb}=0.078, p>0.15; normality for girls D_{cg}=0.092, p>0.15; F-ratio=1.68). Overall score profile percentages included 16.1% 0s, 11.6% 1s, 67.2% 2s and 5.1% 3s. Analysis of the score profile percentages of boys and girls suggested that observed differences were not significant (test statistic D_{cbg}=0.039, critical value K_D=0.142 for α=0.05). In those areas of children's ideas about the Earth which received most attention earlier (E1, E2, E4, E10 and E11), observed differences in median scores between boys and girls were not significant.

The observed difference in mean scores of the control group between first and second interviews (pre- and post experimental treatment), 19.2 and 19.3, was not significant (matched t=-0.12, p=0.903, normality of differences in control scores D_{dc}=0.053, p>0.15; F-

ratio=1.45). Correlation coefficient analysis for pairs of data was significant (Pearson's r=0.736, p=0.000). Analysis of the score profile percentages of the control group at first and second interview suggested that observed differences were not significant (test statistic D_c=0.047, critical value K_D=0.100 for α=0.05). In those areas of children's ideas about the Earth which received most attention earlier (E1, E2, E4, E10 and E11), observed differences in median scores between first and second interviews were not significant

(iii) Experimental and control groups compared

The observed difference in overall mean scores of the experimental group and control group at second interview (post-experimental treatment), 22.9 and 19.3, was significant (t=3.71, df=60, p=0.000; normality of the experimental group D_x=0.103, p>0.15; normality of the control group D_c=0.052, p>0.15; F=1.37). Analysis of the score profile percentages of the experimental group and the control group suggested that observed differences were significant (test statistic D_{xc}=0.201, critical value K_D=0.120 for α=0.01). In those areas of children's ideas about the Earth which received most attention earlier (E1, E2, E4, E10 and E11), observed differences in median scores between the experimental group and control group were significant for items E1 (shape verbal: W_{x2}=1167.0, W_{c2}=786.0, p=0.003), E4 (drawing: W_{x2}=1185.0, W_{c2}=768.0, p=0.000) and E11 (nature: W_{x2}=1283.0, W_{c2}=670.0, p=0.000).

The observed differences in overall mean scores of the experimental and control groups at first and second interviews (pre- and post-experimental treatment) were significant (one-way ANOVA F=6.10, df=3, p=0.001). The observed difference in mean gain of the experimental group (O_3-O_1) and control group (O_4-O_2), +2.9 and +0.1 (SDs 2.57 and 2.92), was significant (t=4.11, df=60, p=0.000; normalities supplied earlier; F-ratio=1.29).

6. The Sun

Pre-experimental treatment

A summary of Sun item scores by group and gender from children in the experimental group and the control group are presented as shown (Table 3).

		Experimental group				Control group			
		n	Mean	Range	SD	n	Mean	Range	SD
Pre-treatment	Class	31	15.4	9 – 22	3.17	31	15.5	10 – 23	3.82
	Boys	17	16.5	10 – 22	3.11	17	16.1	10 – 23	4.09
	Girls	14	14.0	9 - 20	2.75	14	14.7	11 - 21	3.45

Table 3 Sun scores

(i) Experimental group

At first interview (pre-experimental treatment), overall scores in the experimental group ranged from 9 to 22 with a mean of 15.4. 1 child scored between 0 and 11 (3%) and 30 children between 12 and 23 (97%). The boys in the experimental group appeared to score more highly than the girls overall and the observed difference in their mean scores, 16.5 and 14.0, was significant ($t=2.38$, $df=29$, $p=0.024$; normality for boys $D_{xb}=0.109$, $p>0.15$; normality for girls $D_{xg}=0.072$, $p>0.15$; F-ratio=1.28). Overall score profile percentages included 25.0% 0s, 26.1% 1s, 44.6% 2s and 4.3% 3s. Analysis of the score profile percentages of boys and girls suggested that the observed differences were also significant (test statistic $D_{xbg}=0.176$, critical value $K_D=0.170$ for $\alpha=0.01$). In those areas of children's ideas about the Sun which received most attention earlier (S1, S2, S4, S8 and S11), observed differences in median scores between boys and girls were significant in item S2 (shape selection: $W_{xb}=310.5$, $W_{xg}=185.5$, $p=0.039$).

(ii) Control group

At first interview (pre-experimental treatment), overall scores in the control group ranged from 10 to 23 with a mean of 15.5. 4 children scored between 0 and 11 (13%) and 27 children between 12 and 23 (87%). The boys in the experimental group appeared to score more highly than the girls overall but the observed difference in their mean scores, 16.1 and 14.7, was not significant ($t=1.02$, $df=29$, $p=0.32$; normality for boys $D_{cb}=0.119$, $p>0.15$; normality for girls $D_{cg}=0.190$, $p>0.15$; F-ratio=1.41). Overall score profile percentages included 28.5% 0s, 21.2% 1s, 43.0% 2s and 7.3% 3s. Analysis of the score profile percentages of boys and girls suggested that the observed differences were not significant (test statistic $D_{cbg}=0.066$, critical value $K_D=0.142$ for $\alpha=0.05$). In those areas of children's

ideas about the Sun which received most attention earlier (S1, S2, S4, S8 and S11), observed differences in median scores between boys and girls were not significant.

(iii) Experimental and control groups compared

The observed difference in overall mean scores of the experimental group and control group at first interview (pre-experimental treatment), 15.4 and 15.5, was not significant (t=-0.11, df=60, p=0.91; normality of the experimental group D_x=0.056, p>0.15; normality of the control group D_c=0.119, p>0.15; F=1.45). Analysis of the score profile percentages of the experimental group and the control group suggested that the observed differences were not significant (test statistic D_{xc}=0.035, critical value K_D=0.100 for α=0.05). In those areas of children's ideas about the Sun which received most attention earlier (S1, S2, S4, S8 and S11), observed differences in median scores between the experimental group and the control group were not significant.

Post-experimental treatment

As with the pre-experimental data, a summary of Sun item scores by group and gender from children in the experimental group and control group are presented as shown (Table 4).

		Experimental group				Control group			
		n	Mean	Range	SD	n	Mean	Range	SD
Post-treatment	Class	31	20.1	11 – 29	4.31	31	15.4	11 – 23	3.03
	Boys	17	22.1	15 – 29	3.91	17	15.9	11 – 23	3.56
	Girls	14	17.6	11 - 24	3.52	14	14.8	12 - 18	2.19

Table 4 Sun scores

(i) Experimental group

At second interview (post-experimental treatment), overall scores in the experimental group ranged from 11 to 29 with a mean of 20.1. 1 child scored between 0 and 11 (3%), 22 children between 12 and 23 (71%) and 8 children between 24 and 36 (26%). The boys in the experimental group appeared to score more highly than the girls overall and the observed difference in their mean scores, 22.1 and 17.6, was significant (t=3.27, df=29, p=0.003;

normality for boys D_{xb}=0.057, p>0.15; normality for girls D_{xg}=0.144, p>0.15; F-ratio=1.23). Overall score profile percentages included 20.4% 0s, 11.0% 1s, 49.5% 2s and 19.1% 3s. Analysis of the score profile percentages of boys and girls suggested that the observed differences were significant (test statistic D_{xbg}=0.154, critical value K_D=0.142 for α=0.05). In those areas of children's ideas about the Sun which received most attention earlier (S1, S2, S4, S8 and S11), observed differences in median scores between boys and girls were significant in item S1 (shape verbal: W_{xb}=330.0, W_{xg}=166.0, p=0.012), S2 (shape selection: W_{xb}=308.5, W_{xg}=187.5, p=0.026) and S4 (drawing: W_{xb}=323.5, W_{xg}=172.5, p=0.024).

The observed difference in mean scores of the experimental group between first and second interviews (pre- and post experimental treatment), 15.5 and 20.1, was significant (matched t=-8.28, p=0.000, normality of differences in experimental scores D_{dx}=0.134, p>0.15; F-ratio=1.85 which is just significant at α=0.05). Correlation coefficient analysis for pairs of data was significant (Pearson's r=0.685, p=0.000). Analysis of the score profile percentages of the experimental group at first and second interview suggested that observed differences were significant (test statistic D_x=0.196, critical value K_D=0.120 for α=0.01). In those areas of children's ideas about the Sun which received most attention earlier (S1, S2, S4, S8 and S11), observed differences in median scores between first and second interviews were significant for items S1 (shape verbal: W_{x1}=837.0, W_{x2}=1116.0, p=0.029), S4 (drawing: W_{x1}=698.5, W_{x2}=1254.5, p=0.000), S8 (source of heat and light: W_{x1}=832.5, W_{x2}=1120.5, p=0.026) and S11 (nature: W_{x1}=708.0, W_{x2}=1245.0, p=0.000).

