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PROMOTING MENTAL MODEL-BUILDING IN ASTRONOMY EDUCATION

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by

IAN JAMES TAYLOR

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ABSTRACT

The difficulties in learning and teaching astronomy, including the use of models, have been well documented. Models, when used by teachers, are usually utilised in a transmissive way to impart content to pupils. The process of constructing mental models, an essential aspect of the development of astronomy knowledge (both historically and today) is usually overlooked.

This research explored how models can promote mental model building in classrooms. *Mental models* are defined as human cognitive constructions which are used to describe and explain phenomena which cannot be experienced directly. They are used both to understand the world and to articulate understandings to others. *Models* may be scaled miniatures or scaled enlargements or working models, each of which represents a mental model in some, but not all, its properties. An example is an orrery, which is a representation of part of the solar system.

This study investigated how pupils can be helped to construct the scientists' mental model of the Sun-Earth-Moon system. It used an approach suggested by Hesse (1966) in which a model is repeatedly critiqued with respect to the extent that it both represents and fails to represent the structure and properties of a mental model. The study proposed that the process of repeated critiques would assist learners to construct and consolidate the scientists' mental model of the Sun-Earth-Moon system.

A research programme was designed to investigate whether pupils could be assisted to construct the scientists' mental model of the Sun-Earth-Moon system within the constraints of an ordinary classroom by using the process of critiquing a model of the scientists' mental model. A 12-lesson teaching intervention, conducted over a period of three weeks, was designed for that purpose. The teaching strategy, which was developed from well-trialled constructivist research, consisted of four phases: Focus on the Mental Model; Mental Model Building and Critiquing; Using the Mental Model to Solve Problems; and Reflection.

The study reported interviews with twelve intermediate school teachers to ascertain their views about the challenges of teaching astronomy. This was followed by an initial classroom pilot intervention and then a formal classroom trial intervention with Year 7-8 pupils in the same intermediate school in New Zealand. Both classes were similar and both were taught by teachers in their second year of teaching. An orrery was used as the model of the mental model of the Sun-Earth-Moon system in both the pilot and trial interventions.

Insights learned from the pilot intervention were used to modify the format of the trial intervention, which took place one year later. Both the pilot intervention and the trial intervention were monitored by: pre- and post-interviews with Year 7-8 pupils; interviews

with the intervention teacher after most of the lessons; pre-, post- and post-post written surveys of all members of the class; and audio-tapes of the lessons.

The pre-interviews and pre-surveys showed that the pupils began both interventions with a range of mental models of the Sun-Earth-Moon system. Furthermore, their other concepts (about tides, phases of the Moon, spatial relationships, etc.) were often apparently unrelated to the Sun-Earth-Moon system or to each other.

The findings showed that most of these Year 7-8 pupils were enabled to build the scientists' mental model of the Sun-Earth-Moon system and that the use of models is effective in promoting mental model building. As well as acquiring these understandings about processes in astronomy, the pupils also achieved the traditional goals in astronomy knowledge and concepts (although concepts associated with the Moon still proved difficult for these pupils, as did an understanding of Earth's axis of rotation). The pupils responded positively to the approach, they did not tire of the repeated critiquing of the model and they developed their ideas about models in science at large.

The study demonstrated that all four phases of the modified teaching strategy were necessary for the mental model to be both constructed and consolidated. It is also clear that pupil interactions, both in small groups and in the whole class, were important factors in the mental model building process. In addition, the study further indicated that, contrary to some other research, Year 7-8 may be an appropriate age to begin teaching about models in science in general.

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CHAPTER ONE: INTRODUCTION AND OVERVIEW

That's what I hate about astronomy - all those numbers.
[Ann, Year 7 pupil]

1.1 ASTRONOMY EDUCATION: SOME PERSONAL CONCERNS

The main challenge... the teachers themselves needing background information...
[Experienced teacher of Year 7-8 pupils]

Over many years as a teacher of astronomy at primary, secondary and tertiary levels, including teacher education, the researcher has observed with growing concern that the teaching of astronomy at all those levels is frequently fact-based and didactic in style, and is often not particularly effective in its limited aims of transmitting knowledge to the learners. That is, there are considerable difficulties with regard to the methodology of astronomy education.

In the researcher's experience, teachers often have only a limited understanding of the facts and concepts about astronomy and yet, perversely, they often teach it in a fact-orientated manner. Astronomy projects are another favoured approach but they may offer little to promote learning skills (other than book research) and even less towards the development of the learners' concepts.

The pupils often seem to be passive, listening to facts from the teacher or a visiting expert or replicating little-understood data from a book or a computer into a project. It is the researcher's experience that these pupils initially join in this type of activity with some enthusiasm, being rather over-awed yet thrilled by the interesting data and the inconceivably huge distances and sizes. However, they then often quickly become bored by the mere gathering and replication of information and rarely retain the knowledge for an appreciable length of time.

This didactic approach also often fails to reflect that *astronomy is a science* with the usual range of insights, methodologies and discussions which undergo processes of debate and refinement. On the other hand, it is acknowledged that there are particular difficulties associated with teaching astronomy that are less often encountered when teaching other areas of science. These include the inability to manipulate variables and the fact that most data-gathering occurs at night.

In summary, it appears to the researcher that astronomy is usually presented as a body of received knowledge rather than as a set of evolving concepts that are negotiated and constructed by individuals and groups. This thesis seeks to document the current state of astronomy education and to explore possibilities for its enhancement.

The pedagogical climate in astronomy classrooms, and the learning which it generates, will be explored further in chapter two.

1.2 ASTRONOMY IN THE NEW ZEALAND CURRICULUM

My lack of knowledge... It's my biggest challenge.
[Teacher of Year 7-8 pupils]

For most of the twentieth century, astronomy education worldwide was only a tiny and often ignored part of the secondary science curriculum and it was usually voluntary at both primary and tertiary levels. However, astronomy has recently been reintroduced in many countries as a compulsory part of the science curriculum. In those countries, including New Zealand, it is no longer satisfactory or permissible for teachers to ignore this learning area.

After a change in government of New Zealand in 1990, the new Minister of Education proposed reforms to the whole school curriculum. Consequently, in 1993 the *New Zealand Curriculum Framework* (Ministry of Education, 1993a) was published. It stated that all pupils in New Zealand had the right to a broad, balanced education with the individual pupil at the centre of the education process and that the *New Zealand Curriculum Framework* was to be seen as a curriculum document rather than as a directive syllabus. It was to allow local discretion within national direction. The Framework included science as one of the seven Essential Learning Areas in which all school pupils in New Zealand were to be taught, from beginning school to at least Year Eleven.

A consequent document, also for pupils at every level of the school system, was *Science in the New Zealand Curriculum* (Ministry of Education, 1993b) which included four contextual strands and two integrating strands. One of the contextual strands was *Making Sense of Planet Earth and Beyond*. Astronomy, for the first time in New Zealand, was included as a core subject for all pupils and astronomy is now compulsory for all pupils from Years 1-10, and for all pupils in Years 11-13 who choose to study Science rather than the separate science subjects of Biology, Chemistry and Physics.

The demands of a new curriculum in general, and of astronomy in particular, raise issues related to the ability of teachers to successfully implement it as intended. For example, *Science in the New Zealand Curriculum* encourages an investigative teaching-learning style which differs markedly from that usually practised. Successful implementation of the 1993 science curriculum consequently requires innovative teaching-learning approaches and materials. This aspect will be explored further in section 1.5 and chapter two.

1.3 MENTAL MODEL-BUILDING IN ASTRONOMY

Models are *to prove what's what..*
[Caleb, Year 8 pupil]

Astronomers in particular make use of mental models (Sutter, Sneider, Gould, Willard and De Vore, 1993) to explain and describe phenomena (Judson, 1980), to articulate ideas to other people (Harrison and Treagust, 1996) and because they are unable to manipulate astronomy variables. They use a variety of types of model to articulate astronomy ideas which are themselves expressed in the mental models of the time. For example, pre-Galilean mental models of the solar system (such as those of Ptolemy, Copernicus and Tycho Brahe) were dependent upon, and limited by, a view that solid circles and spheres were perfect shapes with natural and perpetual motion (Ferris, 1988). The idea of a force such as gravity, acting at a distance through space, was beyond their experience and comprehension.

Thus the pre-Galilean mental model of the solar system also required solid, translucent, interconnected spheres rotating at a variety of angles to each other to explain the motions of the 'heavenly bodies'. This imagined structure is described in most astronomy texts, with a particularly scholarly description found in Koestler (1979). In turn, the mental model was used to explain the observed facts such as days, years and phases of the Moon. As a consequence, the mental model was itself a barrier to the investigation of alternative explanations for astronomy observations.

The pre-Galilean mental model was, of course, radically different from, and ultimately replaced by, the dynamic Newtonian mental model of attractive gravitational forces acting at a distance and balanced by the inertia of the solar system bodies.

Science in the New Zealand Curriculum (Ministry of Education, 1993b) suggested that teachers and pupils should use mechanical models, which are frequently referred to in the Possible Learning Experiences listed for each level of each contextual strand. Also, one of the achievement objectives for level four astronomy states that "Students can... investigate and use models which explain the changing spatial relationships of the Earth, its moon and the Sun..." (Ministry of Education, 1993b, p.114). The "changing spatial relationship" is the mental model that is to be explained by the use of the mechanical model which represents it.

Given that mental models are generally known to act as a simplified representation of reality which can be used to initiate scientific inquiry (Osborne and Gilbert, 1980b), what mental models for the solar system do today's learners bring to the classroom and how do they respond when teachers present scientists' mental models? How do they respond when teachers use models such as photographs and the orrery to represent the mental models? Do these cause confusion for the learners, who are not likely to be conversant

with the limitations of models? Do learners construe a mechanical model of the solar system, such as the orrery, as being an accurate scale model of the solar system itself and thus having the capacity to test scientists' ideas? How do today's learners respond to the orrery? Would a critique of the uses of models such as the orrery enhance learners' construction of a mental model of the Sun-Earth-Moon system and its implications?

This discussion will be developed further in chapter two and chapter three.

1.4 NEW PEDAGOGIES: THEIR CHALLENGE TO ASTRONOMY EDUCATION

The challenge for me... is to provide novel and interesting ways...
[Experienced teacher of Year 7-8 pupils]

There is a general interest in space and astronomy, as evidenced by the popularity of space fiction movies and the packed lecture theatres in the researcher's home town during recent lectures by the broadcaster Patrick Moore and by the one-time Astronomer Royal Sir Arnold Wolfendale. In addition, school pupils usually react very favourably to their teacher's announcement that the next science topic is to be the study of space or astronomy. Nevertheless, evidence will be presented in this thesis which suggests that astronomy concepts remain poorly understood among pupils, adults and teachers.

Astronomy learning difficulties are discussed in chapter three, in which it is suggested that learners' astronomy concepts are often idiosyncratic and temporary despite, or even because of, formal teaching. This is not unique to astronomy, of course. Pfundt and Duit (1994) have reviewed research in science education conducted in many countries over a long time period that clearly demonstrates that pupil alternative concepts, in a large variety of subject areas, are widespread before and even after classroom teaching.

Perhaps an alternative approach to the more usual didactic one (in which the teacher seeks ever-more efficient ways to transmit the information and concepts to the learner) is necessary to assist learners towards the development of scientists' views. The researcher considers that there is much promise in approaches based on how people actually learn rather than those based on increased efficiency in presenting whatever educators wish to transmit. The challenges and opportunities which new pedagogies present for astronomy education are explored further in chapter three.

1.5 FOCUS OF THIS RESEARCH: TOWARDS A MORE APPROPRIATE INTERVENTION

Teachers need some hands-on stuff that would give them some good background information.
[Experienced teacher of Year 7-8 pupils]

The researcher considers that *Science in the New Zealand Curriculum* will probably fail to live up to expectations if it is taught in a traditional didactic manner. In any case, as will be illustrated in chapter two, *Science in the New Zealand Curriculum* has implicit in its structure the influence, among others, of the constructivist school of thought (Haigh, 1995), which encourages the active processes of cognitive restructuring (Anderson, 1992).

However, while a great deal of literature exists (Pfundt and Duit, 1994) which suggests that interactive approaches may have promise in assisting pupils' development of concepts in science, little of that research was directed particularly at astronomy education. Does that promise also include astronomy education?

In addition, there is very little research reported in the literature about the development, implementation and evaluation of interactive approaches in astronomy education. Can astronomy education benefit from such an approach? Research is necessary to assess whether interactive approaches in classrooms can, in fact, assist New Zealand pupils to construct scientists' mental models and to enhance the astronomy knowledge and understanding suggested in *Science in the New Zealand Curriculum*. The insights to be gained from such research are essential pre-requisites if teachers are to gain the confidence to adopt such interactive approaches.

The researcher's aim was to develop, trial, implement and critique an interactive astronomy teaching-learning intervention for pupils in a New Zealand school to investigate whether pupils are able to construct scientists' mental models through the process of critiquing a model of the mental model. The intervention would also reflect aims and objectives of *Science in the New Zealand Curriculum*. Such an intervention would need to operate within the usual constraints of a typical classroom in terms of availability of resources, including time, and it would be developed with a generalist teacher. The development of the astronomy intervention is described in chapters four and five.

1.6 THE THESIS AND THE RESEARCH ISSUES

The researcher's thesis is that pupils come to class with already formed mental models of scientific phenomena, such as that of the Sun-Earth-Moon system. They can then be assisted to modify their initial mental model towards the scientists' mental model by a

process of repeatedly critiquing the extent to which a model of the phenomenon accurately represents and misrepresents the mental model.

This study seeks to survey and review the current state of astronomy education in general and in New Zealand in particular. It also seeks to document the match or mismatch which exists between the current state of astronomy education and the recently (1993) introduced and innovative *Science in the New Zealand Curriculum.* Furthermore, it seeks to develop an investigative teaching intervention designed to facilitate pupils in constructing for themselves an astronomy mental model which is congruent with that currently accepted by scientists.

The broader research issues pursued in this investigation are therefore:

* cataloguing experienced teachers' perceptions of the main difficulties in teaching astronomy;
* describing pupils' conceptual difficulties associated with learning astronomy;
* exploring the use of models, in particular the orrery, to successfully promote mental model building and conceptual learning by pupils;
* elucidating the features of an intervention which takes into account the above research and the salient features of *Science in the New Zealand Curriculum*;
* documenting whether the intervention operated in the way it was planned;
* evaluating the effectiveness of the intervention in promoting the intentions stated in *Science in the New Zealand Curriculum.*

1.7 OVERVIEW OF THE THESIS

Chapter two describes in detail the current state of astronomy education - its place in curriculum documents, the typical pedagogy of astronomy classrooms and the learning outcomes - and it characterises the special features of astronomy as a science, particularly the central place of mental model building.

Chapter three opens up new possibilities for effective astronomy education, by reviewing recent developments in the theory of teaching and learning generally, and by discussing the relevance of these for the present state of astronomy education in particular.

In chapter four the guiding principles and the specific features of the intervention are discussed. From that discussion is developed the overall structure of the astronomy intervention.

The research methodology is reported in chapter five and five research questions are formulated. Chapter six documents two areas of preparatory research - a pilot intervention and its critique followed by subsequent further developments into the trial intervention.

Chapter seven describes how the trial intervention proceeded in terms of the process

outcomes of the pupils constructing and consolidating the scientists' mental model of the Sun-Earth-Moon system and their developing concepts of the role of models in science. Content outcomes in respect of the astronomy learning objectives relevant to these pupils are described in chapter eight. The trial intervention teacher's perceptions of the intervention are also considered in chapter eight.

In chapter nine, the findings with respect to the research questions are summarised and discussed. It also outlines the conclusions inferred from this study and discusses the implications which arise from it. Chapter nine also describes the limitations of the research and makes suggestions for further investigation.

CHAPTER TWO: ASTRONOMY EDUCATION: A REVIEW OF ITS CURRICULUM AND LITERATURE

2.1 INTRODUCTION

Chapter two documents the current state of astronomy education in general, with special emphasis on New Zealand. It comprises a review of astronomy curricula, teaching and learning difficulties as well as the place of mental models in astronomy. Where relevant, this description of current practice will be placed in its historical context.

Section 2.2 describes the changing status of astronomy education in some countries around the world. The section will examine the underlying reasons why, after a period of neglect from late in the nineteenth century until the 1960s, astronomy education at the present time is once again becoming more prominent. Section 2.3 reviews the changing place of astronomy education in New Zealand, with parallels made to the wider picture in those countries reviewed in section 2.2.

Difficulties perceived by teachers of astronomy are explored in section 2.4. These include factors such as teaching astronomy practically, pupils learning astronomy and public perceptions of the topic. Section 2.5 reviews research into astronomy learning and it evaluates the emphasis and direction of the research in light of recent curriculum changes.

Mental models are developed and widely utilised by astronomers but less so by astronomy educators. Section 2.6 documents the role of mental models in developing and understanding science and astronomy concepts. The classroom use of models in facilitating the construction of pupils' science and astronomy concepts is also introduced in this section.

The chapter closes with section 2.7, which is a summary of current astronomy education practices. It suggests that new approaches, especially in the area of pupil investigation skills, may be needed.

2.2 ASTRONOMY IN THE CHANGING CURRICULUM

2.2.1 Introduction

Astronomy has been alternately neglected and included in science curricula in many countries and is currently experiencing a resurgence in curriculum popularity. This section reviews the changing place of astronomy education in several countries that are likely to influence, and perhaps be influenced by, New Zealand. The countries surveyed were the United States of America, England and Wales, Northern Ireland, Australia and Russia. The discussion is in the following sequence:

* the latter half of the nineteenth century - a boom time for astronomy (section 2.2.2);
* the first half of the twentieth century - a period of neglect (section 2.2.3);
* the arguments for the rebirth of astronomy education (section 2.2.4);

* the re-emergence of astronomy education since the 1950s (section 2.2.5).

2.2.2 The Latter Half of the Nineteenth Century - A Boom Time for Astronomy

The latter half of the nineteenth century was a period of widespread popularity for astronomy education in the USA, England and Wales and Northern Ireland. Major influences in the USA had been the private academies from about 1770, followed by the state schools from the 1840s (which modelled themselves on the academies). They considered astronomy to be one of the seven liberal arts of classical education and the subject was offered either in its own right or as part of a course called *natural philosophy* (Harris, 1982).

In the 1850s, this in turn fostered the popularisation of astronomy in the emerging primary school systems in the United States (Harris, 1982), in England and Wales (Osborne and Simon, 1996) and in Northern Ireland (Jarman and McAleeese, 1996). The teaching methods were largely by textbooks, chalkboard and a few models such as orreries and globes, although in some schools observatories provided a practical adjunct to the classroom theory (Harris, 1982).