(ii) Control group

At second interview (post-experimental treatment), overall scores in the control group ranged from 11 to 23 with a mean of 15.4. 1 child scored between 0 and 11 (3%) and 30 children between 12 and 23 (97%). The boys in the control group appeared to score more highly than the girls overall but the observed difference in their mean scores, 15.9 and 14.8, was not significant (t=1.11, df=27, p=0.28; normality for boys D_{cb}=0.090, p>0.15; normality for girls D_{cg}=0.140, p>0.15; F-ratio=2.64 which is significant at α=0.05). Overall score profile percentages included 29.6% 0s, 16.1% 1s, 50.5% 2s and 3.8% 3s. Analysis of the score profile percentages of boys and girls suggested that the observed differences were not significant (test statistic D_{cbg}=0.046, critical value K_D=0.142 for α=0.05). In those areas of

children's ideas about the Sun which received most attention earlier (S1, S2, S4, S8 and S11), observed differences in median scores between boys and girls were not significant.

The observed difference in mean scores of the control group between first and second interviews (pre- and post-experimental treatment), 15.5 and 15.4, was not significant (matched t=0.13, p=0.897, normality of differences in control scores D_{dc}=0.059, p>0.15; F-ratio=1.59). Correlation coefficient analysis for pairs of data was significant (Pearson's r=0.699, p=0.000). Analysis of the score profile percentages of the control group at first and second interview suggested that observed differences were not significant (test statistic D_c=0.040, critical value K_D=0.100 for α=0.05). In those areas of children's ideas about the Sun which received most attention earlier (S1, S2, S4, S8 and S11), observed differences in median scores between first and second interviews were not significant.

(iii) Experimental and control groups compared

The observed difference in overall mean scores of the experimental group and control group at second interview (post-experimental treatment), 20.1 and 15.4, was significant (t=4.91, df=53, p=0.000; normality of the experimental group D_x=0.084, p>0.15; normality of the control group D_c=0.100, p>0.15; F=2.02 which is significant at α=0.05). Analysis of the score profile percentages of the experimental group and the control group suggested that observed differences were significant (test statistic D_{xc}=0.153, critical value K_D=0.120 for α=0.01). In those areas of children's ideas about the Sun which received most attention earlier (S1, S2, S4, S8 and S11), observed differences in median scores between the experimental group and control group were significant for items S4 (drawing: W_{x2}=1214.5, W_{c2}=738.5, p=0.000), S8 (source of heat and light: W_{x2}=1178.0, W_{c2}=775.0, p=0.001) and S11 (nature: W_{x2}=1198.5, W_{c2}=754.5, p=0.001).

The observed differences in overall mean scores of the experimental and control groups at first and second interviews (pre- and post-experimental treatment) were significant (one-way ANOVA F=12.72, df=3, p=0.000). The observed difference in mean gain of the experimental group (O_3-O_1) and control group (O_4-O_2), +4.7 and –0.1 (SDs 3.15 and 2.76), was significant (t=6.31, df=60 p=0.000; normalities supplied earlier; F-ratio=1.30).

7. The Moon

Pre-experimental treatment

A summary of Moon item scores by group, and gender from children in the experimental group and control group are presented as shown (Table 5).

		Experimental group				Control group			
		n	Mean	Range	SD	n	Mean	Range	SD
Pre-treatment	Class	31	13.3	6 – 21	4.10	31	14.1	6 – 19	3.92
	Boys	17	14.6	6 – 21	4.05	17	14.9	6 – 19	3.95
	Girls	14	11.6	7 - 18	3.61	14	13.2	6 - 19	3.83

Table 5 Moon scores

(i) Experimental group

At first interview (pre-experimental treatment), overall scores in the experimental group ranged from 6 to 21 with a mean of 13.3. 10 children scored between 0 and 11 (32%) and 21 children between 12 and 23 (68%). The boys in the experimental group appeared to score more highly than the girls overall and the observed difference in their mean scores, 14.6 and 11.6, was significant ($t=2.21$, $df=29$, $p=0.035$; normality for boys $D_{xb}=0.113$, $p>0.15$; normality for girls $D_{xg}=0.168$, $p>0.15$; F-ratio=1.26). Overall score profile percentages included 24.7% 0s, 42.5% 1s, 30.4% 2s and 2.4% 3s. Analysis of the score profile percentages of boys and girls suggested that the observed differences were significant (test statistic $D_{xbg}=0.164$, critical value $K_D=0.142$ for $\alpha=0.05$). In those areas of children's ideas about the Moon which received most attention earlier (M1, M2, M4 and M11), observed differences in median scores between boys and girls were significant in items M1 (shape verbal: $W_{xb}=322.5$, $W_{xg}=173.5$, $p=0.016$) and M2 (shape selection: $W_{xb}=319.5$, $W_{xg}=176.5$, $p=0.028$).

(ii) Control group

At first interview (pre-experimental treatment), overall scores in the control group ranged from 6 to 19 with a mean of 14.1. 9 children scored between 0 and 11 (29%) and 22 children

between 12 and 23 (71%). While the boys in the control group appeared to score more highly than the girls, the observed difference in their mean scores, 14.9 and 13.2, was not significant (t=1.19, df=,29 p=0.25; normality for boys D_{cb}=0.218, p=0.039 - deviation; normality for girls D_{cg}=0.153, p>0.15; F-ratio=1.06). Overall score profile percentages included 22.0% 0s, 41.9% 1s, 32.3% 2s and 3.8% 3s. Analysis of the score profile percentages of boys and girls suggested that the observed differences were not significant (test statistic D_{cbg}=0.098, critical value K_D=0.142 for α=0.05). In those areas of children's ideas about the Moon which received most attention earlier (M1, M2, M4 and M11), observed differences in median scores between boys and girls were not significant.

(iii) Experimental and control groups compared

The observed difference in overall mean scores of the experimental group and control group at first interview (pre-experimental treatment), 13.3 and 14.1, was not significant (t=-0.85, df=60, p=0.40; normality of the experimental group D_x=0.093, p>0.15; normality of the control group D_c=0.169, p=0.033 - deviation; F=1.09). Analysis of the score profile percentages of the experimental group and the control group suggested that the observed differences were not significant (test statistic D_{xc}=0.032, critical value K_D=0.100 for α=0.05). In those areas of children's ideas about the Moon which received most attention earlier (M1, M2, M4 and M11), observed differences in median scores between the experimental group and the control group were not significant.

Post-experimental treatment

As with the pre-experimental data, a summary of Moon item scores by group and gender from children in the experimental group and control group are presented as shown (Table 6).

		Experimental group				Control group			
		n	Mean	Range	SD	n	Mean	Range	SD
Post-treatment	Class	31	19.1	6 – 27	4.87	31	13.9	8 – 20	3.54
	Boys	17	20.8	11 – 27	4.23	17	14.5	8 – 20	3.86
	Girls	14	17.1	6 - 23	4.94	14	13.3	8 - 18	3.12

Table 6 Moon scores

(i) Experimental group

At second interview (post-experimental treatment), overall scores in the experimental group ranged from 6 to 27 with a mean of 19.1. 2 children scored between 0 and 11 (7%), 25 children between 12 and 23 (81%) and 4 children between 24 and 36 (13%). The boys in the experimental group appeared to score more highly than the girls overall and the observed difference in their mean scores, 20.8 and 17.1, was significant ($t=2.28$, $df=29$, $p=0.030$; normality for boys $D_{xb}=0.129$, $p>0.15$; normality for girls $D_{xg}=0.146$, $p>0.15$; F-ratio=1.36). Overall score profile percentages included 17.2% 0s, 19.9% 1s, 49.2% 2s and 13.7% 3s. Analysis of the score profile percentages of boys and girls suggested that the observed differences were significant (test statistic $D_{xbg}=0.170$, critical value $K_D=0.170$ for $\alpha=0.01$). In those areas of children's ideas about the Moon which received most attention earlier (M1, M2, M4 and M11), observed differences in median scores between boys and girls were significant in item M11 (nature: $W_{xb}=321.5$, $W_{xg}=174.5$, $p=0.039$).

The observed difference in mean scores of the experimental group between first and second interviews (pre- and post-experimental treatment), 13.3 and 19.1, was significant (matched $t=-9.60$, $p=0.000$, normality of differences in experimental scores $D_{dx}=0.085$, $p>0.15$; F-ratio=1.41). Correlation coefficient analysis for pairs of data was significant (Pearson's $r=0.725$, $p=0.000$). Analysis of the score profile percentages of the experimental group at first and second interview suggested that observed differences were significant (test statistic $D_x=0.301$, critical value $K_D=0.120$ for $\alpha=0.01$). In those areas of children's ideas about the Moon which received most attention earlier (M1, M2, M4 and M11), observed differences in median scores between first and second interviews were significant for items M2 (shape selection: $W_{x1}=860.0$, $W_{x2}=1093.0$, $p=0.029$), M4 (drawing: $W_{x1}=795.5$, $W_{x2}=1157.5$, $p=0.002$) and M11 (nature: $W_{x1}=814.5$, $W_{x2}=1138.5$, $p=0.013$).

(ii) Control group

At second interview (post-experimental treatment), overall scores in the control group ranged from 8 to 20 with a mean of 13.9. 10 children scored between 0 and 11 (32%) and 21 children between 12 and 23 (68%). While the boys in the control group appeared to score

more highly than the girls overall, the observed difference in their mean scores, 14.5 and 13.3, was not significant (t=0.93, df=29, p=0.36; normality for boys D_{cb}=0.125, p>0.15; normality for girls D_{cg}=0.093, p>0.15; F-ratio=1.53). Overall score profile percentages included 21.2% 0s, 44.9% 1s, 30.4% 2s and 3.5% 3s. Analysis of the score profile percentages of boys and girls suggested that the observed differences were not significant (test statistic D_{cbg}=0.064, critical value K_D=0.142 for α=0.05). In those areas of children's ideas about the Moon which received most attention earlier (M1, M2, M4 and M11), observed differences in median scores between boys and girls were not significant.

The observed difference in mean scores of the control group between first and second interviews (pre- and post-experimental treatment), 14.1 and 13.9, was not significant (matched t=0.37, p=0.714, normality of differences in experimental scores D_{dc}=0.074, p>0.15; F-ratio=1.23). Correlation coefficient analysis for pairs of data was significant (Pearson's r=0.699, p=0.000). Analysis of the score profile percentages of the control group at first and second interview suggested that observed differences were not significant (test statistic D_c=0.021, critical value K_D=0.100 for α=0.05). In those areas of children's ideas about the Moon which received most attention earlier (M1, M2, M4 and M11), observed differences in median scores between first and second interviews were not significant.

(iii) Experimental and control groups compared

The observed difference in overall mean scores of the experimental group and control group at second interview (post-experimental treatment), 19.1 and 13.9, was significant (t=4.80, df=54, p=0.000; normality of the experimental group D_x=0.119, p>0.15; normality of the control group D_c=0.091, p>0.15; F=1.89 which is significant at α=0.05). Analysis of the score profile percentages of the experimental group and the control group suggested that observed differences were significant (test statistic D_{xc}=0.290, critical value K_D=0.120 for α=0.01). In those areas of children's ideas about the Moon which received most attention earlier (M1, M2, M4 and M11), observed differences in median scores between the experimental group and control group were significant for items M1 (shape verbal: W_{x2}=1122.5, W_{c2}=830.5, p=0.017), M4 (drawing: W_{x2}=1159.5, W_{c2}=793.5, p=0.004) and M11 (nature: W_{x2}=1172.5, W_{c2}=780.5, p=0.003).

The observed differences in overall mean scores of the experimental and control groups at first and second interviews (pre- and post-experimental treatment) were significant (one-way ANOVA F=13.24, df=3, p=0.000). The observed difference in mean gain of the experimental group (O_3-O_1) and control group (O_4-O_2), +5.9 and –0.2 (SDs 3.40 and 2.92), was significant (t=7.54, df=60, p=0.000; normalities supplied earlier; F-ratio=1.36).

8. Relative size

Pre-experimental treatment

While appearing as a single scored item within data for the Earth, the Sun and the Moon, an inferential analysis of relative size is still presented here.

(i) Experimental group

At first interview (pre-experimental treatment), overall score profile percentages included 6.5% 0s, 48.4% 1s and 45.2% 2s. Analysis of the score profile percentages of boys and girls suggested that the observed differences were not significant (test statistic D_{xbg}=0.172, critical value K_D=0.491 for α=0.05). Observed differences in median scores between boys and girls were not significant.

(ii) Control group

At first interview (pre-experimental treatment), overall score profile percentages included 6.5% 0s, 48.4% 1s and 45.2% 2s (an identical profile to the experimental group). Analysis of the score profile percentages of boys and girls suggested that the observed differences were not significant (test statistic D_{cbg}=0.143, critical value K_D=0.491 for α=0.05). Observed differences in median scores between boys and girls were not significant.

(iii) Experimental and control groups compared

Analysis of the score profile percentages of the experimental group and the control group at first interview (pre-experimental treatment) suggested that the observed differences were not

significant (test statistic D_{xc}=0.000, critical value K_D=0.345 for α=0.05). Observed differences in median scores between the experimental group and control group were not significant.

Post-experimental treatment

Again, appearing as a single scored item within data for the Earth, the Sun and the Moon, only a reduced inferential analysis of relative size is presented here.

(i) Experimental group

At second interview (post-experimental treatment), overall score profile percentages included 0.0% 0s, 19.4% 1s, 83.9% 2s and 16.1% 3s. Analysis of the score profile percentages of boys and girls suggested that the observed differences were not significant (test statistic D_{xbg}=0.164, critical value K_D=0.491 for α=0.05). Observed differences in median scores between boys and girls were not significant.

Analysis of the score profile percentages of the experimental group at first and second interview suggested that observed differences were significant (test statistic D_x=0.354, critical value K_D=0.345 for α=0.05). Observed differences in median scores between first and second interviews were significant (W_{x1}=765.0, W_{x2}=1188.0, p=0.001).

(ii) Control group

At second interview (post-experimental treatment), overall score profile percentages included 12.9% 0s, 32.3% 1s and 54.8% 2s. Analysis of the score profile percentages of boys and girls suggested that the observed differences were not significant (test statistic D_{cbg}=0.155, critical value K_D=0.491 for α=0.05). Observed differences in median scores between boys and girls were not significant.

Analysis of the score profile percentages of the control group at first and second interview suggested that observed differences were not significant (test statistic D_c=0.096, critical value

K_D=0.345 for α=0.05). Observed differences in median scores between first and second interviews were not significant.

(iii) Experimental and control groups compared

Analysis of the score profile percentages of the experimental group and the control group at second interview (post-experimental treatment) suggested that the observed differences were not significant (test statistic D_{xc}=0.258, critical value K_D=0.345 for α=0.05). Observed differences in median scores between the experimental group and control group were significant (W_x=1155.0, W_c=798.0, p=0.004).

9. The day and night cycle

Pre-experimental treatment

A summary of day and night item scores by group and gender from children in the experimental group and control group are presented as shown (Table 7).

		Experimental group				Control group			
		n	Mean	Range	SD	n	Mean	Range	SD
Pre-treatment	Class	31	7.3	2 - 13	3.70	31	7.3	2 – 14	3.95
	Boys	17	8.2	2 - 13	3.32	17	7.8	2 – 14	4.12
	Girls	14	6.1	2 - 13	3.94	14	6.8	2 - 13	3.81

Table 7 Day and night scores

(i) Experimental group

At first interview (pre-experimental treatment), overall scores in the experimental group ranged from 2 to 13 with a mean of 7.3. 11 children scored between 0 and 5 (35%), 15 children between 6 and 11 (48%) and 5 children between 12 and 18 (16%). While the boys in the experimental group appeared to score more highly than the girls overall, the observed difference in their mean scores, 8.2 and 6.1, was not significant (t=1.56, df=29, p=0.13; normality for boys D_{xb}=0.126, p>0.15; normality for girls D_{xg}=0.186, p>0.15; F-ratio=1.41). Overall score profile percentages included 30.6% 0s, 20.4% 1s, 46.2% 2s and 2.7% 3s.