The boom did not last, however. In 1872 in England and Wales, a Revised Code for Teacher Training made no mention of astronomy. In the USA, astronomy education was seriously impaired by the 1893 Report of the Committee of Ten, whose most significant recommendation for astronomy was that it be no longer required for admission to college (Harris, 1982). A similar demise followed in other English-speaking countries around the end of the century and astronomy became almost totally excluded from schools in English-speaking countries (Seymour, 1985).

2.2.3 First Half of the Twentieth Century - A Period of Neglect

From about 1900, astronomy virtually disappeared from secondary schools, teacher-training institutions and liberal-degree colleges in the USA (Harris, 1982), rarely to be taught as a core subject until the late 1980s (McPherson and West, 1988).

In the twentieth century, astronomy played only a very small part in the science curriculum in England and Wales and in Northern Ireland (Jarman and McAleese, 1996). Only a small number of high schools offered an astronomy course (Harris, 1982) and very few examining boards offered it at O-level or A-level (Maddison, 1982). However, Nuffield O-level physics used the history of astronomy as an example of how a scientific theory is developed, *Science 5-13* had a unit on *Time* which introduced some astronomy and *The Earth in Space* was one of the units of the *Nuffield 13-16* science scheme (Seymour, 1985). A minority of local authorities had schemes where astronomy was taught on a peripatetic basis (Harris, 1982). Otherwise, astronomy in British schools was kept alive for a minority of pupils only within the flourishing school astronomical societies (Maddison, 1982).

Thus the overall picture is that astronomy's central position in school science curricula during the latter part of the nineteenth century had given way to neglect during the first half of the twentieth century. However, a recent re-emergence of astronomy (described below) has resulted from the way in which current events have resonated with four traditional arguments.

2.2.4 Arguments for the Rebirth of Astronomy Education

People in a variety of countries have argued for the inclusion and extension of astronomy in science curricula (Seymour, 1985; Sharp, 1996). Osborne (1991) went so far as to comment that it would be "perverse" to omit an area of scientific study such as astronomy.

Arguments for the inclusion of astronomy education usually consist of one or more of the following four propositions:

* *modern astronomy has developed from a very ancient base*;
  Not only was astronomy the first of the sciences (Osborne, 1991; Jarman and McAleese, 1996), it is still the basis of our modern system of time measurement such as the seasons and the calendar and of navigation and surveying (McNally, 1982).
* *its philosophical and data-gathering approaches have unique elements*;
  Its study has a unique philosophical role in schools because of the growing awareness that Earth may not be the only location in the universe where life has developed (Osborne, 1991; Pasachoff, 1995; Sagan, 1995). This concept would challenge philosophies and even religions that see life on Earth as unique.
* *it supports, and relies on, other science knowledge and skills areas*;
  Astronomy has a practical role to play in benefiting from, and contributing to, the other sciences, particularly physics and chemistry (McNally, 1982; Jarman and McAleese,1996).
* *it is a pan-cultural activity.*
  All cultures share in the human endeavour of astronomy and for virtually the same reasons - those of time-keeping, navigation and cosmology/myth-making. Aborigines are an example of a non-European culture that has used astronomy in the above ways (Harris, 1978). While western astronomy is well documented and is the basis for the astronomy curricula taught in many countries, it has many similarities with astronomy from other cultures, which are often merely a different way of looking at and classifying the same phenomena. This will be expanded upon, with particular reference to the astronomy of the Maori of New Zealand, in section 2.3.

2.2.5 The Re-emergence of Astronomy Education Since the 1950s

The re-emergence of astronomy education in four countries is discussed:

United States of America

Pivotal current events, both national and international, have promoted the acceptance of

the general arguments described above. Renewed interest in astronomy education appears to have begun in the USA in 1953 with the formation of a Teachers' Committee of the American Astronomical Society (Bishop, 1977), whose primary purpose was to promote the teaching of astronomy in American schools.

The Soviet launching of *Sputnik One* in 1957 engendered renewed public interest in science education in general and in astronomy education in particular. This was shortly followed by the National Science Teachers' Association (NSTA) Science Curriculum Committee of 1959-69 recommendation that a study of the universe be included in all science curricula from kindergarten to grade twelve (Bishop, 1977). A major departure from previous approaches was that the teaching was to emphasise a process approach rather than a content approach, a view supported by the 1962 NSTA committee (Novak, 1991).

Since that time, major trends have included development from both the transmissive and the process approaches of earlier astronomy curricula towards both a national curriculum (Watson, 1983) and a more inquiry-based and investigative approach (Mayer and Armstrong, 1990). That is, the reforms require a substantial change in how science (including astronomy) is taught, towards the main strategy for teachers becoming one of encouraging pupils to conduct genuine enquiry into their own questions (National Research Council, 1996).

The goal was further developed by PROJECT 2061, initiated by the American Association for the Advancement of Science (AAAS). This was an attempt to reform kindergarten to grade twelve science education around clear statements or objectives of what students should know and be able to do (Roseman, 1997). As part of the process, *Benchmarks for Science Literacy* and *National Science Education Standards* were developed (Pratt, 1995). They are seen as national efforts to improve education through projects such as Goals 2000 legislation and national standards for school subjects (Bybee and Champagne, 1995).

The *Standards*, supported by the NSTA (Bybee and Champagne, 1995), cover virtually all elements of science education (Pratt, 1995) including astronomy. They also include a recommendation that teaching-learning should explicitly take into account pupils' prior knowledge and experiences (Bybee and Champagne, 1995). That is, they include a conceptual approach to pupil-designed investigations for the first time in this first-ever national science curriculum for the USA

England and Wales

As in the USA, there was a resurgence of interest in England and Wales in the subject of science and astronomy following the advent of the space age (Seymour, 1985). There was also widespread dissatisfaction with the restricted and narrow scope of nature studies that was still largely taught in British primary schools (Osborne and Simon, 1996). As in

the USA, there has been a movement towards a more investigative approach to teaching-learning and a parallel movement towards a national science curriculum which includes astronomy.

The growth of astronomy education in Britain has been patchy, however. In the 1970s in England and Wales, individual schools varied markedly in their teaching of astronomy, either alone or in conjunction with other sciences, in that such projects and school-based curricula depended on the availability and enthusiasm of teaching staff (Hill, 1993). A Science Working Group for England and Wales was established in the late 1980s, whose members proposed an entire astronomy Attainment Target, which became AT17 (Jarman and McAleese, 1996). Science, including astronomy, was to join English and mathematics as core subjects in a nation-wide school curriculum (Millar, 1996).

In England and Wales, then, astronomy was included in the core, compulsory science curriculum. Rather than emphasising rote-learning, *The development of basic astronomical knowledge* objective had its emphasis on the development of children's observations of the daily and seasonal changes and their conception of time (Osborne, 1991). Thus the processes of science were included as core partners of the concepts and knowledge of astronomy. The astronomy objectives were listed on the left side of each page of AT17, headed "Pupils should...". These were complemented on the right side of each page with a heading "Pupils could...". That is, for each pupil objective there was an appropriate suggested activity which the pupils could engage in to enhance their attainment of the objective.

Australia

As in Britain, the provision of astronomy in Australian schools appeared to depend on the enthusiasms of individual schools. Out of 54 schools surveyed in 1989, only eight stated that astronomy was included in their school science scheme (Finegold and Pundak, 1990). Among those, for example, the only topic in astronomy that was offered at St Mary's College, Cairns, was The Solar System (Stanbridge, 1990).

Russia

In contrast to the above countries, educational provision in Russia has been centralised and didactic. Astronomy is part of the physics course, which is taught in only the last year (11th grade) of high schools in Russia. It is a separate science unit consisting of eight topic areas taught for one hour per week for a total of only 35 hours (Zafran and Etkina, 1992). Clearly, that amount of content material can only be taught by a transmissive approach to teaching. In any case, the topic is taught too late. Pupils are most interested in astronomy at about the 8th and 9th grades whereas the above is taught in 11th grade, so motivation of pupils is likely to be a problem (Zafran and Etkina, 1992).

2.2.6 Summary of Section 2.2

Astronomy education has followed a similar, but not identical, development in the

countries reviewed above. Over the last 200 years there has been the development from a mainly transmissive approach to teaching astronomy, followed by a period of decline for the subject, through its re-introduction via a process skills approach, to the current emphasis on concept development within national curricula which often propose a pupil investigative approach.

Section 2.2 has provided a historical context in which to describe and discuss the astronomy curriculum in New Zealand (section 2.3) but it has also raised questions about the complex way that approaches to teaching and learning are linked to the fluctuating popularity of astronomy education. The wide range of teaching and learning approaches (chapter three) and an exploration of how one of the approaches can be utilised in a trialled classroom intervention (chapter four) are major concerns of the current research.

2.3 ASTRONOMY IN NEW ZEALAND CURRICULA

2.3.1 Introduction

This section discusses the changing position of astronomy education in New Zealand curricula and notes the extent to which it reflects the changing place of astronomy in the countries described in section 2.2. The discussion is in the following sequence:

* pre-European astronomy education (section 2.3.2);
* astronomy in the New Zealand curriculum to the late 1960s (section 2.3.3);
* the 1978 science curriculum (section 2.3.4);
* the 1989 draft syllabus and developments (section 2.3.5);
* *Science in the New Zealand Curriculum* (1993) (section 2.3.6);
* astronomy within *Science in the New Zealand Curriculum* (section 2.3.7).

2.3.2 Pre-European Astronomy Education

Although neither written nor universal, the first astronomy education in New Zealand was the one passed down through generations of Maori by the *Tohunga*[1]. Maori had a detailed knowledge of the stars and their movements (Orbell, 1985) and utilised astronomy widely (Best, 1959) with some local iwi (tribe) differences.

For example, Maori used their knowledge of the stars, Sun and Moon to journey across the Pacific. They also used their astronomy knowledge to make maps (*Te Ika A Maui*, the Fish of Maui, is a very descriptive name for the North Island) and to note periods of time that signalled particular activity. For example, the kumara crop was planted only at certain phases of the Moon and the first new moon after the morning rising of Matariki (the Pleiades) marked the Maori New Year (Best, 1959). Thus the start of the new year varied, sometimes starting in modern May and sometimes in modern June. This practice varied between iwi. For example, Best (1959) reported that in the far North the new year was marked by the rising of Rigel in the constellation Orion.

[1] Tohunga are wise Maori elders who are the 'vessels' of Maori culture, whose job it is to pass the culture on to the next generation.

Maori divided their year into twelve months, with the days of each month having a name and the months being based on the phases of the Moon (Best, 1959). The relationship between months and the year is not precise (Best, 1959), necessitating the occasional interpolation of a thirteenth month. This was the same problem that had earlier faced astronomers in Babylon, Egypt and Rome (Duncan, 1998).

Cosmology/myth-making based on astronomy was also a feature of Maori science. Examples are the well known story of Papa and Rangi by which the Earth and sky were separated and the descriptive story of how Rona (the woman in the Moon) came to be there (Orbell, 1985). Rona was also known to Maori as the tide-maker, indicating their understanding that the Moon has an important role in causing tides.

Maori perceptions were based on observations that were precise and accurate, such as their knowledge that Jupiter has satellites, that Earth is not flat and that the Pleiades (Matariki) consist of a number of stars (Orbell, 1985). They also understood that the Sun and the stars are essentially the same, referring to the Sun as Ra and the stars as Ra ririki (little suns).

2.3.3 Astronomy in the New Zealand Curriculum to the Late 1960s

Ever since the 1877 Education Act at the time of Haben, the Inspector-General of Schools, there has been a tradition of central direction in New Zealand with respect to education provision, but with some initiative left to the teachers and schools when implementing the content and methodology (Ewing, 1970).

With reviews undertaken approximately every decade, there has been ongoing development of the national curriculum in science ever since the 1950s (Bell, Jones and Carr, 1995). As a result of examinations, by the late 1960s it had become very prescriptive in terms of content to be taught at the high school level. However, more flexibility was granted to primary school teachers although there were national science syllabuses for all levels.

Table 2.3.1 shows the position of astronomy in New Zealand curricula until the late 1960s. Table 2.3.1 shows that there was no provision for astronomy in schools at any level in the various pre-1960s' curricula, with science being largely restricted to Nature Study (Ewing, 1970). Astronomy was taught only by teachers with a personal interest in the topic. As such, the lack of provision for astronomy education in New Zealand reflected the position in the countries reviewed in section 2.2.

Table 2.3.1: Astronomy in New Zealand Science Curricula to the Late 1960s

Year	Pupils	The Astronomy in the Curriculum
Before 1887	Maori	No written national curriculum Stars, Sun, Moon, planets and their movements Navigation and map-making Year based on phases of Moon Myths/Cosmology
1887		Education Act - no astronomy, only nature study
1965	Y.7-8 (draft)	Time and size in the solar system
1968	Y.7-8	One of seven booklets - the Solar System
1968	Y.9-10	11.2 Solar System Current theories of formation of the solar system 11.3 Cosmology Current theories of the origin of the universe, stars and galaxies
1968	Y.11	15.1 Management of Space

Following recommendations from the Currie Commission of 1962 (Ewing, 1970), the first formal introduction of astronomy education, the solar system, occurred in 1965 with the *Draft Curriculum for Form One and Two* (Years 7-8 pupils). Curriculum reforms in the teaching of science came into effect in 1968 (Bell, Jones and Carr, 1995). There were separate official science curriculums for Years 7-8, Years 9-10 and Year 11. For Years 7-8, seven science booklets of detailed content and guidance were published. Astronomy consisted of a single lesson placed at the end of a series of eleven astronomy-related science lessons and it made no provision at all for astronomy practical work such as observation.

Science for Forms III and IV (Dept of Education, 1969), introduced at the same time, extended the topics taught in Years 7-8 into ideas about cosmology and cosmogony. An investigative approach, but without guidance with respect to its implementation, was encouraged. *Science for Form V* (Department of Education, 1968), included the same general objectives as did the Forms III and IV syllabus. However, the only reference to astronomy was in section 15.1, which referred to the "Management of Resources of Soil, Water, Air, and Space" (Department of Education, 1968).

The above analysis indicates that astronomy had a very small role in the 1968 science documents. This may be due to foreseen difficulties of teaching it in a practical and conceptual way. However, in common with the countries reviewed in section 2.2, astronomy had been re-introduced into New Zealand's official curricula, albeit in a small way.

2.3.4 The 1978 Science Curricula

In 1978, *Science Syllabus and Guide Primary: to Standard Four* (Department of Education, 1978a) was introduced for primary schools. At the same time, a draft science

syllabus for Years 7-10, *Science: Forms One to Four Draft Syllabus and Guide* (Department of Education, 1978b) was published. This brought all the non-examinable junior high school science pupils under the umbrella of a unified curriculum for the first time. Both documents recommended a levels-based approach rather than an age-based approach. Table 2.3.2 shows the astronomy topics that became included in the science curricula as a result of the reforms of the 1970s.

The curriculum documents in Table 2.3.2 encouraged a more active role for the learners in astronomy education in that process skills of observing, questioning, exploring, experimenting and making judgements were encouraged (Department of Education, 1978a and b). Astronomy content was increased, to be included for all pupils from Year 1 to Year 11, and was less prescriptive, particularly for primary school children. For levels one to three, "Content Areas" were introduced, one of which was called "Time and Space". Astronomy was allocated an increased and more process skills-based role, as in the other countries reviewed in section 2.2. However, astronomy education through these three curricula was developed independently rather than in an integrated manner.

Nevertheless, the draft syllabus for Years 7 to 10 built on the infants to standard four (Years 0 to 6) science syllabus, with its emphasis both on the content being chosen as the vehicle to expand the pupils' skills and with the expansion of the levels system beyond the primary schools. Furthermore, these new curricula gave enhanced importance to learners. For example, section three of the Forms 1-4 science syllabus said that pupils learn best when they are stimulated and motivated, when they experience success, when they are actively involved in the learning experience, when they enjoy their work, when they communicate with other pupils and when they explore (Department of Education, 1978b).

The situation at Form 5 (Year 11) was not altered by the above reforms and did not encourage astronomy. For example, when the School Certificate Examination Prescription for Science was published in 1982 (Department of Education, 1982), there was no mention of astronomy. If it was not to be examined, it is likely that few teachers would teach it.

Table 2.3.2: Astronomy in New Zealand Science Curricula in 1978

Pupils	The Astronomy in the Curriculum
Years 1-2 [Dept of Education, 1978a]	The day is a natural time interval. The Sun rises and sets in a regular way.
	The shape of the lighted surface of the Moon changes. The seasons change.
Years 3-4 [Dept of Education, 1978a]	Seasonal change is regular.
Years 5-6 [Dept of Education, 1978a]	The cycles of days, weeks, months, centuries were decided arbitrarily - the calendar.
	The Sun is the centre of our solar system. The Sun is a star. Earth is one of the Sun's planets.
Years 7-8 [Dept of Education, 1978b]	List the planets of our solar system and describe their major characteristics. Describe the major features of other components of our solar system.
	Explain the application of space technology to space exploration and to mankind (sic). Use binoculars or a telescope to locate specific objects in the night sky.
	Identify a planet in the night sky. Conduct an independent investigation into current developments in space using a range of reference sources.
	Present a report or in some other way communicate the findings of his (sic) investigation to others. Recognise the tentative nature of man's (sic) knowledge of the universe in which he (sic) lives.
Years 9-10 [Dept of Education, 1978b]	Define the terms star, galaxy, nebula and nova and give examples of where such objects may be found in the night sky.
	Recognise some well-known constellations e.g. Southern Cross, Orion, Pleiades (sic), Scorpio.
	Explain some of the techniques employed in exploring space and outline some of the problems of space exploration.
	Define time and describe ways in which it can be measured.
	Use binoculars, telescopes, cameras and a planisphere correctly.
	Classify stars in various ways e.g. colour, brightness.
	Recognise that much of our knowledge of the universe is tentative.
	Discuss such issues as control of space, pollution beyond the atmosphere, etc.

2.3.5 The 1989 Draft Syllabus and Developments

By 1984 there was support for a shift in emphasis in science curricula towards the learner as the focus of science education (Bell, Jones and Carr, 1995). In 1985, the Department of Education began work on a new science curriculum for Forms 1-5 (Years 7-11), which was based around the findings of the Learning in Science Project at the University of Waikato, which had advocated such a shift. A logical corollary of this was that it would

not be appropriate for the new science curriculum to contain detailed specification of the content to be learned by the pupils or taught by the teacher (Bell, Jones and Carr, 1995).