Analysis of the score profile percentages of boys and girls suggested that the observed differences were not significant (test statistic D_{xbg}=0.180, critical value K_D=0.200 for α=0.05). In those areas of children's ideas about the day and night cycle which received most attention earlier (DN1, DN2, DN3 and DN6), observed differences in median scores between boys and girls were not significant.

(ii) Control group

At first interview (pre-experimental treatment), overall scores in the control group ranged from 2 to 14 with a mean of 7.3. 11 children scored between 0 and 5 (35%), 13 children between 6 and 11 (42%) and 7 children between 12 and 18 (23%). While the boys in the control group appeared to score more highly than the girls overall, the observed difference in their mean scores, 7.8 and 6.8, was not significant (t=0.68, df=29, p=0.50; normality for boys D_{cb}=0.084, p>0.15; normality for girls D_{cg}=0.120, p>0.15; F-ratio=1.17). Overall score profile percentages included 31.2% 0s, 21.5% 1s, 41.4% 2s and 5.9% 3s. Analysis of the score profile percentages of boys and girls suggested that the observed differences were not significant (test statistic D_{cbg}=0.081, critical value K_D=0.200 for α=0.05). In those areas of children's ideas about the day and night cycle which received most attention earlier (DN1, DN2, DN3 and DN6), observed differences in median scores between boys and girls were not significant.

(iii) Experimental and control groups compared

The observed difference in overall mean scores of the experimental group and control group at first interview (pre-experimental treatment), 7.3 and 7.3, was not significant (t=-0.07, df=60, p=0.95; normality of the experimental group D_x=0.085, p>0.15; normality of the control group D_c=0.083, p>0.15; F=1.14). Analysis of the score profile percentages of the experimental group and the control group suggested that the observed differences were not significant (test statistic D_{xc}=0.032, critical value K_D=0.141 for α=0.05). In those areas of children's ideas about the day and night cycle which received most attention earlier (DN1, DN2, DN3 and DN6), observed differences in median scores between the experimental group and the control group were not significant.

Post-experimental treatment

A summary of day and night item scores by group and gender from children in the experimental group and control group are presented as shown (Table 8).

		Experimental group				Control group			
		n	Mean	Range	SD	n	Mean	Range	SD
Post-treatment	Class	31	10.4	1 – 15	3.29	31	7.2	0 – 13	3.12
	Boys	17	11.1	1 – 15	3.44	17	7.8	0 – 13	3.21
	Girls	14	9.6	3 - 14	3.01	14	6.6	2 - 12	2.98

Table 8 Day and night scores

(i) Experimental group

At second interview (post-experimental treatment), overall scores in the experimental group ranged from 1 to 15 with a mean of 10.4. 2 children scored between 0 and 5 (6%), 14 children between 6 and 11 (45%) and 15 children between 12 and 18 (48%). While the boys in the experimental group appeared to score more highly than the girls overall, the observed difference in their mean scores, 11.1 and 9.6, was not significant ($t=1.32$, $df=29$, $p=0.20$; normality for boys $D_{xb}=0.251$, $p<0.01$ - deviation; normality for girls $D_{xg}=0.103$, $p>0.15$; F-ratio=1.31). Overall score profile percentages included 12.4% 0s, 14.0% 1s, 61.3% 2s and 12.4% 3s. Analysis of the score profile percentages of boys and girls suggested that the observed differences were not significant (test statistic $D_{xbg}=0.127$, critical value $K_D=0.200$ for $\alpha=0.05$). In those areas of children's ideas about the day and night cycle which received most attention earlier (DN1, DN2, DN3 and DN6), observed differences in median scores between boys and girls were significant in item DN6 (variation: $W_{xb}=339.5$, $W_{xg}=156.5$, $p=0.04$).

The observed difference in mean scores of the experimental group between first and second interviews (pre- and post-experimental treatment), 7.3 and 10.4, was significant (matched $t=-5.95$, $p=0.000$, normality of differences in experimental scores $D_{dx}=0.112$, $p>0.15$; F-ratio=1.26). Correlation coefficient analysis for pairs of data was significant (Pearson's $r=0.648$, $p=0.000$). Analysis of the score profile percentages of the experimental group at first and second interview suggested that observed differences were significant (test statistic

D_x=0.248, critical value K_D=0.169 for α=0.01). In those areas of children's ideas about the day and night cycle which received most attention earlier (DN1, DN2, DN3 and DN6), observed differences in median scores between first and second interviews were significant for items DN1 (verbal: W_{x1}=794.5, W_{x2}=1158.5, p=0.004), DN2 (use of props: W_{x1}=835.5, W_{x2}=1117.5, p=0.029) and DN3 (drawing: W_{x1}=722.5, W_{x2}=1230.5, p=0.000).

(ii) Control group

At second interview (post-experimental treatment), overall scores in the control group ranged from 0 to 13 with a mean of 7.2. 6 children scored between 0 and 5 (19%), 22 children between 6 and 11 (71%) and 3 children between 12 and 18 (10%). While the boys in the control group appeared to score more highly than the girls overall, the observed difference in their mean scores, 7.8 and 6.6, was not significant (t=1.06, df=29, p=0.30; normality for boys D_{cb}=0.085, p>0.15; normality for girls D_{cg}=0.121, p>0.15; F-ratio=1.16). Overall score profile percentages included 31.2% 0s, 18.3% 1s, 49.5% 2s and 1.1% 3s. Analysis of the score profile percentages of boys and girls suggested that the observed differences were not significant (test statistic D_{cbg}=0.126, critical value K_D=0.200 for α=0.05). In those areas of children's ideas about the day and night cycle which received most attention earlier (DN1, DN2, DN3 and DN6), observed differences in median scores between boys and girls were not significant.

The observed difference in mean scores of the control group between first and second interviews (pre- and post-experimental treatment), 7.3 and 7.2, was not significant (matched t=0.18, p=0.860, normality of differences in control scores D_{dc}=0.069, p>0.15; F-ratio=1.60). Correlation coefficient analysis for pairs of data was significant (Pearson's r=0.655, p=0.000). Analysis of the score profile percentages of the control group at first and second interview suggested that observed differences were not significant (test statistic D_c=0.048, critical value K_D=0.141 for α=0.05). In those areas of children's ideas about the day and night cycle which received most attention earlier (DN1, DN2, DN3 and DN6), observed differences in median scores between first and second interviews were not significant.

(iii) Experimental and control groups compared

The observed difference in overall mean scores of the experimental group and control group at second interview (post-experimental treatment), 10.4 and 7.2, was significant (t=3.92, df=60, p=0.000; normality of the experimental group D_x=0.118, p>0.15; normality of the control group D_c=0.076, p>0.15; F=1.11). Analysis of the score profile percentages of the experimental group and the control group suggested that observed differences were significant (test statistic D_{xc}=0.232, critical value K_D=0.169 for α=0.01). In those areas of children's ideas about the day and night cycle which received most attention earlier (DN1, DN2, DN3 and DN6), observed differences in median scores between the experimental group and control group were significant for items DN1 (verbal: W_{x2}=1141.0, W_{c2}=812.0, p=0.009), DN2 (use of props: W_{x2}=1151.0, W_{c2}=802.0, p=0.004), DN3 (drawing: W_{x2}=1179.0, W_{c2}=774.0, p=0.003) and DN6 (variation: W_{x2}=1145.5, W_{c2}=807.5, p=0.006).

The observed differences in overall mean scores of the experimental and control groups at first and second interviews (pre- and post-experimental treatment) were significant (one-way ANOVA F=6.18, df=3, p=0.001). The observed difference in mean gain of the experimental group (O_3-O_1) and control group (O_4-O_2), +3.2 and –0.1 (SDs 2.96 and 3.03), was significant (t=4.29, df=60, p=0.000; normalities supplied earlier; F-ratio=1.05).