In 1989, then, a new draft science syllabus, *Draft Syllabus For Schools: Forms 1-5 Science* (Department of Education, 1989), was published. It was the first curriculum that brought science for all Years 7-11 pupils into the same document. A notable aspect of the curriculum was that it promoted astronomy and earth science as legitimate areas of school science along with biology, chemistry and physics (Bell, Jones and Carr, 1995). In the Draft Syllabus astronomy was limited in content, allowing more time for teachers to encourage process-skills or investigative approaches.

Table 2.3.3 shows the astronomy topics that became included in the science curriculum as a result of the reforms of the late 1980s.

Table 2.3.3: Astronomy in New Zealand Science Curriculum in 1989

	Pupils	The Astronomy in the Curriculum
	Years 7-11 [Dept of Education 1989]	Earth, Atmosphere and Space. Relative positions and behaviour of Earth in the solar system and the universe.
	Years 7-11 [Dept of Education 1989]	Time. Space travel and exploration.

The 1989 draft science curriculum and its predecessors outlined above can be seen as a developmental process. Over the years there has been a reduction in the emphasis on content to be transmitted and an increase in the idea that the purpose of the curriculum is to develop understandings among the pupils about science to which they can relate. The same pattern was repeated for the astronomy within the science. There was also an affirmed support for pupils to develop their process skills when they learned astronomy and the proposed science curriculum brought Years 7-11 under the same umbrella.

2.3.6 *Science in the New Zealand Curriculum* (1993)

Science, including astronomy, was seen as one of the seven Essential Learning Areas of *The New Zealand Curriculum Framework* (Ministry of Education, 1993a) and "All seven learning areas are essential for a broad and balanced education" (Ministry of Education, 1993a, p.8). That is, for the first time there was a clearly stated commitment to the teaching of astronomy through all the years of schooling in New Zealand. Tables 2.3.4, 2.3.5 and 2.3.6 illustrate that and show the astronomy topics that became included in the science curricula as a result of the reforms of 1993.

Table 2.3.4: Astronomy in the 1993 New Zealand Science Curriculum

	Pupils	The Astronomy in the Curriculum
	Years 1-13 [Ministry of Education,1993a]	The New Zealand Curriculum Framework. Seven Essential Learning Areas, one of which is Science. Eight Essential Skills. Attitudes and Values.
	Years 1-13 [Ministry of Education,1993b]	Science in the New Zealand Curriculum. Making Sense of Planet Earth and Beyond. Investigate and understand relationships between planet Earth and its solar system and galaxy, and the universe.

Table 2.3.5: Astronomy in the 1993 *Science in the New Zealand Curriculum*: Levels One to Four

Pupils	The Astronomy in the Curriculum
Level 1 [Ministry of Education, 1993b]	Share their ideas about objects in space and about very noticeable environmental patterns associated with these objects, e.g. Moon, Sun, stars, day and night, seasons.
Level 2 [Ministry of Education, 1993b]	Investigate easily observable physical features and patterns and consider how the features are affected by people, e.g. tides.
	Use their ideas to investigate major objects in our solar system and very noticeable environmental patterns associated with these objects, e.g. Moon, Sun, planets, day and night, seasons.
Level 3 [Ministry of Education, 1993b]	Locate and use information obtained from space exploration to clarify, challenge and extend their ideas about the general nature and behaviour of Earth, its moon and the other planets in our solar system, e.g. Moon missions, satellites, space stations.
Level 4 [Ministry of Education, 1993b]	Use simple technological devices to observe and describe our night sky, e.g. binoculars, simple star maps.
	Investigate and use models which explain the changing spatial relationships of Earth, its moon and the Sun, and the way different cultures have used these patterns to describe and measure time and position,
	e.g. phases of the Moon, eclipses, tides, seasons, sun clocks.

Tables 2.3.4, 2.3.5 and 2.3.6 show that *Science in the New Zealand Curriculum* developed both from the *Science Syllabus and Guide Primary: to Standard Four* and from the *Draft Syllabus For Schools: Forms 1-5 Science*. It united them in a single document that showed a progression of content and concepts from Year 1 to Year 13 (Bell, Jones and Carr, 1995). Of interest is the recommendation at level four that pupils are to both investigate models and use them to explain patterns in astronomy.

Table 2.3.6: Astronomy in the 1993 *Science in the New Zealand Curriculum*: Levels Five to Eight

Pupils	The Astronomy in the Curriculum
Level 5 [Ministry of Education, 1993b]	Use simple technological devices such as telescopes and simple star maps to observe and describe changing patterns in our night sky, e.g. position of the Moon, orientation of the Southern Cross.
	Use information obtained from technological devices such as radio telescopes and satellites, to clarify, challenge and extend their ideas about the general characteristics of some near and far space objects,
	e.g. structure, size, surface landscape, climate; the Sun and other stars, Earth's moon, planets, comets, meteors, clusters, galaxies; feasibility of life.
Level 6 [Ministry of Education, 1993b]	Use information from a range of sources, including their own observations, to explain spatial relationships of objects in the night sky and the challenge such spatial relationships present to space
	e.g. distance between, and changing positions of, objects; theories about origins of the universe.
Level 7 [Ministry of Education, 1993b]	Examine evidence from a variety of detectors to reach conclusions about the nature of stars and other celestial objects.
Level 8 [Ministry of Education, 1993b]	Carry out an extended investigation, involving a range of techniques, originating from their own interests into some aspect of, or issue related to, Planet Earth and Beyond.
	Research and present a report on a current astronomical event or discovery.

The science in *Science in the New Zealand Curriculum* is structured around four contextual strands and two integrating strands, each with its own achievement aims and objectives (Compton and Jones, 1996). These are:

Contextual Strands

* Making Sense of the Living World;
* Making Sense of the Physical World;
* Making Sense of the Material World;
* Making Sense of Planet Earth and Beyond.

Integrating Strands

* Making Sense of the Nature of Science and its Relationship to Technology;
* Developing Scientific Skills and Attitudes.

Particularly important in this regard is that the integrating strands should be interwoven with the four contextual strands (Ministry of Education, 1993b). That is, an approach to teaching science, including astronomy, is signalled that encompasses both science attitudes and investigative skills. The emphasis on the *processes* in astronomy education is indicated in Tables 2.3.5 and 2.3.6 by the use of words and phrases such as *investigate, locate and use information, use simple technological devices, use information, examine evidence, carry out extended investigations* and *research and present a report*. The processes in astronomy education have in the past posed particular problems for teachers (see section 2.4).

Science in the New Zealand Curriculum contains Achievement Objectives written for eight levels for each strand. It describes the progression of the science curriculum from junior primary to senior secondary (Ministry of Education, 1993b). The levels do not correspond to school years, there being only eight levels compared to the thirteen school years. Teachers are intended to provide learning experiences appropriate to the various learning levels of the pupils in their classes rather than to their ages (Ministry of Education, 1993b).

2.3.7 Astronomy within *Science in the New Zealand Curriculum*

Science in the New Zealand Curriculum is currently the official science curriculum in New Zealand. Astronomy is included in the contextual strand *Making Sense of Planet Earth and Beyond.* It is thus expected that astronomy will be taught in every year of schooling. The overall Achievement Aim for *Making Sense of Planet Earth and Beyond* is shown in Table 2.3.7.

Table 2.3.7: Astronomy Achievement Aim in *Science in the New Zealand Curriculum*

In their study of Planet Earth and Beyond, students will use their developing scientific knowledge, skills and attitudes to:
...
3 investigate and understand relationships between planet Earth and its solar system, galaxy and the universe.

(Ministry of Education, 1993b, p.106)

Table 2.3.7 re-emphasises the integration between skills and content. It also places increased emphasis on the learner to use investigative processes to find out and understand the astronomy content and concepts. The integration between content and investigative approaches is further emphasised by reference to the astronomy suggested (Tables 2.3.4, 2.3.5 and 2.3.6) for the Years and levels.

An omission is that there is no mention of gravity in any of the contextual strands. Gravity has an essential role with respect to astronomy and space in particular, and to notions of weight and other forces in general. While gravity is difficult to teach directly because of the very small value of the universal constant of gravitational attraction, G, there are many opportunities to teach it by discussion of pupil experiences both personal and vicarious.

A major consideration is that what is taught, and its manner of teaching, will depend to a large extent on the way in which the topics are assessed. Previously, astronomy has occupied a minor role in the science curriculum. This has the potential for change with the release of the School Certificate examination prescription (New Zealand Qualifications Authority, 1999). The relevant part for the purposes of this study is on page 321, where it is written that candidates may be assessed on their ability to:

"* Explain why the apparent positions of objects in the night sky change with respect to time.

Range: Objects in the night sky are satellites, moons, planets and constellations."

2.3.8 Summary of Section 2.3

As with the countries reviewed in Section 2.2, astronomy education in New Zealand had a long period of neglect followed by its re-introduction late in the twentieth century. Unlike the other countries, there had been no earlier tradition of school-based astronomy education.

The tables above show several clear patterns over the years. They show:

* a gradual integration of the curriculum to provide a coherent whole from Year 1 to Year 13, rather than the earlier separate curricula for primary schools, intermediate schools and high schools.
* an increase since 1968 in emphasis on astronomy education within science education.
* a gradual change of emphasis in science education, including astronomy education, from a transmissive approach through a process-skills approach to an investigative approach based on concept development.
* the re-introduction of the use of models in astronomy education.

Such changes in approach pose particular challenges to science teachers. Sections 2.4 and 2.5 will investigate those challenges.

2.4 ASTRONOMY: SPECIFIC TEACHING AND LEARNING DIFFICULTIES

2.4.1 Introduction

Despite the increased attention paid by curricula to astronomy over the last thirty years, as discussed in sections 2.2 and 2.3, it still occupies a limited position in many school programmes (Osborne, 1991). Difficulties with teaching astronomy are undoubtedly a major factor. This section discusses three areas of perceived difficulty in teaching and learning astronomy which contribute to the relatively slow development in astronomy education. The discussion is presented in the following sequence:

* practical difficulties in teaching astronomy (section 2.4.2);
* pupil learning difficulties with astronomy (section 2.4.3);
* perceptions of astronomy education (section 2.4.4).

In the absence of New Zealand research, studies from other countries are cited.

2.4.2 Practical Difficulties in Teaching Astronomy

Major difficulties perceived by teachers in implementing astronomy education

programmes include:

(1) **the lack of knowledge or understanding**

Osborne (1991) and Osborne and Simon (1996) noted that teachers lacked knowledge and understanding of astronomy concepts and 'flavour'. Thus it is a frustrating and unrewarding topic to teach (Smith, 1988). Few teachers have studied astronomy either at school or at university (Ratliff, 1995) and very few schools have teachers who are confident to teach it (Harris, 1982; Carre and Carter, 1993; Tebbutt, 1993; Swinbank, 1997).

(2) **the shortage of physics teachers**

Physics teachers are most often viewed as being the logical people to teach astronomy. However, Maddison (1982) noted in Great Britain that there was a "lamentable" shortage of physics teachers who were willing to teach it in spite of the fact that many universities in the UK offer astronomy as either support or major degree subjects, as can be seen in the annual lists published in the monthly magazine *Astronomy Now*.

(3) **there is very little in-service help**

McNally (1982) noted that there was very little in-service help for those few teachers who were willing to introduce astronomy into their science programmes. This is especially true for recently introduced curricula which differ markedly from previous ones. New curricula should not be introduced without extensive and well organised support programmes (Piburn, 1972).

(4) **there is no practical work**

A fairly common complaint among teachers called on to teach astronomy has been that there is no practical work in astronomy (Osborne, 1991), although, perhaps surprisingly, he saw this as an advantage in that it can free learning from what he called the "tyranny" of practical work. However, most other authorities on the subject appear to value practical work as an essential area of science education while understanding the particular difficulties for astronomy teaching. One example of these particular difficulties is that astronomical variables cannot be manipulated in the same way that electrical circuits and mirrors and lenses can (Tebbutt, 1993; Swinbank, 1997).

(5) **observational work is mostly at night**

More specifically, educators (Maddison, 1982; Tebbutt, 1993; Jarman and McAleese, 1996) have drawn attention to a problem that particularly affects the study of astronomy - that observational work is mostly at night. That is clearly a major difficulty for schools, accentuated by the fact that bad weather or clouds can unpredictably interfere with an observing night (Ratliff, 1995). In any case, as Tebbutt (1993) noted, visibility in urban areas is poor because of light pollution. Yet a further restraining factor on observing the night sky is that most parents would be uncomfortable for their children to conduct night sky observations without responsible adult support and supervision (Robson, 1992). However, that particular problem can be overcome if the teachers, with parental support, conduct evening group observation 'star parties'. They can also utilise the local

conduct evening group observation 'star parties'. They can also utilise the local observatories, which are usually keen to accommodate school groups (Taylor, 1993). This, and visiting planetaria, is a practice that is growing, although visits to planetaria and observatories are much more numerous by primary schools than by secondary schools (Seymour, 1985).

(6) **astronomical events take place very slowly**

Another concern is the time factor. Tebbutt (1993) noted that astronomical events take place very slowly, a factor that clearly has implications for observational astronomy, particularly for younger pupils. This may infer that astronomy has to be taught over a longer time period than other curriculum topics in order for events to be observed and patterns elicited. This is a particular concern for teachers of astronomy (Swinbank, 1997).

(7) **astronomy teaching is transmissive**

As a result of the perceived lack of practical work for astronomy, many teachers think that astronomy teaching has to be transmissive. As a result, they do not consider investigative approaches, relying instead on exposition and individual or group projects, and are likely to be unhappy both with the results and their role. Swinbank (1997) saw the transmissive approach as undesirable and Carson (1995) reported that initial pupil enthusiasm for project-based approaches often became opportunities to draw lots of colourful posters.

(8) **the lack of visual resources**

In Osborne's (1991) survey of teachers about the challenges they faced when teaching astronomy, frequent comments were that it is boring because of the lack of visual resources. The teachers felt that they were left with little choice other than to transmit the information. As is often the case when new curricula and topics are introduced, there may be a time delay between their introduction and the emergence of supporting resources. In addition, the resources may not be directly related to the curriculum expectations. For example, in reference to the astronomy section of A-level physics in Britain, Swinbank (1997) wrote that, despite the large variety of astronomical material in books, on CD-ROM and on the Internet, there is little that meets the particular curriculum needs of teachers and pupils.

2.4.3 Pupil Learning Difficulties with Astronomy

Section 2.4.3 enumerates astronomy education difficulties experienced by pupils. The first point, pupils' astronomy concepts, is introduced at this stage. It is developed further in section 2.5, which is a review of the known research about pupils' learning difficulties with astronomy concepts.

Major learning difficulties experienced by pupils in astronomy education include:

(1) **pupils form their own concepts about astronomy**

As with other areas of knowledge, pupils form their own concepts about astronomy both before and during the teaching (Tebbutt, 1993). Furthermore, such concepts are likely to interfere with any new ideas being introduced. Section 2.5 expands on this particular

interfere with any new ideas being introduced. Section 2.5 expands on this particular point.

(2) **pupils have difficulty with the use of language in astronomy**

Related to concept development, and inseparable from it, is the use of language in astronomy. This is a problem that is exacerbated in that the language used by astronomers themselves is geocentric and 'everyday' language even though they know it is not true. For example, astronomers talk of stars being 'up' in the sky, of the Sun 'rising' and 'setting' and of Jupiter being 'in' Scorpius (Orchiston, Carter and Dodd, 1996). This is in contrast to the problem experienced in other areas of science, in which the language used by scientists is generally precise, even if the same words are often used differently by the general public. Astronomers often use language in the same way as the general public but retain in their minds that they do not actually mean what they say. They do not believe that Jupiter, at a distance of about 780 million kilometres, is 'in' Scorpius, whose brightest star is 520 light years away from Earth, any more than they really believe that the constellation Scorpius has any more meaning than a directional indication whose stars appear to form that pattern only from our unique position in space. If astronomers were to use the precise language of their science, then communication between them and the public, including their families, would be difficult. For example, it is certain that most astronomers ask their children to be home 'before sunset' rather than 'before the Sun is occulted by the nearest part of the horizon'.

(3) **pupils are required to construct their own mental models of astronomy**

Osborne (1991) noted that while astronomy education does offer opportunities for practical work, such practical work would have a limited range of investigative skills based largely on observation and description. He added that much of the activity and learning would be based on helping pupils to construct their own mental models of astronomy processes. The mental models often have a limited connection to pupils' observations and require them to relinquish geocentric views of the world. While supporting mental model building by pupils, Osborne (1991) was well aware of the difficulties, noting that many astronomy concepts, such as the seasons, require the relation of other concepts within an overall mental model of the Sun-Earth-Moon system. In addition, he noted that mechanical models such as orreries have the potential to cause confusion when used to assist pupils' learning.

(4) **many distances, numbers and dimensions are beyond pupils' comprehension**

Tebbutt (1993) referred to the fact that many distances, numbers and dimensions are beyond the comprehension of many pupils. For example, the distance to our nearest star beyond the Sun, Proxima Centauri, is 100 million million kilometres, the mass of the Sun is 2×10^{30} kg, the Milky Way galaxy contains approximately 2×10^{11} stars and there are at least a billion (1×10^{9}) galaxies in the Universe. Smith (1988) noted that these quantities are beyond the experience of pupils.

(5) **astronomy utilises physics concepts**

The difficulty with pupils' astronomy concepts is exacerbated, in fact, in that much concept development in astronomy builds on physics concepts (such as force and motion, gravity, circular motion and light). These have their own conceptual difficulties for pupils. Thus pupils are placed in the position of developing astronomy concepts on the foundations of other incompletely developed concepts.

(6) **astronomy appearances and reality differ**

The development of astronomy concepts has a particular problem in that appearances and reality differ more greatly in astronomy than in most areas of understanding (MacRobert, 1995). As an example, Earth has the appearance of being stationary with the Sun in orbit around it, whereas, in fact, Earth spins on its axis and orbits the Sun. Furthermore, to many observers the Moon appears to orbit Earth once each day rather than the actual once each month, which adds to the difficulty of understanding the monthly variation in the phases of the Moon.

2.4.4 Perceptions of Astronomy Education

Many educators claim that there is a variety of reasons why astronomy should not be taught. These include:

(1) **astronomy does not qualify people for any career**

McNally (1982) pointed out that there is a common view that the study of astronomy does not qualify pupils for any career except as an astronomer.

(2) **astronomy is often seen as a male preserve**

A further problem with the perception of astronomy education, particularly in view of the more gender-inclusive intentions of *Science in the New Zealand Curriculum,* is that the subject is often seen as being more attractive to males than to females (Spradley, 1990). He attempted to partly remedy this aspect by outlining the contributions of about a dozen women astronomers, hoping that they would be role models for girls.

(3) **religious objections**

In addition to the above perceived difficulties, there are teachers, students and others who have religious objections to the teaching of astronomy (Lawson and Worsnop, 1992). Such objections are often centred on a conflict between cosmology and a 'creation science' point of view. There is clearly a large gap to bridge, if it is indeed possible, between those who believe Bishop Ussher's statement that the universe began in its present form in the year 4004 B.C. and those for whom the evidence suggests the age of the universe is between 10 and 20 billion years. Should astronomy attempt to cater for every diverse view in the community? Would it lose its very essence as a probing and questioning science were it to do so?

(4) **media misrepresentation of astronomy**

Related to the above is the concern that the mass media often misrepresent both the content and the relative open-minded methodology of astronomy. Wellington (1991)

content and the relative open-minded methodology of astronomy. Wellington (1991) observed that newspapers tend to give prominence to the more sensational events such as possible asteroid impacts on Earth. He further added that the media misrepresent the nature of astronomy in that they usually report it as unquestioned facts. Little mention is made of how those 'hard facts' became so, and indeed if they are hard facts. Media influences have the potential to encourage perceptions both about the knowledge included in astronomy education and the processes by which that knowledge is obtained. These could impact negatively on teachers' attempts to develop the learning and investigative skills objectives of *Science in the New Zealand Curriculum.*

2.4.5 Summary of Section 2.4

The discussion above identified eighteen concerns and challenges about astronomy education, particularly with respect to teaching it in such a way that investigative skills are encouraged and transmissive teaching approaches reduced. An obvious question relates to the extent to which the above concerns are repeated in New Zealand. Do New Zealand teachers and pupils have the same or different difficulties? Can astronomy education be gender-inclusive, for example? It may not be astronomy itself that is not attractive to girls but the way in which it is taught. Perhaps a more conceptually-based and inclusive approach might enhance girls' participation and understanding in astronomy education without diminishing those of boys.

Whether or not New Zealand teachers perceive similar difficulties will be addressed in section 6.2. Nevertheless, it can be established at this point that a major worldwide nexus of difficulty - problems relating to facilitating astronomy investigative processes in classrooms - would need to be addressed in New Zealand if astronomy education is to support and promote the integrating strands of *Science in the New Zealand Curriculum.* i.e. *Making Sense of the Nature of Science and its Relationship to Technology* and *Developing Investigative Skills and Attitudes.*

If astronomy education is to reflect astronomy itself, then it is necessary for it to adopt an investigative approach because astronomy facts, ideas and concepts develop in precisely that way. Astronomers do gather data, conduct validating and invalidating experiments and subject their ideas to rigour similar to that for other branches of science. Building physical models and constructing mental models are crucial procedures by which astronomers document their current knowledge outcomes. This survey of difficulties has revealed that in astronomy education the development by learners of appropriate mutually consistent mental models poses particular difficulties. This problem will be further explored in section 2.6.

In conclusion, is it possible to develop an astronomy teaching-learning package which will reduce the effect of the difficulties discussed above; which will assist teachers to enhance the investigative aims inherent in *Science in the New Zealand Curriculum* when they are teaching astronomy; and which will help learners to construct appropriate mental

models? Is it possible to teach astronomy in a way that is investigative and that will help pupils develop their astronomy concepts towards the scientists' ones? These are questions worthy of further investigation. As a first step to answer these questions, section 2.5 will consider the research evidence pertaining to the development of pupils' astronomy concepts.

2.5 LEARNING IN ASTRONOMY: A RESEARCH REVIEW

2.5.1 Introduction

Since early civilisations, astronomy has assisted people to reach beyond themselves to understand the universe (Statler, 1994), yet astronomy has until recently had only a minor place in most school curricula (see section 2.2). Perhaps as a consequence, there has been relatively little research into the learning and teaching of astronomy (Treagust and Smith, 1989), although it was noted in section 2.4 that pupils often develop astronomy concepts different to those held by astronomers. Discussion is presented in the following sequence:

* concept areas studied (section 2.5.2);
* astronomy learning outcomes (section 2.5.3);
* astronomy mental models (section 2.5.4).

2.5.2 Concept Areas Studied

The researcher reviewed pupils' learning in science by consulting 460 journal articles published since 1970. While the list, shown in Table 2.5.1, is not exhaustive of all science education journals, it is representative.

Table 2.5.1: Journals Consulted For Science Learning

1. Australian Science Teachers Journal	9. Research in Science Education
2. European Journal of Science Education	10. SAMEPapers
3. International Journal of Science Education	11. School Science Review
4. Journal of Research in Science Teaching	12. Science and Education
5. New Zealand Science Teacher	13. Science Education
6. Physics Education	14. The Science Teacher
7. Physics Teacher	15. Studies in Science Education
8. Research in Science and Technological Education	

The articles were then classified according to the contextual strands in *Science in the New Zealand Curriculum*. The results are graphed in Figure 2.5.1, which shows that research into pupils' ideas about the physical world accounted for 51% of the published research. This finding is similar to that of Treagust (1991), who pointed out that over 50% of published science education papers were concerned with physics education, and to the findings of Watts (1988), Driver (1989) and Qualter (1995). On the other hand, research into pupils' astronomy concepts constituted only 8% of the research. There is clearly a need for research in this area of the curriculum.

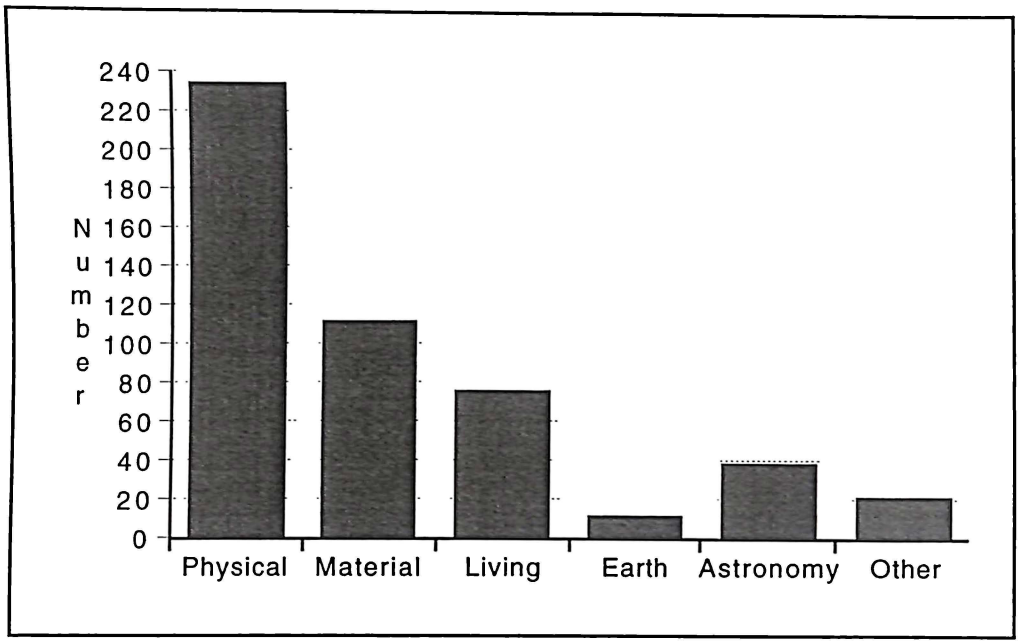


Figure 2.5.1: Numbers of Science Concept Studies, by Subject Area

2.5.3 Astronomy Learning Outcomes

Section 2.5.3 reviews the available research into learning and teaching in astronomy. The review will be explored in terms of the *Making Sense of Planet Earth and Beyond* contextual strand described above. That is, this section will consider astronomy concept outcomes related to day and night, the Moon, phases of the Moon, eclipses, tides, seasons and gravity.

Day and Night

Table 2.5.2 lists research conducted into learners' ideas about day and night. Most pupils and many student teachers did not demonstrate the scientists' understanding of the Earth's rotation as the cause of night and day.

Table 2.5.2: Investigations of Learners' Ideas About Night and Day

Year	Researchers	Country	Sample Age
1982	Klein	USA	Grade 2
1989	Baxter	England	9-16 years old
1991	Adams, Doig and Rosier	Australia	Year 5
1995	Atwood & Atwood	USA	Primary Student Teachers
1996	Sharp	England	Year 6

It appears from Baxter's (1989) work that scientists' concept about the cause of night and day is more easily understood than many other astronomy concepts. Nevertheless, he found that the most common explanation of night and day was that Earth moves round the Sun once per day, while the scientists' idea was only the pupils' second choice. Other explanations had the Sun orbiting Earth and the Sun being covered either by the Moon or by clouds. This is a little different to the investigation carried out in Australia by Adams, Doig and Rosier (1991) on behalf of the Australian Council for Education Research. They found that the most common explanation (25%) for night and day was the scientists' one

of Earth's rotation on its axis. Other explanations were that the Sun moves round Earth and that Earth rotates on its axis to alternately present each side in turn to the Moon for night and to the Sun for day.

The Moon

The Moon has important effects for Earth, such as phases of the Moon, tides and eclipses. Table 2.5.3 lists research conducted into learners' ideas about the Moon.

Table 2.5.3: Investigations of Learners' Ideas About the Moon

Year	Researchers	Country	Sample Age
1977	Milkent	USA	Tertiary
1979	Linke & Venz	Australia	Year 12
1989	Baxter	England	9-16 years old
1991	Adams, Doig & Rosier	Australia	Year 5
1994	Skam	Australia	Primary Student Teachers
1996	Sharp	England	Year 6

A question asked by Linke and Venz (1979) was whether the so-called 'dark' side of the Moon would radiate heat, to which most pupils responded that without light there could be no heat. While that erroneous concept is interesting, it is also of interest that there is a reference to a 'dark' side of the Moon. No such thing exists, as a study of an orrery or reasonable Earth-Moon-Sun diagram will make clear. Presumably, the term is used in reference to the far side, the unseen side, of the Moon (from a geocentric point of view). As mentioned in section 2.4, loose use of terminology such as this may well be a source of some of the misconceptions in the wider community.

Adams, Doig and Rosier (1991) investigated Year 5 children's ideas about why the Moon shines. Only 19% explained the phenomenon in the scientific sense, while another popular (24%) explanation was that moon-light is from the Sun, but without mentioning reflection. Other explanations included that the Moon makes its own light or that it just appears to be bright relative to the dark sky.

Sharp (1966) found that most children were unaware of the Moon's position in the sky or of its apparent movement across the sky. Without the scientists' view of such matters, pupils are not in a position to develop scientific explanations of related events such as tides, eclipses and phases of the Moon.

Phases of the Moon

Milkent (1977) found that 40% of the tertiary students he surveyed indicated that the phases of the moon are caused by Earth casting its shadow on to the Moon, 13% thought that the tides were responsible for the phases of the Moon and only 15% had the scientists' idea. Related research has revealed the same common misconceptions among nine to sixteen years old pupils in England (Baxter, 1989), among primary student teachers in Australia (Skam, 1994) and among Year 6 children in England (Sharp, 1996).

It appears that only a minority of people in our education systems are able to correctly explain the phases of the Moon, events that are observable by them on a regular basis.

Eclipses

Considering the evident confusion between phases of the Moon and eclipses, it is of some surprise that so little research has been conducted into ascertaining learners' concepts about eclipses. Mohapatra (1991) administered a 20-item three-point Likert scale questionnaire to 87 thirteen to sixteen years old pupils in India, where solar eclipses are regarded as ominous phenomena. He found that a majority of Standard 3-11 pupils correctly saw a solar eclipse as being due to the Moon's shadow falling on to Earth. However, many also believed that solar eclipses occur only once each year. Because the pupils' initial concepts persisted over many years, Mohapatra concluded that alternative concepts were resistant to change.

Tides

Little research has been conducted to elicit learners' views about tides. Galili (1995) thought, however, that the phenomenon was sufficiently important to be addressed more fully than merely stating that they are caused by the Moon's gravitation, a statement that is in any case only partially correct.

Skam (1994) found that only 22.2% of his sample of English primary student teachers agreed with the scientists' view about the causes of the tides. However, 75% of them agreed that particular places on the shoreline experience two high tides and two low tides each day. He furthermore found out that this group of primary student teachers understood that the Moon is a major cause of tides but also had the misconception that the Moon orbits Earth once every 24 hours. Many of them also thought that high tides only occur when the Moon is visible and that low tides are on the side of Earth opposite to high tides.

Seasons

Seasons are experienced by most people on Earth. Table 2.5.4 lists research conducted into learners' ideas about seasons.

Table 2.5.4: Investigations of Learners' Ideas About Seasons

Year	Researchers	Country	Sample Age
1989	Baxter	England	9-16 years old
1991	Baxter	England	Form 3
1992	Ojala	Finland	Primary Student Teachers
1996	Atwood and Atwood	USA	Primary Student Teachers

The most common explanation for the seasons was that the Sun is further away from Earth during winter (Baxter, 1989; Baxter, 1991; Atwood and Atwood, 1996) and a minority of Baxter's respondents attributed the seasons to the tilt of Earth's axis. For Ojala's respondents, however, the most common reason (32%) for the temperature

differences in different seasons was that the angle of the Sun's radiation varied in different parts of Earth (Ojala, 1992), which is in agreement with the usual textbook explanation. Others thought that Earth's tilt had the effect of changing the distance of the tilted side of Earth from the Sun, a view shared by several of Atwood and Atwood's (1996) sample.

The above findings further imply that merely stating to learners that it is the tilt of Earth's axis that causes the seasons may be sufficient only to modify their concept partially towards the scientists' idea while they continue to accommodate the old concept that Earth's changing distance from the Sun is the cause.

Atwood and Atwood (1996) suggested that textbook graphics ought to more clearly represent the causes of seasons, although Ojala (1992) posited that it may actually be the illustrations in textbooks that contribute to the non-scientific concepts developed by pupils.

Gravity

Gravity is not solely an astronomy concept. It is included here both because it is the force that binds our solar system and because it is a necessary concept if the study of astronomy is to be developed beyond the descriptive into the predictive and explanative. There have been numerous investigations into people's understanding of gravity, this appearing to be the most common area of investigation into astronomy education. Table 2.5.5 lists research into learners' ideas about gravity on Earth, conducted in a variety of countries.

Table 2.5.5: Investigations of Learners' Ideas About Gravity on Earth

Year	Researchers	Country	Sample Age
1980	Gunstone & White	Australia	Tertiary
1981	Stead & Osborne	New Zealand	Years 7-11
1982	Watts	England	12-17 years old
1983	Hope & Townsend	New Zealand	Tertiary
1986	Gardner	Australia	Year 11
1987	Ameh	Nigeria	Teachers, Years 9-11
1988	Noce, Torosantucci & Vicentini	Italy	Adults, Tertiary, High School
1989	Baxter	England	9-16 years old
1991	Adams, Doig & Rosier	Australia	Year 5
1994	Bar, Zinn, Goldmuntz & Sneider	Israel	4-13 years old
1995	Arnold, Sarge & Worrall	England	7-11 years old
1996	Galili & Kaplan	Israel	Year 9 to Tertiary

Confusion about gravity on Earth was revealed at all levels of the education system whether or not teaching had occurred, with only 1% of Adams, Doig and Rosier's (1991) Year 5 pupils having the generally accepted scientific concept. For example, Watts (1982) uncovered eight frameworks among only twenty respondents and expected to find many more as interviews progressed.

The combined research supported the findings of Watts and demonstrated that some pupils saw gravity as a push from below (Stead and Osborne, 1981; Gardner, 1986), some saw gravity as acting differently on different masses (Gunstone and White, 1980; Stead and Osborne, 1981), some saw gravity as increasing with distance from Earth's surface (Stead and Osborne, 1981; Osborne, 1984; Ameh, 1987), some saw it as being a property of the atmosphere (Stead and Osborne, 1981; Hope and Townsend, 1983; Gardner, 1986; Ameh, 1987; Noce, Torosantucci and Vicentini, 1988; Bar, Zinn, Goldmuntz and Sneider, 1994; Galili, 1995), some saw it as existing only when objects are moving away from Earth (Ameh, 1987) and some saw gravity as having a definite up-down direction not related to Earth' shape (Baxter, 1989; Arnold, Sarge and Worrall, 1995). In addition, pupils can hold contradictory misconceptions, as revealed by those who held the two ideas that gravity increases with height above Earth and that there is no gravity in space (Osborne, 1984).

A further finding was that gravity concepts develop rather slowly over time towards closer agreement with the scientists' views (Ameh, 1987; Noce, Torosantucci and Vicentini, 1988; Bar, Zinn, Goldmuntz and Sneider, 1994; Galili, 1995), improvement being more in the way of language development than concept development.

The above finding that gravitational forces decrease with distance from Earth leads naturally to questions about learners' concepts of gravitational forces beyond Earth. Such research is collated in Table 2.5.6.

Table 2.5.6: Investigations of Learners' Ideas About Gravity Beyond Earth

Year	Researchers	Country	Sample Age
1981	Stead & Osborne	New Zealand	Tertiary
1981	Watts & Zylbersztajn	England	Year 9
1983	Hope & Townsend	New Zealand	Tertiary
1984	Osborne	New Zealand	13 years old to Tertiary
1985	Ruggiero, Minzoni, Cartelli, Alighieri, Dupre & Vicentini-Missoni	Italy	12-13 years old
1987	Ameh	Nigeria	Years 9-11, Teachers
1988	Boeha	Papua New Guinea	16-17 years old
1988	Smith & Treagust	Australia	Years 9-10
1989	Treagust & Smith	Australia	Year 10
1991	Adams, Doig & Rosier	Australia	Year 5
1991	Berg & Brouwer	Canada	High School Teachers, Year 9
1994	Bar, Zinn, Goldmuntz & Sneider	Israel	4-13 years old
1994	Skam	England	Tertiary
1994	Twigger, Byard, Driver, Draper, Hartley, Hennessy, Mohamed, O'Malley, O'Shea & Scanlon	England	10-15 years old

The research listed in Table 2.5.6 reveals a variety of inconsistent concepts about gravity

in space, such as the view that gravity does not act on Earth-orbiting satellites (Hope and Townsend, 1983), possibly because of the view that there is neither air nor gravity in space (Ruggiero, Minzoni, Cartelli, Alighieri, Dupre and Vicenti-Missoni, 1985; Berg and Brouwer, 1991; Bar, Zinn, Goldmuntz and Sneider, 1994; Twigger, Byard, Driver, Draper, Hartley, Hennessy, Mohamed, O'Malley, O'Shea and Scanlon, 1994). This is particularly felt to be the case with respect to the Moon (Watts and Zylbersztajn, 1981; Stead and Osborne, 1981; Hope and Townsend, 1983; Osborne, 1984; Ameh, 1987; Boeha, 1988; Adams, Doig and Rosier, 1991; Berg and Brouwer, 1991; Bar, Zinn, Goldmuntz and Sneider, 1994; Skam, 1994), where pupils think there is no gravity there because there is no air on the Moon.