10. Seasonal change

Pre-experimental treatment

A summary of seasonal change item scores by group and gender from children in the experimental group and control group are presented as shown (Table 9).

		Experimental group				Control group			
		n	Mean	Range	SD	n	Mean	Range	SD
Pre-treatment	Class	31	3.3	0 – 7	1.83	31	3.8	0 – 10	2.42
	Boys	17	3.9	1 – 7	1.78	17	4.0	0 – 10	2.55
	Girls	14	2.4	0 - 5	1.56	14	3.5	0 - 9	2.31

Table 9 Seasonal change scores

(i) Experimental group

At first interview (pre-experimental treatment), overall scores in the experimental group ranged from 0 to 7 with a mean of 3.3. 27 children scored between 0 and 5 (87%) and 4 children between 6 and 11 (13%). The boys in the experimental group appeared to score more highly than the girls overall and the observed difference in their mean scores, 3.9 and 2.4, was significant ($t=2.49$, $df=29$, $p=0.019$; normality for boys $D_{xb}=0.083$, $p>0.15$; normality for girls $D_{xg}=0.094$, $p>0.15$; F-ratio=1.30). Overall score profile percentages included 59.1% 0s, 27.4% 1s, 13.4% 2s and 0.0% 3s. Analysis of the score profile percentages of boys and girls suggested that the observed differences were not significant (test statistic $D_{xbg}=0.180$, critical value $K_D=0.200$ for $\alpha=0.05$). In those areas of children's ideas about seasonal change which received most attention earlier (SC1, SC2, SC3 and SC6), observed differences in median scores between boys and girls were not significant.

(ii) Control group

At first interview (pre-experimental treatment), overall scores in the control group ranged from 0 to 10 with a mean of 3.8. 25 children scored between 0 and 5 (81%) and 6 children between 6 and 11 (19%). While the boys in the control group appeared to score more highly than the girls overall, the observed difference in their mean scores, 4.0 and 3.5, was not significant ($t=0.57$, $df=29$, $p=0.58$; normality for boys $D_{cb}=0.147$, $p>0.15$; normality for girls $D_{cg}=0.129$, $p>0.15$; F-ratio=1.22). Overall score profile percentages included 58.1% 0s, 21.5% 1s, 19.9% 2s and 0.5% 3s. Analysis of the score profile percentages of boys and girls suggested that the observed differences were not significant (test statistic $D_{cbg}=0.070$, critical value $K_D=0.200$ for $\alpha=0.05$). In those areas of children's ideas about seasonal change which received most attention earlier (SC1, SC2, SC3 and SC6), observed differences in median scores between boys and girls were not significant.

(iii) Experimental and control groups compared

The observed difference in overall mean scores of the experimental group and control group at first interview (pre-experimental treatment), 3.3 and 3.8, was not significant ($t=-0.95$, $df=60$, $p=0.35$; normality of the experimental group $D_x=0.061$, $p>0.15$; normality of the

control group D_c=0.124, p>0.15; F=1.75). Analysis of the score profile percentages of the experimental group and the control group suggested that the observed differences were not significant (test statistic D_{xc}=0.070, critical value K_D=0.141 for α=0.05). In those areas of children's ideas about seasonal change which received most attention earlier (SC1, SC2, SC3 and SC6), observed differences in median scores between the experimental group and the control group were not significant.

Post-experimental treatment

A summary of seasonal change item scores by group and gender from children in the experimental group and control group are presented as shown (Table 10).

		Experimental group				Control group			
		n	Mean	Range	SD	n	Mean	Range	SD
Post-treatment	Class	31	9.0	0 – 16	5.10	31	4.0	0 – 14	3.49
	Boys	17	10.2	0 – 16	5.04	17	4.5	0 – 14	3.73
	Girls	14	7.6	1 - 15	4.94	14	3.4	1 - 11	3.20

Table 10 Seasonal change scores

(i) Experimental group

At second interview (post-experimental treatment), overall scores in the experimental group ranged from 0 to 16 with a mean of 9.0. 10 children scored between 0 and 5 (32%), 8 children between 6 and 11 (26%) and 13 children between 12 and 18 (42%). While the boys in the experimental group appeared to score more highly than the girls overall, the observed difference in their mean scores, 10.2 and 7.6, was not significant (t=1.48, df=29, p=0.15; normality for boys D_{xb}=0.179, p>0.15; normality for girls D_{xg}=0.189, p>0.15; F-ratio=1.04). Overall score profile percentages included 22.6% 0s, 24.2% 1s, 33.3% 2s and 19.9% 3s. Analysis of the score profile percentages of boys and girls suggested that the observed differences were significant (test statistic D_{xbg}=0.232, critical value K_D=0.200 for α=0.05). In those areas of children's ideas about seasonal change which received most attention earlier (SC1, SC2, SC3 and SC6), observed differences in median scores between boys and girls were not significant.

The observed difference in mean scores of the experimental group between first and second interviews (pre- and post-experimental treatment), 3.3 and 9.0, was significant (matched t= -7.53, p=0.000, normality of differences in experimental scores D_{dx}=0.113, p>0.15; F-ratio=7.77 which is significant at α=0.01). Correlation coefficient analysis for pairs of data was significant (Pearson's r=0.594, p=0.000). Analysis of the score profile percentages of the experimental group at first and second interview suggested that observed differences were significant (test statistic D_x=0.398, critical value K_D=0.169 for α=0.01). In those areas of children's ideas about seasonal change which received most attention earlier (SC1, SC2, SC3 and SC6), observed differences in median scores between first and second interviews were significant for items SC1 (verbal: W_{x1}=692.5, W_{x2}=1260.5, p=0.000), SC2 (use of props: W_{x1}=664.0, W_{x2}=1289.0, p=0.000) and SC3 (drawing: W_{x1}=627.5, W_{x2}=1325.5, p=0.000).

(ii) Control group

At second interview (post-experimental treatment), overall scores in the control group ranged from 0 to 14 with a mean of 4.0. 23 children scored between 0 and 5 (74%) , 7 children between 6 and 11 (23%) and 1 child between 12 and 18 (3%). While the boys in the control group appeared to score more highly than the girls overall, the observed difference in their mean scores, 4.5 and 3.4, was not significant (t=0.88, df=29, p=0.39; normality for boys D_{cb}=0.138, p>0.15; normality for girls D_{cg}=0.242, p=0.034 - deviation; F-ratio=1.36). Overall score profile percentages included 58.1% 0s, 18.8% 1s, 22.0% 2s and 1.1% 3s. Analysis of the score profile percentages of boys and girls suggested that the observed differences were not significant (test statistic D_{cbg}=0.135, critical value K_D=0.200 for α=0.05). In those areas of children's ideas about seasonal change which received most attention earlier (SC1, SC2, SC3 and SC6), observed differences in median scores between boys and girls were not significant.

The observed difference in mean scores of the control group between first and second interviews (pre- and post-experimental treatment), 3.8 and 4.0, was not significant (matched t=-0.55, p=0.586, normality of differences in control scores D_{dc}=0.064, p>0.15; F-ratio=2.08 which is significant at α=0.05). Correlation coefficient analysis for pairs of data was significant (Pearson's r=0.841, p=0.000). Analysis of the score profile percentages of the control group at first and second interview suggested that observed differences were not

significant (test statistic D_c=0.027, critical value K_D=0.141 for α=0.05). In those areas of children's ideas about seasonal change which received most attention earlier (SC1, SC2, SC3 and SC6), observed differences in median scores between first and second interviews were not significant.

(iii) Experimental and control groups compared

The observed difference in overall mean scores of the experimental group and control group at second interview (post-experimental treatment), 9.0 and 4.0, was significant (t=4.57, df=53, p=0.000; normality of the experimental group D_x=0.153, p=0.064; normality of the control group D_c=0.174, p=0.026 - deviation; F=2.14 which is significant at α=0.05). Analysis of the score profile percentages of the experimental group and the control group suggested that observed differences were significant (test statistic D_{xc}=0.355, critical value K_D=0.169 for α=0.01). In those areas of children's ideas about seasonal change which received most attention earlier (SC1, SC2, SC3 and SC6), observed differences in median scores between the experimental group and control group were significant for items SC1 (verbal: W_{x2}=1208.0, W_{c2}=745.0, p=0.001), SC2 (use of props: W_{x2}=1261.0, W_{c2}=692.0, p=0.000) and SC3 (drawing: W_{x2}=1294.0, W_{c2}=659.0, p=0.000).