There is evidence that alternate concepts about gravity are held almost regardless of age (Hope and Townsend, 1983; Ameh, 1987), although an age-related improvement towards acceptance of the scientists' view was noted by Stead and Osborne (1981).

With respect to ideas about planets and gravity, Smith and Treagust (1988) found that while many pupils were knowledgeable about solar system facts, a variety of influences was seen to affect a planet's gravitational field. These are tabulated in Table 2.5.7.

Table 2.5.7: Misunderstandings About Planets and Gravity Elicited by Smith and Treagust (1988)

1	A planet's gravity is related to its distance from the Sun.
2	The Sun's gravity influences not only the planets to orbit around the Sun but also the gravity of the planet.
3	A planet's rotation or lack of it affects its gravity - zero or slow rotating planets have less gravity than fast rotating planets.
4	The rotation of a planet is dependent on its position with respect to the Sun or to its size.

The findings in Table 2.5.7 were supported by Treagust and Smith (1989), the most widespread belief they discovered being that rotation causes gravity. This finding was also revealed by 48% of Adams, Doig and Rosier's (1991) Year 5 pupils with respect to the Moon and by Stead and Osborne (1981). Thus many pupils think that lift-off would be easier if the planet or Moon was not rotating. Many film and television programmes depict artificial gravity on space stations as being created by spinning, so it is logical that many learners suppose that planetary gravity is created in the same way.

2.5.4 Astronomy Mental Models

Research into astronomy mental models appears to be limited and yet people who possess non-scientists' mental models about our solar system must have great difficulty in their development of related concepts such as tides, phases of the Moon, seasons and eclipses of both the Sun and Moon. Thus construction of a mental model is important. This section will consider:

* the solar system;
* planet Earth;

* the Sun-Earth-Moon system.

The Solar System

Baxter (1989) noted that solar system alternative concepts persist for many pupils up to the age of 16 years despite teaching. He concluded that the construction of the heliocentric mental model is a complex factor involving a variety of supporting concepts and knowledge and that it might not be reasonable to expect such understanding before pupils reach early adolescence. This suggests that an intervention programme with respect to the development of such a heliocentric mental model might best be targeted at early adolescence, perhaps at the Years 7-8 stage.

Baxter (1989) deduced the development of four solar system mental models, these being:

* the static Earth view, in which Earth is saucer-shaped and north is 'up';
* Earth is spherical and central and ideas of 'up' and 'down' persist;
* Earth is spherical and central with astral bodies in orbit around Earth;
* the scientifically accepted heliocentric model.

Finegold and Pundak (1990) noted that a pre-science framework accounted for a low but fairly constant proportion of responses over Years 7-12 pupils, that a sidereal framework became dominant from Year 8 onwards, but that there was little increase in astronomy knowledge until Year 9, indicating that any conceptual understanding at Year 8 is not supported by content knowledge.

Planet Earth

Investigations into children's ideas of planet Earth have mainly focused on the way children's thinking evolves through a progression of mental models from more or less geocentric in character to more or less heliocentric in character. Table 2.5.8 lists research conducted into learners' ideas about Planet Earth.

Table 2.5.8: Investigations of Learners' Ideas About Planet Earth

Year	Researchers	Country	Sample Age
1976	Nussbaum & Novak	USA	Grade 2
1979	Mali & Howe	Nepal	
1982	Klein	USA	Grade 2
1983	Sneider & Pulos	USA	Grade 2
1983	Nussbaum & Sharoni-Dagan	Israel	
1985	Nussbaum	Israel	
1989	Baxter	England	9-16 years old
1992	Vosniadou & Brewer	USA	Grades 1-3

Nussbaum and Novak (1976) uncovered five different 'notions' (concepts), as shown in Figure 2.5.2 and described in Table 2.5.9.

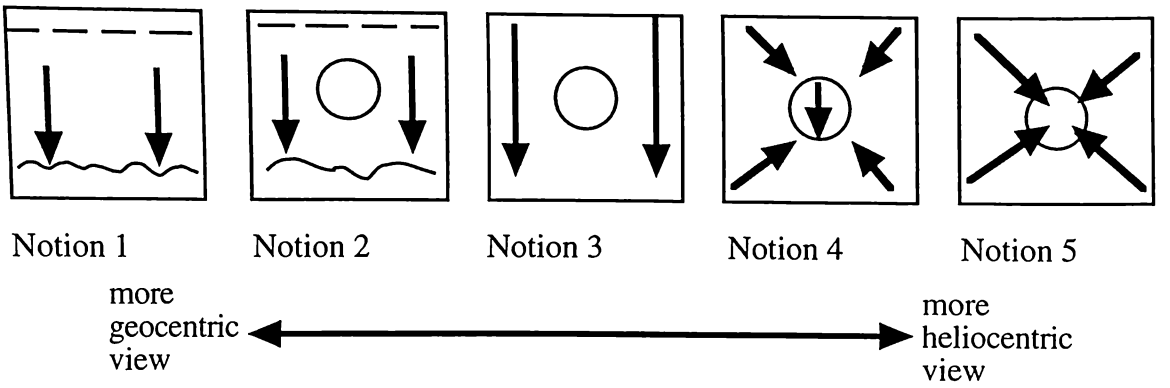


Figure 2.5.2: Nussbaum and Novak's (1976) Five Notions of Planet Earth

Related research has suggested a similar sequence of mental models among children in Nepal (Mali and Howe, 1979), in the USA (Klein, 1982; Sneider and Pulos, 1983), in Israel (Nussbaum and Sharoni-Dagan, 1983; Nussbaum, 1985), and in England (Baxter, 1989).

Table 2.5.9: Nussbaum and Novak's Five Planet Earth Mental Models

Notion	Mental Model
1	The Earth we live on is flat and not round like a ball.
2	Earth is round but the pupils lack a notion of unlimited space. They need a 'bottom'.
3	Some idea of unlimited space that surrounds the round Earth. Do not use Earth as a frame of reference for up-down.
4	Seem to believe that we live on a spherical planet. Use Earth as the frame of reference for up-down.
5	Demonstrate a satisfactory and stable notion of the three aspects of the Earth concept:
	(i) a spherical planet;
	(ii) surrounded by space; and
	(iii) things fall to its centre.

Much of the research (Nussbaum and Novak, 1976; Mali and Howe, 1979; Sneider and Pulos, 1983; Nussbaum, 1985; Baxter, 1989) inferred that the scientists' concept (Notion 5) is accomplished in a series of identifiable steps rather than in a single 'conceptual leap'. Vosniadou and Brewer (1992) pointed out that the process is gradual and often gives rise to intermediate models. Conversely, Nussbaum (1979) concluded that there is no general development from Notion 1 to Notion 5 through which all pupils progress.

Nussbaum and Sharoni-Dagan (1983) reported that about half the children exposed to intervention teaching underwent some cognitive accommodation towards a higher-numbered Notion. The teaching effect was estimated to be a gain equivalent of about two or three years. The investigators concluded that their intervention approach supported Ausubel's (1968) theory that learners usually construct their own alternative conceptions when they encounter cognitive conflict (see chapter three).

The Sun-Earth-Moon System

The mental model of the Sun-Earth-Moon system is the framework within which many other astronomy concepts are developed. Table 2.5.10 lists research conducted into learners' ideas about our Sun-Earth-Moon system.

Table 2.5.10: Investigations of Learners' Ideas About Our Sun-Earth-Moon System

Year	Researchers	Country	Sample Age
1982	Klein	USA	Grade 2
1987	Jones & Lynch	Australia	9-12 years old
1989	Baxter	England	9-16 years old
1990	Finegold & Pundak	Australia	Years 7-12
1991	Adams, Doig & Rosier	Australia	Year 5
1996	Sharp	England	Year 6

Klein's (1982) data showed an approximately even split in the numbers between those who thought Earth is larger than the Sun and those who thought the Sun is larger than Earth, while Jones and Lynch (1987) found no evidence of any relationship between grade level and whether or not the pupils knew the correct relative sizes. Following the introduction of the national curriculum in England and Wales, Sharp (1996) found that 62% of those interviewed were able to place the Sun, Earth and Moon in their correct sequence of relative sizes. Thus there appears to be little consensus as to the prevalence of pupils' concepts about the relative sizes of the Sun, Earth and Moon.

In Australia, Adams, Doig and Rosier (1991) found that a majority of Year 5 pupils understood that the Sun is hot and uninhabitable but that few had any understanding of its structure or composition. Some saw the Sun as being different, in some unexplained way, from Earth, while a similar proportion thought that Earth and the Sun were essentially the same composition.

Jones and Lynch's (1987) interviews revealed that most pupils' spatial mental models of the Sun-Earth-Moon system fell into one of only five distinct systems, shown in Figure 2.5.3. Three of these (models A, B and C) are egocentric and geocentric and two (models D and E) are Sun-centred mental models. Model E is the one that most nearly equates to the generally accepted scientists' mental model. However, Earth's axis of tilt is not included in this model. The scientists' understanding of the relationship between the Sun, Earth and Moon is necessary for learners to develop the ability to propose and question the subordinate concepts of night and day, months, years, seasons, the Moon's phases, eclipses and tides.

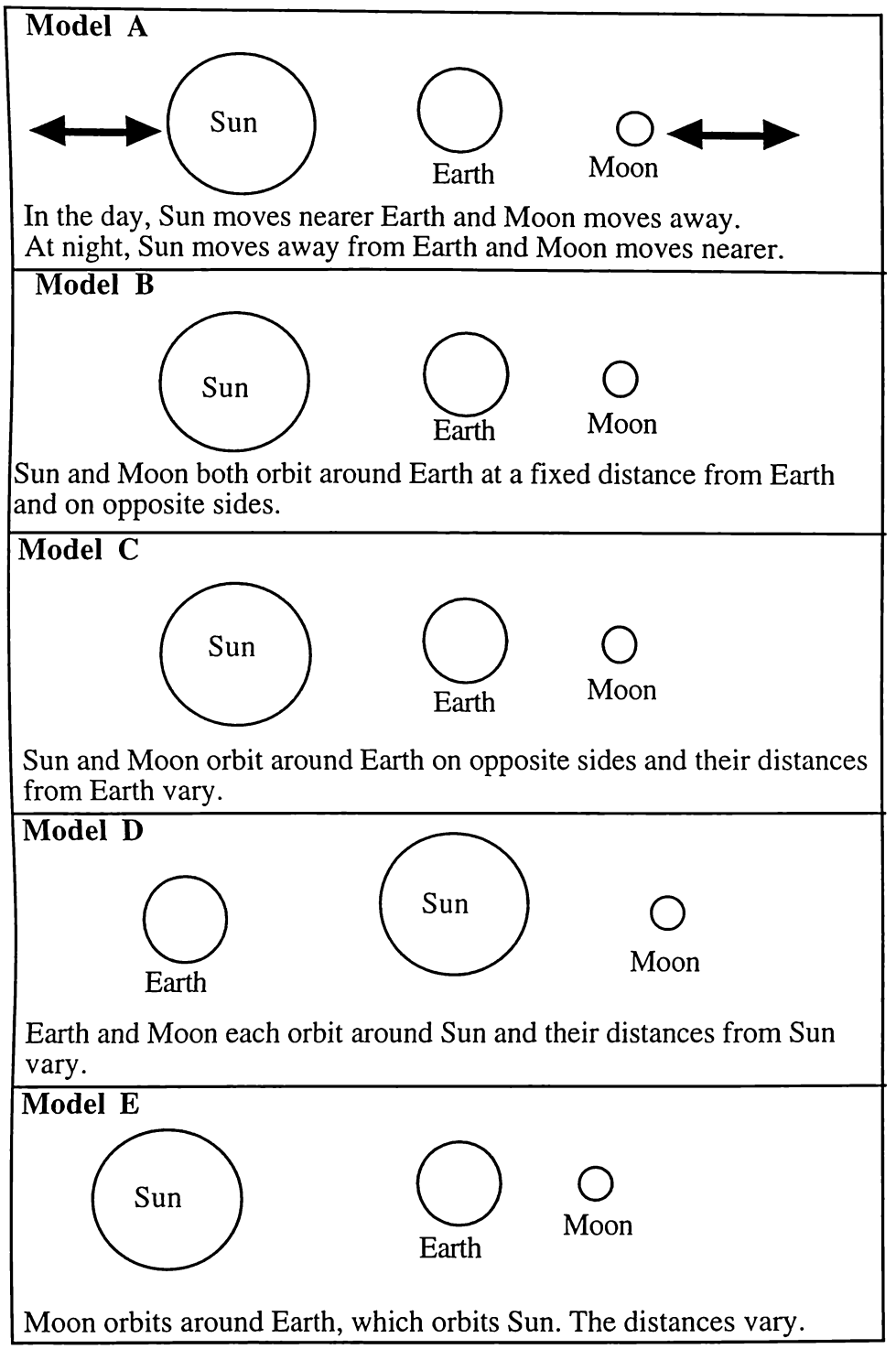


Figure 2.5.3: Jones and Lynch's (1987) Five Mental Models of the Sun-Earth-Moon system

2.5.5 Summary of Section 2.5

Most astronomy education research appears to have concentrated on the products of education, learners' knowledge outcomes, rather than on the investigative processes by which those products are developed. There was an emphasis on gravity concepts and a noticeable lack of reported research with respect to the relative difficulties of various astronomy concepts or with respect to astronomy packages being trialled. Is there an optimum conceptual developmental level for different ages of pupils? Is the sequence advocated by *Science in the New Zealand Curriculum* likely to aid in the development of

astronomy concepts? Are the Achievement Objectives stated for the various levels attainable by pupils at those levels?

The review of the research has revealed:

* there are widespread alternative concepts in astronomy among learners of all ages and in many countries;
* there is an imbalance of research effort across astronomy concepts;
* research tends to be isolated on individual topics such as seasons or tides. Conceptual interdependence is rarely considered;
* research has concentrated on the products, rather than the processes, of astronomy learning.

It appears that current teaching methods are not producing the desired development of pupil astronomy concepts and nor are they addressing the alternate concepts that pupils bring to school. That is, many pupils currently advance to the next stage of their education with little perturbation of their existing astronomy concepts. Such a situation suggests that a comprehensive change in teaching approach is required. Perhaps a teaching approach based on addressing the interdependency of astronomy concepts within an overall mental model which encourages pupil development of investigative skills might be effective.

There is limited research into astronomy mental models or into the processes of learning astronomy, such as pupils' manipulative and thinking skills, attitudes towards and about astronomy and applying science investigation skills towards the acquisition of astronomy knowledge and concepts. An investigative approach suggests a greater emphasis on research into learning processes rather than into products and *Science in the New Zealand Curriculum* has integrating strands which encourage an investigative process. Research is called for into the development and trial of an astronomy teaching-learning package that encourages the process of pupils constructing astronomy mental models and pupils' development of astronomy concepts through investigative approaches.

2.6 MODELS AND MENTAL MODELS IN ASTRONOMY AND IN ASTRONOMY EDUCATION

2.6.1 Introduction

Section 2.6 will first define the term *mental model* and will then outline the role that mental models have occupied in helping scientists in general, and astronomers in particular, make scientific sense of the world. Models will then be defined and explained and their use in education will be investigated.

The discussion is presented in the following sequence:

* mental models and science (section 2.6.2);
* mental models and astronomy (section 2.6.3);
* models (section 2.6.4);

* models in science texts (section 2.6.5);
* teachers and models (section 2.6.6);
* learners and models (2.6.7);
* research into teaching-learning with models (section 2.6.8).

2.6.2 Mental Models and Science

Mental models are defined as human cognitive constructions (Smit and Finegold, 1995; Ritchie, Tobin and Hook, 1997) which are used to describe and explain phenomena which cannot be experienced directly. They are attempts by humans both to understand the world (Judson, 1980) and to articulate their concepts to others (Harrison and Treagust, 1996).

Halloun (1996) stated that it was Galileo who set the foundations for a modern epistemology of science whereby systems in the real world could be simplified and studied through the use of mental models and their representations (Gilbert, 1994). That is, mental models play an essential role in the practice of science (Gilbert, 1994; Halloun, 1996; Ogborn and Martins, 1996) and also for learning and understanding it (Lunetta and Hofstein, 1981; Dagher, 1995a). Accounts of the work of professional scientists are dominated by the building and testing of mental models (Penner, Giles, Lehrer and Schauble, 1997), such as Rutherford's solar system mental model of the atom (Zeitoun, 1984) and Volta and Ampere's representations of electricity in terms of the pressure and flows of liquids (Stavy, 1991).

In fact, science cannot proceed without recourse to mental models (Lind, 1980) because of their necessary and central role both in research and in the communication of knowledge (Osborne and Gilbert, 1980b; Black and Solomon, 1987; Treagust, 1993; Wong, 1993; Harrison, 1994; Dagher, 1994). Examples include Huygens' water wave mental model of light (Osborne and Gilbert, 1980b), the role of mental models in the development of Einstein's theories of relativity (Thiele and Treagust, 1991) and Maxwell's mental model of electromagnetic waves (Thagard, 1992b; Dupin and Johsua, 1989).

Scientists resort to mental model making when they are confronted by phenomena which are complex or inaccessible to their direct senses or conceptually difficult or new to them (Poole, 1995). Mental models simplify phenomena to make them easier for scientists to use (Smit and Finegold, 1995), to make predictions about future events, to make inferences from their data and to understand observed phenomena and events. However, it is important to note that mental models change as new information and insights are gathered. Examples are the mental models used to represent light. These have changed over the years from Newton's particle theory, through Huygens' wave theory to the current wave-particle duality theory.

2.6.3 Mental Models and Astronomy

Astronomers in particular make use of mental models and their representations (Sutter, Sneider, Gould, Willard and De Vore, 1993), both to understand phenomena and to transmit that understanding to others (Weller, 1970). This may be due to the particular inability of manipulating astronomical variables. Astronomers' attempts to understand the place of Earth within the universe have been articulated by a series of such mental models. They began with a flat Earth on a sea enclosed within a solid celestial firmament, progressed to a series of concentric spheres and on to Newton's gravitational forces acting through space (Black and Solomon, 1987).

Within the concentric spheres mental model, Judson (1980) described both the Ptolemaic mental model of a geocentric universe and the contrary Copernican mental model of a heliocentric universe. Both mental models agreed with observations and made predictions that were accurate within the existing instrumental tolerances. Ptolemy's mental model was publicly unchallenged for almost 1400 years, largely for religious reasons but also because it was fruitful in terms of its predictions (Poole, 1995).

The concentric spheres mental model required a force to drive it, which lead to Robert Boyle in the seventeenth century envisaging the universe as a machine (Poole, 1995). This view was accepted by Kepler, who then developed his mental model of planetary motion as being similar to the workings of a clock (Treagust, Harrison and Venville, 1996), thus providing a base for making predictions.

As in science in general, astronomy mental models undergo constant evolution (Glynn, 1997), as is illustrated by the history of the development of ideas of the solar system (Smit and Finegold, 1995). Furthermore, the mental models are themselves affected by observations. For example, Galileo's discovery of four satellites orbiting Jupiter lead to his view that Earth itself might be a planet orbiting the Sun (Poole, 1995).

2.6.4 Models

Mental models are not to be confused with the *models* and *analogies* that are often used to represent them (Wheeler and Hill, 1990). These two terms often have many quite different, and even contradictory, meanings (Sutton, 1978; Lind, 1980; Gilbert and Osborne, 1980; Zeitoun, 1984; Treagust, Duit, Joslin and Lindauer, 1992; Lagoke, Jegede, and Oyebanji; 1997) yet they are frequently used interchangeably (Duit, 1991). This review will assume that the terms are similar and that discussion about analogies is also applicable to models. The term *model* will be used in this study.

Models are defined as scaled miniatures or scaled enlargements or working models, each of which represents a mental model in some, but not all, its properties. That is, they are simplified representations of phenomena or ideas in that they take up an intermediate position between reality and a mental model (Sutton, 1978; Osborne and Gilbert, 1980b; Gilbert and Osborne, 1980). Models concentrate attention on specific aspects (Ingham

and Gilbert, 1991) to explain something that is not familiar in terms of something that is familiar (Dyche, McClurg, Stepans and Veath, 1993).

The domain used as the basis for comparison is referred to as the *source* and the domain to be explained is referred to as the *target* (Treagust, Duit, Joslin and Lindauer, 1992; Jarman, 1996). That is, making a model is to map the target on to the source (Lind, 1980; Duit, 1991; Treagust, 1993; Dagher, 1995a; Kaufman, Patel and Magder, 1996; Glynn, 1997) with the domain of a model consisting of attributes which share common features with the reality it represents (Weller, 1970; Treagust, Duit, Joslin, and Lindauer, 1992; Dagher, 1994; Halloun, 1996; Hesse, 1966).

The target and source share some, but not all, attributes (James, 1983; Zeitoun, 1984; Treagust, Duit, Lindauer and Joslin, 1989; Thiele and Treagust, 1991; Treagust, 1993; Harrison, 1995), otherwise the model would become an example (Poole, 1995). Given that, those features that are not shared between target and source indicate the limitations of the model (Venville, Bryer and Treagust, 1994) and sooner or later the model will break down (Sutton, 1978).

Hesse (1966) suggested a format for analysing the value of a model was to list its positive, negative and neutral attributes with respect to the mental model it represents. Positive attributes are those properties which both the model and the mental model share and negative ones are those attributes not common to both the model and the mental model. Neutral attributes are simply those attributes not yet classified as positive or negative (Hesse, 1966). As an example, Judson (1980) analysed the map of the London Underground as a model for the reality it represents. He listed its positive features (such as the correct sequence of the stations), its negative ones (such as the incorrect scale) and those which were neutral (such as train frequencies). As astronomy education often utilises models to represent mental models, Hesse's proposal offers promise in this area. For example, an orrery (the model) could be analysed by learners to identify the attributes it shares with the mental model of the Sun-Earth-Moon system it represents. This process should help the pupils in their construction of the mental model.

The relationship between the model and the mental model might be one of either structure or function (Thiele and Treagust, 1991). For example, an orrery might be utilised to illustrate the general structural relationships between the Sun, Earth and Moon, but it may also be used to show their functional relationships such as phases of the Moon and eclipses.

Models come in a variety of forms, most of which have a concretising function to assist learners in developing their mental models (Zeitoun, 1984). They are most often used with a formal target and a more concrete model (Thiele and Treagust, 1991). Differentiating between the types is difficult (Gilbert and Osborne, 1980; Osborne and Gilbert, 1980b), although Gilbert (1994) classified models into four types - scale models

(such as a model of the solar system), analogy models (such as ball-and-stick models of chemical structures), mathematical models (such as F = ma) and theoretical models (such as Einstein's theories of relativity).

Models may also be differentiated along a concrete-abstract continuum, from mechanical models such as the orrery, Turley's (1994a) model to show potential difference, Turley's (1994b) model to show standing waves, Steinberg and Wainwright's (1993) model to show the operation of capacitors and atomic models built from toothpicks and marshmallows (Dyche, McClurg, Stepans and Veath, 1993); through to iconic models such as pictures and diagrams (Thiele and Treagust, 1991), picture-word diagrams, block-word diagrams (Winn, 1980) and flow-charts, which usually present a scientific idea in a manageable and coherent display (Holliday, Brunner and Donais, 1977); and through to mathematical models such as Kepler's three laws of planetary orbits.

Simulations are another type of model (Hartley, 1976). They come in a variety of types and, as with all models, generally provide vicarious experiences that are either too complex or dangerous or expensive or time-consuming to use in the laboratory or classroom (Lunetta and Hofstein, 1981; Oliver and Okey, 1986; Faryniarz and Lockwood, 1992).

Computer simulations, what Hartley (1976) called 'working models' of a scientific system, allow the safe comparative testing of different variables (Hennessy, Twigger, Driver, O'Shea, O'Malley, Byard, Draper, Hartley, Mohamed and Scanlon, 1995a), reduce the tedium of solving mathematical equations (Whitmer, 1990; Gillis, Sinclair and Swithenby, 1996), allow pupils to practise and refine their scientific reasoning skills and knowledge (Kinnear, Martin and Novak, 1982; Maor, 1990) and allow people to make repeated 'what-if' experiments in perfect safety (Oliver and Okey, 1986; Krieger and Stith, 1990). They can be used to analyse properties of systems which may be impossible to study otherwise (Andaloro, Donzelli and Sperandeo-Mineo, 1991). As with all models, the aim is to achieve a mapping from the simulation to the target (Hennessy, Twigger, Driver, O'Shea, O'Malley, Byard, Draper, Hartley, Mohamed and Scanlon, 1995a).

Examples of the use of computer simulations are *Software Teaching of Modular Physics* to teach waves and vibrations and measurement and uncertainty (Gillis, Sinclair, and Swithenby, 1996), Weller's (1995) microcomputer simulation of dynamics, Whitmer's (1990) use of a spreadsheet to model the Milky Way and Bridges' (1995a, 1995b) spreadsheet to plot planetary orbits and to plot Jupiter's moons' orbits. In astronomy education, the complex forces causing tides lend themselves to a computer simulation approach.

Other examples of models used to represent reality include line graphs (Berg and Smith, 1994), videos (De Yong, 1983), films (Woodman, 1972) and simulation games (Lunetta and Hofstein, 1981; Spraggins and Rowsey, 1986), an example of which is *Eleusis*

(Romesburg, 1979).

2.6.5 Models in Science Texts

Despite the difficulties of obtaining a precise definition of the term *model*, examples of them are widespread in science, in science texts and in teaching. For example, a well-known model used in teaching electricity is the train (Dupin and Johsua, 1989) in which a series electric current is the target, with a train moving continuously on a circular track acting as the model to represent the electric current. Other electrical models are that between the flow of current and the flow of water (Stocklmayer and Treagust, 1996) and a moving air model to show voltages changing over varying resistances (Grant, 1996). In chemistry teaching, reams of paper are often used to represent the mole, the mole being the target concept while the reams of paper act as the model. The attribute shared by both the target and the source in this case is the grouping of large quantities (Thiele and Treagust, 1991).

Publications such as *The New Zealand Science Teacher*, *The Australian Science Teachers Journal* and *School Science Review* often contain models that are presented for teachers to use to enhance their teaching of difficult concepts. Examples include an isostasy working model (Austen, 1986), a computer simulation of chemical equilibrium (Simpson, 1986), a geological working model of landforms (Grenfell, 1986), a model geyser (Stephens, 1989), a radioactive decay model (Austen, 1990), verbal models for chemical equilibrium (Thiele, 1990) and cranial models from different geological eras (Wyatt, 1994). Most are described with little or no research evidence as to their effectiveness from the learner's point of view and few of them seem to have been developed primarily for that purpose (Gilbert and Osborne, 1980).

Even a cursory glance at modern science textbooks reveals the existence of many models (Harrison and Treagust, 1996) whose purpose is to assist learners to understand the science concept under consideration (Gabel and Sherwood, 1984; Thiele, Venville and Treagust, 1995). Again, little research has been conducted to ascertain the extent of their effectiveness in this regard, although Gilbert (1989) found little difference in results when using text-based models, similes and metaphors to teach embryo and seed development to 210 Grade 9-10 children in the USA.

Thiele, Venville and Treagust (1995) found an average of 43.5 models per biology textbook and an average of 9.3 models per chemistry textbook. Duit (1991) found that physics texts utilised the most elaborate models while Thiele and Treagust (1991) found the highest percentage of pictorial-verbal models was found in chemistry textbooks.

Harrison (1994) examined 56 tertiary level textbooks published between 1952 and 1992 to investigate their treatment of the concept of refraction. He found widespread use of models and not one of the reviewed textbooks offered a model-free explanation for the phenomenon. The most utilised model was the wave front one, followed by the wheels

model. He was a little disconcerted to find that 10 of the 38 upper secondary texts used the Newtonian particle model to explain refraction. He was also concerned about the use of the lifesaver model, which could encourage students to believe that light can make decisions. He noted that the use of models has the capacity to cause further learning problems rather than resolve current ones. Harrison (1995) suggested that this may be because textbook models do not usually inform students where the model breaks down. Such a view would be supported by Hesse (1966) who advocated that the negative points about models should be addressed, as well as their positive features.

2.6.6 Teachers and Models

As long ago as 1970, Weller (1970) commented that science teachers use models extensively. That view was repeated later by Duit (1991), who noted that teachers commonly use models to explain ideas to pupils. An advantage is seen in that they force teachers to consider pupils' prior knowledge and misconceptions (Treagust, Duit, Lindauer and Joslin, 1989). Models appear to be valuable tools in conceptual change learning in that they are believed to provide visualisation of abstract concepts by comparing similarities between the pupils' world and the new concepts and by increasing pupils' motivation (Treagust, 1993). A helpful teaching sequence thus becomes an attempt to convince pupils that some situations which they already understand are analogous to other situations which they misunderstand (Stavy, 1991) and to emphasise the similarities between the model and the idea to be taught (Treagust, 1993).

Models used by teachers include one in which a train is depicted as passing through a tunnel rather than over a hill to represent catalysis (Thiele and Treagust, 1991), the tossing coin model when teaching half-lives in radioactivity (Treagust, Duit, Joslin and Lindauer, 1992), the rotating propeller as a model for the electron cloud around an atom (Treagust, 1993), a bath sponge to simulate air compressibility (Treagust, Duit, Joslin and Lindauer, 1992) and a vertical bookcase to represent energy levels in an atom (Venville, Bryer and Treagust, 1994).

The limited research on the frequency of use of models in teaching is summarised in Table 2.6.1.

Table 2.6.1: Research into Teachers' Use of Models

Year	Researchers	Country	Level
1970	Weller	USA	
1989	Treagust, Duit, Lindauer & Joslin	Australia	Secondary
1991	Duit	Germany	
1991	Stavy	Israel	Secondary
1991	Thiele and Treagust	Australia	Secondary
1992	Treagust, Duit, Joslin & Lindauer	Australia	Secondary
1993	Treagust	Australia	Secondary
1994	Venville, Bryer and Treagust	Australia	Secondary
1995b	Dagher	USA	Secondary
1996	Jarman	Northern Ireland	Secondary

Findings from the above research suggest that:

1. science teachers use fewer models than examples (Treagust, Duit, Lindauer and Joslin, 1989; Duit, 1991; Treagust, Duit, Joslin and Lindauer, 1992; Treagust, 1993; Dagher, 1995b; Jarman, 1996).
2. science teachers do not have a clear understanding of models (Treagust, Duit, Joslin and Lindauer, 1992).
3. exemplary use of models is infrequent (Treagust, Duit, Lindauer and Joslin, 1989; Treagust, 1993; Dagher, 1995b).

Limitations of the use of particular models were rarely discussed with pupils (Jarman, 1996), yet teachers might advance pupils' understanding if they were to emphasise the limitations of each model used, pointing out which questions it fails to answer (Schamp, 1990; Doerr, 1997). An example of such a use might be discussing the limitations and strengths of the orrery in illustrating and explaining the Moon's phases.

2.6.7 Learners and Models

The challenge in science teaching is to use models to help pupils develop their mental models of phenomena towards those shared by scientists (Osborne and Gilbert, 1980b). Yet there is an abundance of empirical evidence that pupils use very few meaningful models (Stocklmayer and Treagust, 1996), that model use often fails because pupils do not understand them and that pupils only employ them when they feel they are necessary to help their understanding (Duit, 1991).

In South Africa and Namibia, Smit and Finegold (1995) surveyed 196 secondary student teachers' ideas about models. They reported that most of the student teachers were of the view that models are always scaled replicas of real things, a view held particularly strongly by biology student teachers. If models are seen only as scaled representations of reality then use of the orrery, for example, could suggest to learners that the Sun is only a little larger than Earth and that Earth's distance from the Sun is only about twice the Moon's distance from Earth.

Factors that may impede pupils' effective use of models include:

* some learners may learn the model rather than the concept it is meant to illustrate (Thiele and Treagust, 1991; Treagust, 1993);
* pupils may lack awareness of the boundary between the model and the reality the model is representing (Osborne and Gilbert , 1980b; Gilbert and Osborne, 1980; Zeitoun, 1984; Dyche, McClurg, Stepans and Veath, 1993);
* unshared attributes are often a cause of misunderstanding for learners (Thiele and Treagust, 1991; Thagard, 1992b);
* pupils may use multiple models for the same target (Osborne and Gilbert, 1980b);
* some pupils tend to think that models such as models of the solar system are scale models of reality (Osborne and Gilbert, 1980b);
* given a range of models, pupils often continue to use the least sophisticated one (Gilbert and Osborne, 1980; Osborne and Gilbert, 1980b);

* some pupils lack the necessary visual imagery (Treagust, 1993);
* some pupils find it difficult to apply the model in different contexts (Gilbert and Osborne, 1980; Osborne and Gilbert, 1980b). An example is failing to apply the Doppler effect with sound waves to their similar effect with light;
* pupils may mix their models. For example they may have the concept that heat makes molecules expand (Gilbert and Osborne, 1980; Osborne and Gilbert, 1980b);
* pupils may already be functioning at a formal operational level, thus the use of the model may confuse them (Treagust, 1993).

Overall, then, there are difficulties with the uninformed use of models to explain concepts and mental models. These difficulties have the capacity to cause alternate learning (Stavy, 1991; Treagust, 1993).

2.6.8 Research into Teaching-Learning With Models

Research into the effectiveness of using models is limited, particularly with respect to specific curriculum development (Gilbert, 1994) or to consideration of possible alternative concepts by pupils (Brown, 1994). Table 2.6.2 lists research into the effective use of models.

Only two of the investigations reported in Table 2.6.2 were related to the use of models in astronomy education, which is surprising when the essential role of mental models in astronomy is considered. The possibility of pupils' misinterpretations of physical models was highlighted by Dyche, McClurg, Stepans and Veath (1993), who found that 20 percent of the learners thought that Earth was in the centre of the solar system because in the physical model used Earth happened to be about in the middle. After the lessons, 60% of the pupils also thought that the planets would collide because in the physical model used they frequently bumped into one another. However, Atwood and Atwood (1995) reported positive effects of the use of models in teaching about night and day.

Researchers who reported positive effects of using models include Black and Solomon (1987), Dupin and Johsua (1989), Stavy (1991), Treagust, Duit, Joslin and Lindauer (1992), Atwood and Atwood (1995), Hennessy, Twigger, Driver, O'Shea, O'Malley, Byard, Draper, Hartley, Mohamed and Scanlon (1995b), Weller (1995), Williamson and Abraham (1995), Kaufman, Patel and Magder (1996) and Doerr (1997). On the other hand, the work of Gabel and Sherwood (1980), Zeitoun (1984), Seddon and Moore (1986), Gilbert (1989), Friedel, Gabel and Samuel (1990), Mensch and Rubba (1991), Dyche, McClurg, Stepans and Veath (1993) and Arnold and Millar (1996) did not support the view that models are effective in science education.

Table 2.6.2: Research into Effective Use of Models

Year	Researchers	Country	Level	Topic
1980	Gabel & Sherwood	USA	High School	Chemistry
1986	Seddon & Moore	UK	Year 9	Chemistry
1987	Black & Solomon	UK	High School	Electricity
1989	Dupin & Johsua	France	Grade 6-10	Electricity
1989	Gilbert	USA	Grade 9-10	Genetics
1990	Friedel, Gabel & Samuel		Tertiary	Stoichiometry
1991	Mensch & Rubba	USA	Grade 9	Proteins
1991	Stavy		High School	Physics
1992	Treagust, Duit, Joslin and Lindauer	Australia	High School	Refraction
1993	Dyche, McClurg, Stepans and Veath	USA	Grade 4	Astronomy
1994	Brown	USA	Primary	Forces
1995	Atwood & Atwood	USA	Tertiary	Day & Night
1995b	Hennessy, Twigger, Driver, O'Shea, O'Malley, Byard, Draper, Hartley, Mohamed and Scanlon	UK	12-13 years old	Mechanics
1995	Raghaven & Glaser	USA	Grade 6	Force
1995	Weller	USA	Grade 8	Dynamics
1995	Williamson & Abraham	USA	Tertiary	Properties of Matter
1996	Arnold & Millar	UK	12-13 years old	Thermodynamics
1996	Kaufmann, Patel and Magder	Canada	Tertiary	Our Body
1997	Doerr	USA	Grade 9-12	Force

All in all, little has yet been been learned from empirical studies in this teaching-learning area (Thiele and Treagust, 1991; Treagust, 1993). There is, then, no universal agreement as to the effectiveness of models in promoting science learning. There is the view that model-based reasoning can, given the right conditions, facilitate meaningful learning (Duit, 1991; Brown, 1994; Dagher, 1994), while other views are that their effectiveness in teaching is not proven (Friedel, Gabel and Samuel, 1990). In fact, Driver, Leach, Millar and Scott (1996) argued that model-based reasoning was rare in pupils under 16 years of age. They regarded model-based reasoning as when pupils use models to explain theoretical systems and they noted a clear distinction between that process and simply visually describing a physical model. Dagher (1994) lamented that very few research studies examined the critical influence of teachers' models on conceptual change in pupils.