The observed differences in overall mean scores of the experimental and control groups at first and second interviews (pre- and post-experimental treatment) were significant (one-way ANOVA F=19.10, df=3, p=0.000). The observed difference in mean gain of the experimental group (O_3-O_1) and control group (O_4-O_2), +5.8 and +0.2 (SDs 4.27 and 1.96), was significant (t=6.61, df=42, p=0.000; normalities supplied earlier; F-ratio=4.75 which is significant at α=0.01).

11. Phases of the Moon

Pre-experimental treatment

A summary of Moon phase item scores by group and gender from children in the experimental group and control group are presented as shown (Table 11).

		Experimental group				Control group			
		n	Mean	Range	SD	n	Mean	Range	SD
Pre-treatment	Class	31	3.5	0 – 7	1.95	31	3.9	0 – 11	2.31
	Boys	17	4.4	2 – 7	1.50	17	4.0	0 – 11	2.69
	Girls	14	2.4	0 - 6	1.95	14	3.9	2 - 8	1.83

Table 11 Moon phase scores

(i) Experimental group

At first interview (pre-experimental treatment), overall scores in the experimental group ranged from 0 to 7 with a mean of 3.5. 27 children scored between 0 and 5 (87%) and 4 children between 6 and 11 (13%). The boys in the experimental group appeared to score more highly than the girls overall and the observed difference in their mean scores, 4.4 and 2.4, was significant ($t=3.11$, $df=29$, $p=0.004$; normality for boys $D_{xb}=0.052$, $p>0.15$; normality for girls $D_{xg}=0.099$, $p>0.15$; F-ratio=1.69). Overall score profile percentages included 57.0% 0s, 28.0% 1s, 15.1% 2s and 0.0% 3s. Analysis of the score profile percentages of boys and girls suggested that the observed differences were significant (test statistic $D_{xbg}=0.285$, critical value $K_D=0.240$ for $\alpha=0.01$). In those areas of children's ideas about the Moon's phases which received most attention earlier (MP1, MP2, MP3 and MP6), observed differences in median scores between boys and girls were significant for items MP1 (verbal: $W_{xb}=327.5$, $W_{xg}=168.5$, $p=0.010$), MP2 (use of props: $W_{xb}=316.5$, $W_{xg}=179.5$, $p=0.041$) and MP3 (drawing: $W_{xb}=316.5$, $W_{xg}=179.5$, $p=0.041$).

(ii) Control group

At first interview (pre-experimental treatment), overall scores in the control group ranged from 0 to 11 with a mean of 3.9. 24 children scored between 0 and 5 (77%) and 7 children between 6 and 11 (23%). While the boys in the control group appeared to score more highly than the girls overall, the observed difference in their mean scores, 4.0 and 3.9, was not significant ($t=0.17$, $df=29$, $p=0.87$; normality for boys $D_{cb}=0.115$, $p>0.15$; normality for girls $D_{cg}=0.148$, $p>0.15$; F-ratio=2.16). Overall score profile percentages included 55.4% 0s, 27.4% 1s, 13.4% 2s and 3.8% 3s. Analysis of the score profile percentages of boys and girls

suggested that the observed differences were not significant (test statistic D_{cbg}=0.032, critical value K_D=0.200 for α=0.05). In those areas of children's ideas about the Moon's phases which received most attention earlier (MP1, MP2, MP3 and MP6), observed differences in median scores between boys and girls were not significant.

(iii) Experimental and control groups compared

The observed difference in overall mean scores of the experimental group and control group at first interview (pre-experimental treatment), 3.5 and 3.9, was not significant (t=-0.83, df=60, p=0.41; normality of the experimental group D_x=0.056, p>0.15; normality of the control group D_c=0.102, p>0.15; F=1.40). Analysis of the score profile percentages of the experimental group and the control group suggested that the observed differences were not significant (test statistic D_{xc}=0.038, critical value K_D=0.141 for α=0.05). In those areas of children's ideas about the Moon's phases which received most attention earlier (MP1, MP2, MP3 and MP6), observed differences in median scores between the experimental group and the control group were not significant.

Post-experimental treatment

A summary of Moon phase item scores by group and gender from children in the experimental group and control group are presented as shown (Table 12).

		Experimental group				Control group			
		n	Mean	Range	SD	n	Mean	Range	SD
Post-treatment	Class	31	7.7	1 – 16	4.01	31	3.2	0 – 9	2.31
	Boys	17	8.9	1 – 16	3.80	17	4.0	0 – 9	2.48
	Girls	14	6.3	1 - 14	3.89	14	2.3	0 - 5	1.73

Table 12 Moon phase scores

(i) Experimental group

At second interview (post-experimental treatment), overall scores in the experimental group ranged from 1 to 16 with a mean of 7.7. 11 children scored between 0 and 5 (32%), 15 children between 6 and 11 (48%) and 5 children between 12 and 18 (16%). While the boys

in the experimental group appeared to score more highly than the girls overall, the observed difference in their mean scores, 8.9 and 6.3, was not significant ($t=1.92$, $df=29$, $p=0.065$; normality for boys $D_{xb}=0.153$, $p>0.15$; normality for girls $D_{xg}=0.165$, $p>0.15$; F-ratio=1.05). Overall score profile percentages included 26.3% 0s, 25.3% 1s, 41.4% 2s and 7.0% 3s. Analysis of the score profile percentages of boys and girls suggested that the observed differences were significant (test statistic $D_{xbg}=0.236$, critical value $K_D=0.200$ for $\alpha=0.05$). In those areas of children's ideas about the Moon's phases which received most attention earlier (MP1, MP2, MP3 and MP6), observed differences in median scores between boys and girls were significant for item MP6 (eclipse: $W_{xb}=329.0$, $W_{xg}=167.0$, $p=0.016$).

The observed difference in mean scores of the experimental group between first and second interviews (pre- and post-experimental treatment), 3.5 and 7.7, was significant (matched $t=-6.38$, $p=0.000$, normality of differences in experimental scores $D_{dx}=0.068$, $p>0.15$; F-ratio=4.23 which is significant at $\alpha=0.01$). Correlation coefficient analysis for pairs of data was significant (Pearson's $r=0.388$, $p=0.031$). Analysis of the score profile percentages of the experimental group at first and second interview suggested that observed differences were significant (test statistic $D_x=0.333$, critical value $K_D=0.169$ for $\alpha=0.01$). In those areas of children's ideas about the Moon's phases which received most attention earlier (MP1, MP2, MP3 and MP6), observed differences in median scores between first and second interviews were significant for items MP1 (verbal: $W_{x1}=741.0$, $W_{x2}=1212.0$, $p=0.000$), MP2 (use of props: $W_{x1}=733.0$, $W_{x2}=1220.0$, $p=0.000$) and MP3 (drawing: $W_{x1}=763.0$, $W_{x2}=1190.0$, $p=0.001$).

(ii) Control group

At second interview (post-experimental treatment), overall scores in the control group ranged from 0 to 9 with a mean of 3.2. 27 children scored between 0 and 5 (87%) and 4 children between 6 and 11 (13%). The boys in the control group appeared to score more highly than the girls overall and the observed difference in their mean scores, 4.0 and 2.3, was significant ($t=2.19$, $df=29$, $p=0.037$; normality for boys $D_{cb}=0.088$, $p>0.15$; normality for girls $D_{cg}=0.129$, $p>0.15$; F-ratio=2.05). Overall score profile percentages included 61.8% 0s, 25.8% 1s, 9.1% 2s and 3.2% 3s. Analysis of the score profile percentages of boys and girls suggested that the observed differences were not significant (test statistic $D_{cbg}=0.175$, critical

value K_D=0.200 for α=0.05). In those areas of children's ideas about the Moon's phases which received most attention earlier (MP1, MP2, MP3 and MP6), observed differences in median scores between boys and girls were significant for items MP2 (use of props: W_{cb}=327.0, W_{cg}=169.0, p=0.012) and MP3 (drawing: W_{cb}=319.0, W_{cg}=177.0, p=0.038).