One of the few consistent findings from the research is that a model approach requires more class time than is usually spent in covering topics in a transmissive way (Hennessy, Twigger, Driver, O'Shea, O'Malley, Byard, Draper, Hartley, Mohamed and Scanlon, 1995b; Raghavan and Glaser, 1995; Doerr, 1997). That, of course, raises questions about the comparative quality of the learning in both approaches.

Models might provide an interpretive bridge between unfamiliar topics and the concepts which pupils already have (Zeitoun, 1984; Duit, 1991; Thiele and Treagust, 1991; Thagard, 1992b). However, research into their effectiveness is limited, consisting of that

conducted by Brown (1994) and by Kaufman, Patel and Magder (1996). The results, though tentative, suggest that a bridging approach may have potential in teaching for conceptual growth.

2.6.9 Summary of Section 2.6

In the absence of generally agreed definitions of the terms, section 2.6 adopted definitions of both *model* and *mental model* to be used in the remainder of this study. It discussed the widespread use of them in science in general and in astronomy in particular. It then described the ways in which scientists, teachers and learners use models. It was argued that they are utilised extensively by educators, textbook writers and learners but that their use has not generally been structured, informed or informative. Section 2.6 further discussed the research evidence for the effectiveness of the use of models in teaching. It concluded that their use might be beneficial to learners within parameters which encourage the learners to critically examine the models and their relationship to the mental models they represent.

No model, of course, can completely represent reality. While it is sensible, for example, to test ideas about days and years on the orrery, it cannot be used to portray the relative or real durations of those events. There is the danger that learners using the orrery might spend a large amount of time studying the orrery itself rather than the Sun-Earth-Moon system it represents. However, the approach suggested by Hesse (1966) appears promising in that critiquing the model, rather than using it as a portrayal of reality, might enhance mental model-building by pupils.

It is proposed in this research, then, to investigate the effectiveness of astronomy education in which pupils are assisted to construct the scientists' mental model of the Sun-Earth-Moon system by use of a model, the orrery, which represents the mental model. In a significant departure from normal practice, the pupils, rather than merely being informed of the concepts, will repeatedly critique the orrery in analysing its effectiveness in portraying and explaining astronomy concepts that are dependent on an understanding of the overall mental model.

2.7 SUMMARY AND CONCLUSIONS

Chapter two traced the changing position of astronomy in science curricula in a variety of countries (section 2.2), with particular emphasis on the position in New Zealand (section 2.3). The analysis showed that, in the latter half of the twentieth century, astronomy education has regained a central role similar to the one it had a century ago. The re-emergence of astronomy can be attributed to the increasing public awareness of, and interest in, astronomy since the 'space age' began with the 1957 launch of Sputnik One. However, there have been changes in curriculum emphasis from an essentially content-transmissive approach to a more investigative one.

An investigative approach poses particular challenges to astronomy education, as was discussed in section 2.4. The challenges relate to teachers' perceptions of the difficulties

of observing astronomical events, the long time frames of many of those events and the difficulties of conducting experiments that include manipulating variables and controls. In practice, of course, there are many astronomy activities which can be conducted by pupils, both during the day and in the evenings. However, the difficulties perceived by the teachers may encourage them to adopt or persist with a more traditional, transmissive mode when teaching astronomy. That approach could well lead to its demise from science curricula once more.

A review of research into astronomy learning (section 2.5) revealed a preponderance of research into the products of astronomy education and a lack of focus on the investigative skills by which those products are constructed. The emphasis may be a reflection of traditional transmission-based pedagogy. It signals a need for research into learning processes that occur in investigative astronomy teaching. That is, a change of approach towards an investigative one is necessary when teaching astronomy, both because that approach reflects many recent curriculum expectations and because the more traditional approaches are apparently not successful.

Section 2.6 reviewed the limited amount of research into the roles of models and mental models in science education. The research revealed that models are widely used but generally misunderstood both as product and process. However, their use has promise and requires further research. The section concluded that Hesse's (1966) approach of critiquing models has much to offer astronomy education. It will be a key feature of this study.

The overall conclusions to be drawn from this chapter are that, although recent curricula require an emphasis on learning processes, science education research to date reflects the fact that classroom learning in astronomy has mainly focused on knowledge outcomes. Mental model building, which has been a key investigative process in astronomy itself, offers promise as a fruitful classroom approach in the promotion of current curriculum expectations.

Thus this research will consider a classroom intervention in which pupils are helped to construct the scientists' mental model of the Sun-Earth-Moon system by the process suggested by Hesse (1966) of critiquing a model which represents the mental model. The process of formulating the astronomy intervention will be described in chapter four. Before that, chapter three will review the literature related to teaching and learning in order that recent findings will be incorporated into the formulation of the astronomy intervention.

CHAPTER THREE: TEACHING AND LEARNING: A REVIEW OF THE LITERATURE

3.1 INTRODUCTION

Chapter three extends the suggestion made in chapter two that new approaches in astronomy education are necessary. It explores new possibilities with respect to teaching and learning science in general and astronomy education in particular. Furthermore, this chapter makes recommendations about an improved approach to teaching astronomy. The approach will be utilised in chapter four to use principles which will guide the development of an alternative teaching intervention that is designed to assist learners to construct astronomy mental models.

Section 3.2 will review learning theories that arise both from a positivist epistemological perspective and from a relativist epistemological perspective. A recommendation will be made from among the competing learning theories for use in the research.

Section 3.3 examines the desirable features of a learning model that develop from the discussion in section 3.2. It will suggest that, and explain why, the Generative Learning Model reflects those features. It briefly describes the Generative Learning Model and explains why it was adopted as a basis for this investigation.

Section 3.4 describes a teaching model which is appropriate to the Generative Learning Model. It describes its features, outlines the role of teachers in implementing the model, and suggests that modifications may be required to meet the particular needs of the planned astronomy intervention.

Section 3.5 examines the use of mental models in astronomy education. It considers whether their use is compatible with the chosen teaching model and discusses strategies to facilitate pupils'construction of astronomy mental models.

Section 3.6 explores the particular relationship of constructivist-influenced approaches to *Science in the New Zealand Curriculum.* It examines whether *Science in the New Zealand Curriculum* does, in fact, encourage the suggested approach to teaching science and astronomy.

Challenges which teachers could experience when teaching astronomy by utilising a more effective approach are considered in section 3.7. These include teachers' own alternative concepts, possible teacher resistance to the adoption of the new approach and the difficulties of conducting investigations in astronomy.

The chapter concludes with a summary of the findings from each section and makes recommendations about an interactive approach to astronomy education.

3.2 A REVIEW OF SOME THEORIES OF LEARNING

3.2.1 Introduction

A review of research into astronomy learning (section 2.5) revealed a preponderance of research into the *products* of astronomy education and a lack of focus on the *process* skills by which those products are constructed. This research may be a reflection of traditional transmission-based pedagogy. A more investigative approach is necessary when teaching astronomy to better reflect recent curriculum expectations and the ways in which astronomy knowledge was generated. Also, because more traditional approaches are apparently not successful, new modes of teaching astronomy need to be explored and developed, based on the ways in which pupils learn science concepts. Thus section 3.2 considers some theories which address how pupils meaningfully learn science concepts. The section considers the nature of science knowledge and concepts and considers contrasting ways in which pupils learn. It concludes by selecting a more promising approach for the proposed intervention.

The discussion is presented in the following sequence:

* epistemology: passive and active learning (section 3.2.2);
* constructivism - origins and diversity (section 3.2.3);
* trivial constructivism (section 3.2.4);
* radical constructivism (section 3.2.5);
* social constructivism (section 3.2.6).

3.2.2 Epistemology: Passive and Active Learning

Epistemology is the branch of philosophy which deals with theories of knowledge and knowing (Bliss, 1995; Driver, Leach, Millar and Scott, 1996). That is, it deals with the nature and production of knowledge rather than its products (Novak, 1991; Larochelle and Desautels, 1991). It is tempting to assume that individuals will learn science in the same way that the science knowledge initially came to be known, although there is no necessary connection (Osborne, 1996; Ogborn, 1997).

One branch of epistemology sees science as being concerned with absolute knowledge that is independent of humans. Scientists such as Bacon and Comte who adopt this position are described as *positivists* (Pope and Gilbert, 1983) because they believe in the idea that a real objective world exists independently of human perceivers (Loving, 1997). On this view, the role of science is to discover (Ogborn, 1997) science ideas such as electrons, viruses and galaxies. It assumes that things would still exist even if there were no humans to think about them (Nola, 1997), for example that Uranus existed before Herschel discovered it and that Earth orbited the Sun before Copernicus suggested it.

If science knowledge is absolute and logically organised, then science educators best help their pupils to learn it by presenting the material in a logical and structured way (Dawson, 1992), even an authoritarian way (Nola, 1997), using teacher-talk and textbooks. That is, learners are seen as mentally and physically passive. Pupils' prior ideas are not a

consideration (Lijnse, 1995; McComas, 1996) and the teaching methods are usually a variation on lectures and other transmissive modes (Anderson, 1997). These, however, have rarely been effective in changing pupils' prior ideas towards those of scientists (Grant, 1994; Thomaz, Malaquias, Valente and Antunes, 1995; Bezzi, 1996). Positivist ideas were common among science teachers in the 1960s, 1970s and 1980s (Mestre and Touger, 1989; Cleminson, 1990). Such teachers frequently subscribed to an epistemology which assumed that learners come into classrooms in a *tabula rasa* state, in which they have no knowledge of a topic before it is formally taught to them (Gilbert, Osborne and Fensham, 1982). In addition, any prior knowledge and concepts of the learners could easily be replaced (Gilbert, Osborne and Fensham, 1982).

An alternative epistemology, which came to be known as constructivism, emerged in the 1980s. Constructivism challenged many of the assumptions of positivism, especially the traditional image of teaching as the transmission of knowledge to uncluttered minds (Carr, 1987). The existence and relevance of learners' knowledge prior to formal schooling - variously described, for example, as alternative frameworks (Driver and Easley, 1978), misconceptions (Gilbert, 1977) and out-of-school-knowing (Solomon, 1982) - has been widely documented (Pfundt and Duit, 1994). For example, in France Sere (1986) noted that even before teaching began children had a variety of experiences of air and gases; Arnold and Miller (1994) noted the wide range of heating and cooling experiences of pupils prior to being taught the topic; Driver (1981) wrote that pupils already have expectations and their own beliefs about the concept 'living' and they are often different to those the teacher wishes to develop; and Turner (1997) found that five- and six-year-olds already have considerable knowledge of food and diet. She suggested that home, friends and the media are influential in developing children's views.

Such findings have been supported by research in all areas of the science curriculum (see section 2.5). The *tabula rasa* view of learners has generally been replaced with a view that learners bring to class a complicated and varied body of knowledge and understanding (Berg and Brouwer, 1991; Brickhouse, 1994; Monk, 1995). Learners' ideas cover the whole range of science knowledge, views about the processes of science and the activities of scientists themselves, which are reported as being stereotypical even by six years of age (Newton and Newton, 1992).

In its essentials, the constructivist view proposes that science knowledge is *made* by humans rather than discovered by them (Ogborn, 1997). In support of this view, von Glaserfeld (1989) articulated the following two hypotheses:

* Knowledge is actively constructed by thinking subjects. It is not passively received from the environment.
* Gaining knowledge is an adaptive process of organising the learner's view of the world. People do not discover an independent, pre-existing world outside their minds.

3.2.3 Constructivism: Origins and Diversity

Although the work of Driver and Easley (1978) on alternative frameworks stimulated widening interest in, and development of, constructivist theory (Solomon, 1994), the origins of constructivism substantially predate Driver and Easley. Various writers trace its origins to George Kelly (Solomon, 1994), to Jean Piaget (Solomon, 1994; Zevenbergen, 1996; Ogborn, 1997), to John Dewey, to eighteenth century Giambattista Vico (Nola, 1997) - and even as far back as Aristotle (Hawkins, 1994).

While there is no universal agreement on the meaning of constructivism (Strike, 1987; Loving, 1997), essentially it argues that learning is not passive in that pupils actively construct their own understandings by making meaning of their experiences (Ernest, 1994; Zevenbergen, 1996) and then hold on to those ideas tenaciously (Osborne (1996). That is, learning will be unique to each individual. Constructivism focuses on the learner as an active participant in the learning process (Osborne, 1996; Ogborn, 1997), its common thread being that it is individual-centred and experience-based. Matthews (1992, 1995) was of the view that it has done a service to science education by focusing on pupils' prior learning, by emphasising understanding rather than memorisation and by encouraging pupils' active participation in their own learning, a view shared by Ogborn (1997). Zevenbergen (1996) added that constructivism has replaced rote learning in science classrooms.

However, constructivism has aroused heated debate. Millar (1989) argued that constructivism is too easily open to different interpretations which lead to conflicting variants of constructivism (Watts, Jofili and Bezerra, 1997). These different interpretations, trivial, radical and social constructivism, will be considered next.

3.2.4 Trivial Constructivism

Trivial constructivism limits itself to von Glaserfeld's (1989) first proposition, that knowledge is actively constructed by thinking subjects rather than passively received from the environment (Hameed, 1997). Matthews (1992), Suchting (1992) and Osborne (1996) argued that this form of constructivism is not only self-evident but is also essentially empiricist in nature - while science knowledge is to be actively acquired by individual pupils, it remains objective knowledge to be received by them. Osborne (1996) criticised trivial constructivism because it ignored the role of language and because it does not explain how the 'viability' of different theories can be contrasted.

Matthews (1992) was particularly critical of his perception that science education, as expressed in the contextual strands of *Science in the New Zealand Curriculum,* is about making sense to pupils rather than about finding the truth. He noted that much science, such as Galileo's account of pendulum motion, is often different to the experienced world and that much science defied the sense of the times in which it was articulated. A good example of that is Galileo's adherence to the idea of a Sun-centred rather than an Earth-centred universe. Alternately, Matthews (1998) noted that things that are not true can nevertheless make sense. A good example is the child who thinks that the Moon orbits

Earth once each day because it makes sense and agrees with observations.

3.2.5 Radical Constructivism

Kelly (1955) argued that people construct knowledge, ideas and understandings that are unique to each individual. In the view of Solomon (1994) and Ogborn (1997), von Glaserfeld's (1989) second hypothesis, that gaining knowledge is each individual's adaptive process of organising his or her view of the world, accentuated this idea. It leads to a view that knowledge is truly relative, made or constructed by each individual learner, and not open to verification or refutation. That is, knowledge exists only in the mind of each learner, rather than in books (Osborne, 1996). Furthermore, there can be no knowledge without a knower, there can be no objective reality that can be transferred from one person to another (Zevenbergen, 1996) and all knowledge is defined as being personally owned (Ogborn, 1997).

Matthews (1992) referred to radical constructivism as the 'Robinson Crusoe' model of constructing knowledge, while Osborne (1996) criticised radical constructivism for its apparent attempt to refute notions of any absolute truths. He used the example of the child who sees the Sun as orbiting Earth. While this satisfies the radical constructivists' criteria of viability and the child's experience, it is shown by space satellites to be not true. Ogborn (1997) said the logical outcome of the radical constructivist view is either that nothing exists outside each individual's mind or that if it does we cannot absolutely know anything about it. Nola (1997) added that radical constructivism presents a distorted picture of science, is based on a discredited philosophy of science learning and demonstrates a distorted conception of knowledge.

In addition to the above objections, Zevenbergen (1996) criticised radical constructivism on the grounds that science education built on its premises would marginalise many pupils from the accepted scientific community. It would not allow them to build the cultural capital so essential to the building of their social and economic capital. He saw radical constructivism as ignoring the socio-political context. In addition, Osborne (1996) noted that constructivism, particularly its radical version, had taken no account of its limitations, thus becoming an act of faith. In particular, a limitation of the epistemology is that it fails to consider the social effects of learning (Yager, 1991; Matthews, 1992; O'Loughlin, 1992; Solomon, 1994; Zevenbergen, 1996).

3.2.6 Social Constructivism

Social constructivism is a view that considers humans are social beings who learn through social interactions, often in groups (Vygotsky, 1962; Resnick, 1991; Matthews, 1992; Zevenbergen, 1996). It accepts an attenuated relativist view of knowledge and concepts rather than objective positivism in that science knowledge is seen as never completely understood and is often understood differently by different individuals within a society. It sees human interactions and social organisations as being the defining arbiters. The community of scientists is one such social organisation which develops its own shared truths and ways of testing those truths by a process of enculturation (Osborne, 1996). Yet

fierce debate often exists within a social organisation. For example there are debates about constructivism itself within the education community, debates about the epistemology of science within the philosophy of science community and debates about cosmology within the astronomy community.

Acceptance of the views of the social constructivists implies that science education should also be collaborative and social-based so that pupils explicate and share their meanings and then utilise the socially approved method of deciding the worth of competing ideas.

3.2.7 Summary of Section 3.2

Section 3.2 has considered two broadly contrasting epistemologies of science and their implications for science learning at large. What implications emerge for the development of a more informed classroom approach to astronomy education? It has been suggested (chapter 2) that science education research to date reflects the fact that classroom learning in astronomy has mainly focused on knowledge outcomes and that mental model building, which has been a key investigative process in astronomy itself, might also be a fruitful classroom approach in the promotion of current curricular demands.

Astronomy education is compatible with a constructivist view which holds that there *is* objective astronomy to be discovered but that it is not yet completely known. In addition, individuals' and groups' mental models about astronomy are not constructed in identical ways. However, people do act and learn as part of one or more groups.

3.3 FEATURES OF A CONSTRUCTIVIST APPROACH TO LEARNING SCIENCE

3.3.1 Introduction

The adoption of a constructivist-based approach to learning is only the first step. The obvious question is "What does this tell us about a particular approach to learning science?" Section 3.3 will describe the features of such a learning model and will examine and critique a teaching-learning model against those features. Discussion is presented in the following sequence:

* meaningful learning is preferred over rote learning (section 3.3.2);
* pupils come to classes with prior science knowledge (section 3.3.3);
* pupils learn in an active way (section 3.3.4);
* information new to pupils is either assimilated or accommodated (section 3.3.5);
* pupils need to become dissatisfied with their non-science concepts before they can assimilate or accommodate currently accepted science concepts (section 3.3.6);
* pupils are more likely to adopt new science ideas if those ideas are intelligible, plausible and fruitful (section 3.3.7);
* learning is a social activity (section 3.3.8);
* the generative learning model: an example of a constructivist learning model (section 3.3.9).

While the above features are described separately in the interests of clarity, they overlap and are mutually supportive.

3.3.2 Meaningful Learning is Preferred Over Rote Learning

Learning covers a continuum between meaningful learning and rote or reception learning. In the latter, knowledge is transmitted to the learner, who attempts to incorporate it into his/her cognitive structure without necessarily understanding it (Novak, 1979). Novak (1978) had previously pointed out that knowledge acquired by rote learning is rarely retained other than in short-term memory. For example, rote learning of mnemonics, such as those for the elements in the periodic table, can rarely be used effectively in problem solving and are, of course, another person's interpretation of events and reality (Pines and West, 1986).