The observed difference in mean scores of the control group between first and second interviews (pre- and post-experimental treatment), 3.9 and 3.2, was not significant (matched t=1.88, p=0.070, normality of differences in control scores D_{dc}=0.060, p>0.15; F-ratio=1.00). Correlation coefficient analysis for pairs of data was significant (Pearson's r=0.585, p=0.001). Analysis of the score profile percentages of the control group at first and second interview suggested that observed differences were not significant (test statistic D_c=0.064, critical value K_D=0.141 for α=0.05). In those areas of children's ideas about the Moon's phases which received most attention earlier (MP1, MP2, MP3 and MP6), observed differences in median scores between first and second interviews were not significant.

(iii) Experimental and control groups compared

The observed difference in overall mean scores of the experimental group and control group at second interview (post-experimental treatment), 7.7 and 3.2, was significant (t=5.44, df=47, p=0.000; normality of the experimental group D_x=0.101, p>0.15; normality of the control group D_c=0.075, p>0.15; F-ratio=3.01 which is significant at α=0.01). Analysis of the score profile percentages of the experimental group and the control group suggested that observed differences were significant (test statistic D_{xc}=0.360, critical value K_D=0.169 for α=0.01). In those areas of children's ideas about the Moon's phases which received most attention earlier (MP1, MP2, MP3 and MP6), observed differences in median scores between the experimental group and control group were significant for items MP1 (verbal: W_{x2}=1172.0, W_{c2}=781.0, p=0.002), MP2 (use of props: W_{x2}=1211.5, W_{c2}=741.5, p=0.000), MP3 (drawing: W_{x2}=1142.5, W_{c2}=810.5, p=0.012) and MP6 (eclipse: W_{x2}=1114.5, W_{c2}=838.5, p=0.029).

The observed differences in overall mean scores of the experimental and control groups at first and second interviews (pre- and post-experimental treatment) were significant (one-way ANOVA F=18.22, df=3, p=0.000). The observed difference in mean gain of the

experimental group (O_3-O_1) and control group (O_4-O_2), +4.3 and –0.7 (SDs 3.72 and 2.10), was significant (t=6.48, df=47, p=0.000; normalities supplied earlier; F-ratio=3.14 which is significant at α=0.01).

12. The Solar System and wider Universe

Pre-experimental treatment

A summary of Solar System item scores by group and gender from children in the experimental group and control group are presented as shown (Table 13).

		Experimental group				Control group			
		n	Mean	Range	SD	n	Mean	Range	SD
Pre-treatment	Class	31	10.1	0 – 16	3.74	31	9.6	4 – 17	3.29
	Boys	17	11.9	7 – 16	3.00	17	11.0	5 – 17	3.35
	Girls	14	7.9	0 - 12	3.42	14	7.9	4 - 14	2.37

Table 13 Solar System scores

(i) Experimental group

At first interview (pre-experimental treatment), overall scores in the experimental group ranged from 0 to 16 with a mean of 10.1. 19 children scored between 0 and 11 (61%) and 12 children between 12 and 23 (39%). The boys in the experimental group appeared to score more highly than the girls overall and the observed difference in their mean scores, 11.9 and 7.9, was significant (t=3.49, df=29, p=0.002; normality for boys D_{xb}=0.113, p>0.15; normality for girls D_{xg}=0.195, p>0.15; F-ratio=1.30). Overall score profile percentages included 33.6% 0s, 48.9% 1s, 17.5% 2s and 0.0% 3s. Analysis of the score profile percentages of boys and girls suggested that the observed differences were significant (test statistic D_{xbg}=0.234, critical value K_D=0.170 for α=0.01). In those areas of children's ideas about the Solar System which received most attention earlier (SOL5, 9, 10, 11 and 12), observed differences in median scores between boys and girls were significant for items SOL5 (Solar System map: W_{xb}=311.0, W_{xg}=185.0, p=0.017) and SOL9 (movements of planets: W_{xb}=325.5, W_{xg}=170.5, p=0.011).

(ii) Control group

At first interview (pre-experimental treatment), overall scores in the control group ranged from 4 to 17 with a mean of 9.6. 22 children scored between 0 and 11 (71%) and 9 children between 12 and 23 (29%). The boys in the control group appeared to score more highly than the girls overall and the observed difference in their mean scores, 11.0 and 7.9, was significant (t=2.88, df=29, p=0.007; normality for boys D_{cb}=0.060, p>0.15; normality for girls D_{cg}=0.131, p>0.15; F-ratio=2.00). Overall score profile percentages included 37.1% 0s, 46.0% 1s, 16.7% 2s and 0.3% 3s. Analysis of the score profile percentages of boys and girls suggested that the observed differences were significant (test statistic D_{cbg}=0.229, critical value K_D=0.142 for α=0.05). In those areas of children's ideas about the Solar System which received most attention earlier (SOL5, 9, 10, 11 and 12), observed differences in median scores between boys and girls were significant for item SOL9 (movements of planets: W_{cb}=368.0, W_{cg}=128.0, p=0.000).

(iii) Experimental and control groups compared

The observed difference in overall mean scores of the experimental group and control group at first interview (pre-experimental treatment), 10.1 and 9.6, was not significant (t=0.50, df=60, p=0.62; normality of the experimental group D_x=0.081, p>0.15; normality of the control group D_c=0.082, p>0.15; F=1.29). Analysis of the score profile percentages of the experimental group and the control group suggested that the observed differences were not significant (test statistic D_{xc}=0.035, critical value K_D=0.100 for α=0.05). In those areas of children's ideas about the Solar System which received most attention earlier (SOL5, 9, 10, 11 and 12), observed differences in median scores between the experimental group and the control group were not significant.

Post-experimental treatment

A summary of Solar System item scores by group and gender from children in the experimental group and control group are presented as shown (Table 14).

		Experimental group				Control group			
		n	Mean	Range	SD	n	Mean	Range	SD
Post-treatment	Class	31	18.6	11 – 30	4.90	31	8.7	4 – 19	3.14
	Boys	17	19.9	11 – 30	5.35	17	9.9	5 – 19	3.44
	Girls	14	17.0	12 - 24	3.92	14	7.1	4 - 11	1.88

Table 14 Solar System scores

(i) Experimental group

At second interview (post-experimental treatment), overall scores in the experimental group ranged from 11 to 30 with a mean of 18.6. 1 child scored between 0 and 11 (3%), 24 children between 12 and 23 (77%) and 6 children between 24 and 36 (19%). While the boys in the experimental group appeared to score more highly than the girls overall, the observed difference in their mean scores, 19.9 and 17.0, was not significant ($t=1.73$, $df=28$, $p=0.095$; normality for boys $D_{xb}=0.077$, $p>0.15$; normality for girls $D_{xg}=0.124$, $p>0.15$; F-ratio=1.86 which is significant at $\alpha=0.05$). Overall score profile percentages included 11.8% 0s, 29.3% 1s, 51.1% 2s and 7.8% 3s. Analysis of the score profile percentages of boys and girls suggested that the observed differences were not significant (test statistic $D_{xbg}=0.088$, critical value $K_D=0.142$ for $\alpha=0.05$). In those areas of children's ideas about the Solar System which received most attention earlier (SOL5, 9, 10, 11 and 12), observed differences in median scores between boys and girls were not significant.

The observed difference in mean scores of the experimental group between first and second interviews (pre- and post-experimental treatment), 10.1 and 18.6, was significant (matched $t=-13.89$, $p=0.000$, normality of differences in experimental scores $D_{dx}=0.089$, $p>0.15$; F-ratio=1.72). Correlation coefficient analysis for pairs of data was significant (Pearson's $r=0.719$, $p=0.000$). Analysis of the score profile percentages of the experimental group at first and second interview suggested that observed differences were significant (test statistic $D_x=0.414$, critical value $K_D=0.120$ for $\alpha=0.01$). In those areas of children's ideas about the Solar System which received most attention earlier (SOL5, 9, 10, 11 and 12), observed differences in median scores between first and second interviews were significant in all: SOL5 (Solar System map: $W_{x1}=632.5$, $W_{x2}=1320.5$, $p=0.000$), SOL9 (movements of planets: $W_{x1}=757.0$, $W_{x2}=1196.0$, $p=0.001$), SOL10 (forces: $W_{x1}=804.5$, $W_{x2}=1148.5$, $p=0.003$),

SOL11 (Solar System age: W_{x1}=785.0, W_{x2}=1168.0, p=0.002) and SOL12 (origin: W_{x1}=720.5, W_{x2}=1232.5, p=0.000).

(ii) Control group

At second interview (post-experimental treatment), overall scores in the control group ranged from 4 to 19 with a mean of 8.7. 27 children scored between 0 and 11 (87%) and 4 children between 12 and 23 (13%). The boys in the control group appeared to score more highly than the girls overall and the observed difference in their mean scores, 9.9 and 7.1, was significant (t=2.88, df=25, p=0.008; normality for boys D_{cb}=0.199, p=0.073; normality for girls D_{cg}=0.138, p>0.15; F-ratio=3.35 which is significant at α=0.01). Overall score profile percentages included 44.4% 0s, 39.2% 1s, 16.1% 2s and 0.3% 3s. Analysis of the score profile percentages of boys and girls suggested that the observed differences were not significant (test statistic D_{cbg}=0.125, critical value K_D=0.142 for α=0.05). In those areas of children's ideas about the Solar System which received most attention earlier (SOL5, 9, 10, 11 and 12), observed differences in median scores between boys and girls were significant for item SOL9 (movements of planets: W_{cb}=329.5, W_{cg}=166.5, p=0.006).

The observed difference in mean scores of the control group between first and second interviews (pre- and post-experimental treatment), 9.6 and 8.7, was significant (matched t=2.12, p=0.043, normality of differences in control scores D_{dc}=0.086, p>0.15; F-ratio=1.10). Correlation coefficient analysis for pairs of data was significant (Pearson's r=0.708, p=0.000). Analysis of the score profile percentages of the control group at first and second interview suggested that observed differences were not significant (test statistic D_c=0.073, critical value K_D=0.100 for α=0.05). In those areas of children's ideas about the Solar System which received most attention earlier (SOL5, 9, 10, 11 and 12), observed differences in median scores between first and second interviews were significant for items SOL10 (forces: W_{c1}=1053.5, W_{xc2}=899.5, p=0.05), SOL11 (Solar System age: W_{xc1}=1068.5, W_{xc2}=884.5, p=0.044) and SOL12 (origin: W_{c1}=1082.0, W_{c2}=871.0, p=0.048). (Note: lower mean post- also reflected in median scores.)

(iii) Experimental and control groups compared

The observed difference in overall mean scores of the experimental group and control group at second interview (post-experimental treatment), 18.6 and 8.7, was significant (t=9.47, df=51, p=0.000; normality of the experimental group D_x=0.067, p>0.15; normality of the control group D_c=0.136, p=0.145; F=2.44 which is significant at α=0.01). Analysis of the score profile percentages of the experimental group and the control group suggested that the observed differences were significant (test statistic D_{xc}=0.425, critical value K_D=0.120 for α=0.01). In those areas of children's ideas about the Solar System which received most attention earlier (SOL5, 9, 10, 11 and 12), observed differences in median scores between the experimental group and the control group were significant in all: SOL5 (Solar System map: W_{x2}=1398.5, W_{c2}=554.5, p=0.000), SOL9 (movements of planets: W_{x2}=1245.5, W_{c2}=707.5, p=0.000), SOL10 (forces: W_{x2}=1182.5, W_{c2}=770.5, p=0.000), SOL11 (Solar System age: W_{x2}=1221.5, W_{c2}=731.5, p=0.000) and SOL12 (origin: W_{x2}=1277.5, W_{c2}=675.5, p=0.000).

The observed differences in overall mean scores of the experimental and control groups at first and second interviews (pre- and post-experimental treatment) were significant (one-way ANOVA F=44.7, df=3, p=0.000). The observed difference in mean gain of the experimental group (O_3-O_1) and control group (O_4-O_2), 8.5 and –0.9 (SDs 3.41 and 2.46), was significant (t=12.50, df=54, p=0.000; normalities supplied earlier; F-ratio=1.92 which is significant at α=0.05).

13. Multiple linear regression analyses

	Age	Intellectual maturity	Science curiosity
Age	-		
	-		
Intellectual	-0.442	-	
maturity	0.013	-	
Science	-0.248	0.143	-
curiosity	0.178	0.443	-

Table 15 Inter-correlation experimental group (Pearson's r and probability)

	Age	Intellectual maturity	Science curiosity
Age	-		
	-		
Intellectual	-0.310	-	
maturity	0.090	-	
Science	0.007	0.033	-
curiosity	0.969	0.861	-

Table 16 Inter-correlation control group (Pearson's r and probability)

Pre-experimental

	Age		Intellectual maturity		Science curiosity		Model			
	t	p	t	p	t	p	R^2	F	df	p
Earth	2.95	0.007	1.14	0.266	1.67	0.107	0.267	3.28	3	0.036
Sun	3.10	0.005	1.51	0.142	2.09	0.046	0.307	3.99	3	0.018
Moon	2.83	0.009	0.85	0.405	1.24	0.226	0.240	2.84	3	0.057
Day and night	2.34	0.027	1.62	0.116	1.46	0.156	0.210	2.39	3	0.091
Seasonal change	1.70	0.101	-0.04	0.967	2.73	0.011	0.250	3.01	3	0.048
Moon's phases	2.45	0.021	0.05	0.959	-0.15	0.879	0.227	2.64	3	0.069
Solar System	5.41	0.000	2.59	0.015	2.67	0.013	0.543	10.70	3	0.000

Table 17 Multiple linear regression analyses experimental group

	Age		Intellectual maturity		Science curiosity		Model			
	t	p	t	p	t	p	R^2	F	df	p
Earth	1.89	0.069	3.29	0.003	1.99	0.057	0.374	5.37	3	0.005
Sun	2.60	0.015	5.57	0.000	1.40	0.173	0.561	11.49	3	0.000
Moon	0.94	0.354	3.10	0.005	0.70	0.490	0.275	3.42	3	0.031
Day and night	2.77	0.010	2.16	0.040	2.37	0.025	0.366	5.20	3	0.006
Seasonal change	1.67	0.106	1.26	0.217	2.59	0.015	0.279	3.48	3	0.029
Moon's phases	2.52	0.018	2.71	0.012	2.53	0.018	0.392	5.81	3	0.003
Solar System	2.12	0.043	3.75	0.001	2.91	0.007	0.475	8.14	3	0.001

Table 18 Multiple linear regression analyses control group

Post-experimental

	Age		Intellectual maturity		Science curiosity		Model			
	t	p	t	p	t	p	R^2	F	df	p
Earth	4.69	0.000	2.48	0.019	2.09	0.046	0.469	7.93	3	0.001
Sun	3.35	0.002	1.53	0.137	0.81	0.428	0.294	3.75	3	0.022
Moon	3.81	0.001	2.18	0.038	1.54	0.136	0.367	5.21	3	0.006
Day and night	3.53	0.001	0.99	0.333	0.35	0.731	0.326	4.35	3	0.013
Seasonal change	1.88	0.070	0.19	0.852	0.91	0.369	0.135	1.40	3	0.264
Moon's phases	4.95	0.000	1.72	0.097	1.49	0.149	0.480	8.29	3	0.000
Solar System	3.51	0.002	2.66	0.013	0.73	0.470	0.342	4.68	3	0.009

Table 19 Multiple linear regression analyses experimental group

	Age		Intellectual maturity		Science curiosity		Model			
	t	p	t	p	t	p	R^2	F	df	p
Earth	1.88	0.071	3.44	0.002	2.01	0.054	0.389	5.73	3	0.004
Sun	1.52	0.139	2.90	0.007	2.17	0.039	0.342	4.69	3	0.009
Moon	1.29	0.209	3.87	0.001	0.61	0.549	0.366	5.19	3	0.006
Day and night	2.12	0.044	2.74	0.011	-0.21	0.837	0.256	3.10	3	0.043
Seasonal change	1.78	0.086	1.85	0.075	2.50	0.019	0.302	3.89	3	0.020
Moon's phases	2.47	0.020	1.86	0.074	1.80	0.084	0.289	3.66	3	0.025
Solar System	0.074	0.465	1.75	0.091	3.23	0.003	0.342	4.67	3	0.009

Table 20 Multiple linear regression analyses control group