At the other end of the continuum, and commonly seen as the most effective learning (Taber, 1996), is meaningful learning. It occurs when new knowledge is integrated into related concepts already in the learner's cognitive structure (Novak, 1976; Novak, 1979; Cavallo and Schafer, 1994). It is an active process, conscious or not, in that the learner's existing knowledge interacts with the new learning (West and Fensham, 1974; Hackling, 1982; Okebukola, 1990; Lowe, 1993; Gil-Perez, 1996) with the result that the learner develops a modified version of the concept to which he or she was exposed. Both the new learning and the existing concept are altered (Novak, 1976). That is, each person experiences an individual learning experience (Gonzalez, 1997) by interacting with the new idea in a unique process of concept development. The process is continuous and changes in meaningful learning occur with differentiation and integration of concepts into each individual's cognitive structure (Novak, 1978).

Meaningful learning of science is considered to be a success when the learner fully understands the scientific ideas under consideration (Smith, Blakeslee and Anderson, 1993) and can successfully use the new knowledge in solving novel problems (Novak, 1976; Pearsall, Skipper and Mintzes, 1997; Palmer, 1996). A constructivist-based learning theory, then, needs to be consonant with pupils' meaningful learning.

3.3.3 Pupils Come to Classes with Prior Science Knowledge

Each pupil has a personal knowledge and understanding (Berg and Brouwer, 1991) formed from that individual's unique learning experiences. That is, concepts develop from experiences and social interactions (Gunstone, White and Fensham, 1988) and from a variety of formal and informal agencies (Furnham, 1992; Francis and Hill, 1993). That is why we find a wide variety of science concepts among people (Monk, 1995), as was shown in section 2.5 .

Even before coming to school, children have concepts about a variety of topics (Osborne and Wittrock, 1985; Solomon, 1992; Claxton, 1993; Barman, Barman and Miller, 1996; Koumaras, Kariotogloy and Psillos, 1996) which are often not in agreement with those held by scientists (Wheeler and Hill, 1990; Garnett, Garnett and Hackling, 1995; Leach

and Scott, 1995; Lin, Shiau and Lawrenz, 1996; Christiadou and Koulaidis, 1996; Treagust, Harrison and Venville, 1996; Hynd, Alvermann, and Qian, 1997; Trumper, 1997). The learner's prior knowledge is clearly an important facet of meaningful learning (West and Fensham, 1974; Novak, 1977; Cavallo and Schafer, 1994) because without such propositions or concepts the learning can only be by rote.

Pupils' prior ideas, then, become of central importance to the learning process (West, 1973; Osborne and Cosgrove, 1983; Pereira, 1996) because a teacher's logical enunciation of facts, data and propositions may have little, unanticipated or even adverse effects on the learner, who is seeing and hearing through that learner's filter of prior concepts (Fensham, 1972; West and Pines, 1984; Hashweh, 1988; Mestre and Touger, 1989; Cleminson, 1990; Berg and Brouwer, 1991).

Novak, Ring and Tamir (1971) made the assumption that what they referred to as new knowledge "bits" will impinge on the learner's cognitive structure. Not all knowledge "bits" are equally effective, as was pointed out by Trowbridge and Mintzes (1988), particularly for higher-order concepts such as ecology and evolution. One such impinging "bit" is referred to as a *subsumer*, which was defined by Lowe (1993) as a concept or idea or knowledge that the learner already possesses that can provide a bridge to a new concept or knowledge. All learners possess a variety of subsumers (West and Fensham, 1974), which are the primary determinants of learning success (Novak, Ring and Tamir, 1971). Thus learners' prior knowledge has an important organizing or subsuming role in facilitating meaningful learning (West and Fensham, 1976).

3.3.4 Pupils Learn in an Active Way

From a constructivist point of view, learning is not passive. This is the major reason why education research has moved its focus from teaching to viewing learning as an active, spontaneous, self-directed learning process (Gunstone, White and Fensham, 1988; Novak, 1991) in which the learner must actively attempt to relate new concepts to existing ones (Cavallo and Schafer, 1994).

Learning is a highly active process directed at meaningful learning. This requires mental effort (Kuhn, 1972; Driver, 1989; Dreyfus, Jungwirth and Eliovitch, 1990; Wheatley, 1991; Yager, 1991; Anderson, 1992; Saunders, 1992; Pfundt and Duit, 1994; Milne and Taylor, 1995; Cobern, 1996; Lloyd and Wallace, 1996). That is, learning involves the active generation and restructuring of pupils' concepts (Osborne and Wittrock, 1985; Thijs, 1992; Anderson, 1992; Searle, 1993; Lloyd and Wallace, 1996). Active learning presupposes that there will be interaction between each learner's prior ideas and the new experiences and concepts (Strike and Posner, 1982; Champagne, Gunstone and Klopfer, 1983; Trumper, 1990; Constable and Long, 1991; Carr, Barker, Bell, Biddulph, Jones, Kirkwood, Pearson and Symington, 1994). Thus learners are each responsible for their own learning (Driver, 1989) and different pupils may learn different things from similar experiences (Driver and Bell, 1986).

So from a teaching-learning perspective, learning becomes the active re-construction of each learner's existing ideas in a process of conceptual development (Bell, 1991).

3.3.5 Information New to Pupils is Either Assimilated or Accommodated

Of significance to educators are the effects when information and concepts are presented to learners. Both Piaget and Ausubel utilised the terms *assimilation* and *accommodation* to describe these effects. When confronted with new material, the meaningful learner either assimilates it into existing cognitive structure or the cognitive structure must undergo accommodation (Nussbaum and Sharoni-Dagan, 1983). While they are treated separately in the analysis which follows, a continuum exists between assimilation and accommodation (Dekkers and Thijs, 1998).

Assimilation is the perceiving of external concepts in terms of one's own prior concepts (Lawson, 1979; Posner, Strike, Hewson and Gertzog, 1982). It is what Zuzovsky (1994) referred to as 'weak restructuring'. If the new learning can be easily related to the existing cognitive structure of the learner, then assimilation is likely to occur, making little alteration to both the prior concept and the new one being learned (Novak, 1978; McElwee, 1991; Brody, 1994; Zuzovsky, 1994; Demastes, Good and Peebles, 1996). For example, if the learner possesses a concept of 'planet' and is told that astronomers have discovered a planet around a star, then the learner can assimilate the new information with no alteration to his or her existing concept of planet. Nevertheless, assimilation requires active effort on the part of the learner to the extent that it requires a selective ignoring of non-salient information (Dykstra, Boyle and Monarch, 1992). For assimilation to occur, the educator must match as closely as possible the new concept with the learner's existing cognitive structure. A knowledge of that learner's existing cognitive structure is thus an essential pre-requisite.

Accommodation is when a learner's existing mental structures change, gradually or otherwise, when a new concept is experienced (Lawson, 1979; Posner, Strike, Hewson and Gertzog, 1982; Dykstra, Boyle and Monarch, 1992; Brody, 1994; Zuzovsky, 1994; Demastes, Good and Peebles, 1996; Tyson, Venville, Harrison and Treagust, 1997). That is, accommodation is a more difficult process than assimilation for the learner. It occurs when the new information is not fully congruent with the learner's existing cognitive structure. Thus prior knowledge and skills are brought to bear on the new learning experience (Driver, 1989; Anderson, 1997). For example, if an individual has previously developed a concept of *planet* but subsequently learns that scientists now question whether Pluto is one, then he or she must engage in significant mental restructuring in order to make sense of this new information. This restructuring should result in a change in the learner's meaning of the concept *planet.* (Pearsall, Skipper and Mintzes, 1997).

If a concept presented to a learner is consistent with the learner's existing concepts, then assimilation of the new concept should more easily occur. For example, the concepts of

synodic and sidereal months are more likely to be assimilated into the learner's cognitive structure if the learner already has the science concept of the relative motions of Earth and the Moon. If, however, the learner thinks the Moon orbits Earth once every 24 hours, then synodic and sidereal months cannot be meaningfully learned except by the process of accommodation, in which the learner's existing cognitive structure undergoes change.

3.3.6 Pupils Need to Become Dissatisfied with their Non-science Concepts Before they can Assimilate or Accommodate Currently Accepted Science Concepts

A necessary prerequisite for accommodation to occur is that pupils become dissatisfied with their current concept (Hewson, 1981a; Strike and Posner, 1982; Anderson, 1992; Hennessy, Twigger, Driver, O'Shea, O'Malley, Byard, Draper, Hartley, Mohamed and Scanlon, 1995a; Thorley and Stofflett, 1996; Hynd, Alvermann, and Qian, 1997). Dissatisfaction occurs when pupils realise that their existing concept is not adequate for describing, explaining or predicting new phenomena (De Yong, Acampo and Verdonk, 1995). That is, they must first lose some faith in their current concept (Stofflett, 1994) because there is no incentive to change one's views if those views are fully serving their purpose of allowing understanding of current events and reasonable predictions of future events. That is, pupils need to experience some anomaly within their prior concept or the current concept must come to be seen as overly clumsy or overly complicated.

C*ognitive conflict* (Adey, 1992) is a process of encouraging dissatisfaction. It occurs when a pupil meets an idea which she/he cannot explain using his/her current concepts. It is now generally accepted that a pupil's cognitive accommodation requires some experience that would invoke a state of *disequilibrium*, *dissonance* or *conflict* (Stavy and Berkovitz, 1980; Nussbaum, 1989). Alternative terms which describe the same effect are *cognitive disequilibration* (Dykstra, Boyle and Monarch, 1992; Appleton, 1993), *cognitive dissonance* (Aronsen, 1972), *discrepant event* (Adey, 1992), *ideational confrontation* (Champagne, Gunstone and Klopfer, 1983) and *perturbation* (Davis, McCarty, Shaw and Sidani-Tabbaa, 1993; Zuzovsky, 1994). During this process, existing neuronal linkages become inadequate and the learner takes action in reorganizing them to more effectively integrate the new concept (Anderson, 1997). A tactic is required to arouse the learner sufficiently to engage with the learning task for accommodation to occur (Anderson, 1992) and the learning theory suggests that greater change will occur in those who experience the greatest dissonance (Steiner, 1980). However, the new concept must not be too discrepant compared to the prior concept or the learner may feel threatened sufficiently to deny the mismatch and refuse to engage in the concept change process (Anderson, 1992). That is, different pupils may react differently to the same dissonance (Waring, 1979; McElwee, 1991; Bezzi, 1996).

What appears to be a cognitive conflict from the teacher's point of view is not necessarily one from the pupils' viewpoint (Koumaras, Kariotogloy and Psillos, 1996; Pfundt and Duit, 1994). Furthermore, discrepant events may be perceived by pupils merely as odd

exceptions to their prior conceptual picture of the world (Wheeler and Hill, 1990). It is likely, then, that a result of accommodation via cognitive conflict may be that the learner's existing cognitive structure develops towards, but not necessarily become consonant with, that of the scientifically accepted viewpoint. Different developments will occur for different learners because of their different prior cognitive structures, a process known as *progressive differentiation* (Posner, Strike, Hewson and Gertzog, 1982; Brody, 1994).

The conclusion is that cognitive conflict is a necessary but not a sufficient condition for dissatisfaction with existing concepts (Driver, 1989; Stofflett, 1994; Arnold and Millar, 1996). The learning of a new concept, and thus a learning theory about encouraging it, must satisfy a number of further conditions before it can be accepted. These are now described.

3.3.7 Pupils are More Likely to Accept New Science Ideas if Those Ideas are Intelligible, Plausible and Fruitful

The first condition for acceptance of a new concept is that the learner must understand it. That is, it must be *intelligible* (Hewson, 1981a; Hewson, 1981b; Posner, Strike, Hewson and Gertzog, 1982; Strike and Posner, 1982). It must be meaningfully understood and able to be internally represented by the learner (Stofflett, 1994). That is, the learner must know what it means and be able to express its meaning (De Yong, Acampo and Verdonk, 1995; Treagust, Harrison and Venville, 1996).

For acceptance, the new concept must be reconciled with the learner's prior concepts (Hewson, 1982). That is, the new concept also has to be *plausible* to the learner (Hewson, 1981a; Posner, Strike, Hewson and Gertzog, 1982; Strike and Posner, 1982). Existing theories are never rejected unless a plausible alternative one is available (Driver Leach, Millar, and Scott, 1996). So the new concept has to be believable and consistent with the learner's accepted prior ideas (Hewson, 1981b; Stofflett, 1994; De Yong, Acampo and Verdonk, 1995; Treagust, Harrison and Venville, 1996). Plausibility, then, depends upon the relationship of the new knowledge to that already existing in the learner's cognitive structure. For example, geologists' idea that Earth is billions of years old could not become plausible to them until they understood how the Sun could provide energy for that length of time.

A further condition to be met before a learner is able to fully accept a new concept that replaces a prior one is that the new concept must be *fruitful* (Hewson, 1981a; Hewson, 1981b). The new concept must explain phenomena (Hewson, 1981b; Strike and Posner, 1982), have the capacity to solve related problems (Hewson, 1981b; Posner, Strike, Hewson and Gertzog, 1982; Treagust, Harrison and Venville, 1996; Hynd, Alvermann and Qian, 1997) and suggest further research into new areas of inquiry (Posner, Strike, Hewson and Gertzog, 1982; Strike and Posner, 1982; De Yong, Acampo and Verdonk, 1995; Treagust, Harrison and Venville, 1996). For example, a learner, after accommodating the scientists' mental model of the Sun-Earth-Moon system into his/her

cognitive structure should then be able to use that mental model to explain the phases of the Moon or to predict tidal patterns.

The above three conditions are separately a necessary but not a sufficient condition for the likely accommodation of a new concept into a learner's existing cognitive structure (Basili and Sanford, 1991; Demastes, Good and Peebles, 1996; Tyson, Venville, Harrison and Treagust, 1997). All the conditions must be met before accommodation can occur. In fact, a conception cannot be fruitful without being plausible and cannot be plausible without being intelligible (Hewson, 1981a; Thorley and Stofflett, 1996).

The researcher has summarised the above discussion in Figure 3.3.1.

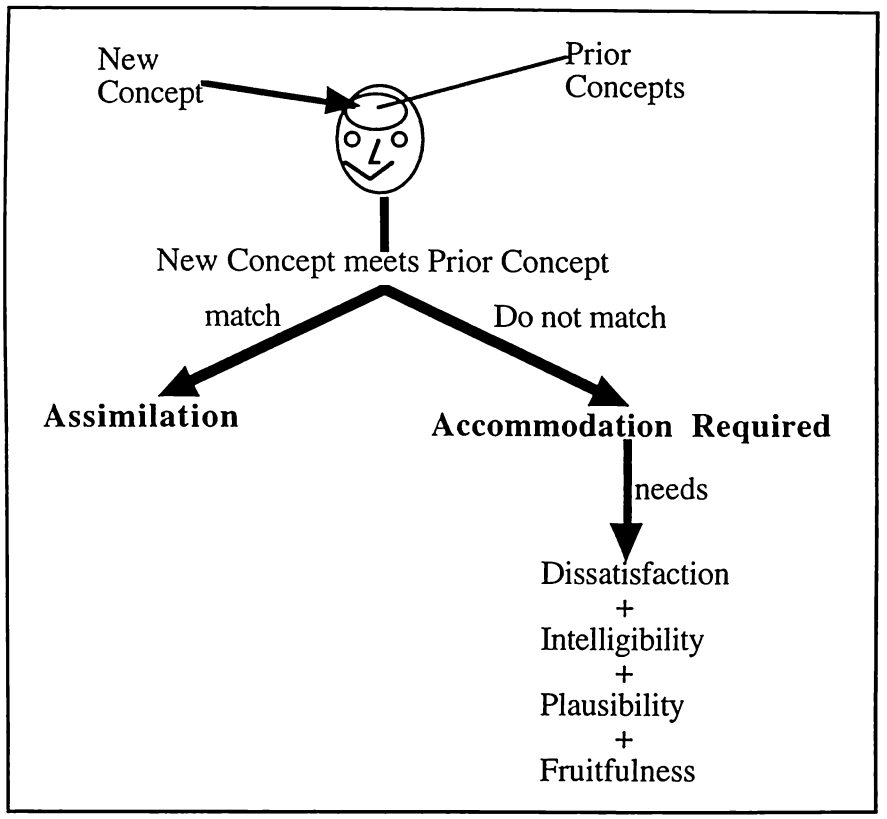


Figure 3.3.1: The Concept Change Model

3.3.8 Learning is a Social Activity

In addition to the above, a further feature is that knowledge is socially constructed (Bianchini, 1997; Shepardson, 1997). Scientific inquiry itself is usually conducted by the social activity of a discourse in which scientists' varied knowledge and experiences are shared to solve a problem (Gilbert and Priest, 1997). The equivalent in schools is when several pupils are working in a social setting to complete an assigned task (Towns and Grant, 1997).

A constructivist-based approach to learning, then, should promote opportunities for cooperative learning experiences (Palmer, 1997) and should foster conceptual learning and creative problem solving (Bianchini, 1997). Group collaboration allows pupils to

negotiate meanings (Palmer, 1997), which evolve and are constructed as much through talk by individuals within the group setting as by practical activities (Mortimer, 1998). That is, cooperative learning activities are consistent with the idea that pupils must actively process information to learn it in a meaningful way (Towns and Grant, 1997).

Towns and Grant (1997) observed that cooperative learning leads to more meaningful learning of science concepts, greater acceptances of differences among peers and enhanced conceptual development. For example, in observing children during a museum visit, Gilbert and Priest (1997) noted that group construction of knowledge occurred, mainly mediated by verbal discourse among the pupils.

However, Bianchini (1997) cautioned that group work is not a magical solution to science education problems. Mortimer (1998) observed that social pressure to conform is less than in the whole class and so obstacles can reappear in group discussions, while Towns and Grant (1997) cautioned that pupils working in groups tended to accept explanations from pupils perceived to be intelligent, with the corollory that some pupils' opinions were neglected. In addition, many pupils continued to seek validation from the teacher for their ideas (Watts, Gould and Alsop, 1997).

To reduce detrimental effects, Towns and Grant (1997) recommended that the pupils need to be carefully prepared for cooperative learning, such as giving each group member a specific responsibility. However, Bianchini (1997) cautioned that such procedures reduce but do not eliminate the probability that one person in a group will dominate.

Any learning model that reflects constructivist approaches needs to include the features summarised both in Figure 3.3.1 and in the discussion with respect to co-operative learning.

3.3.9 The Generative Learning Model (GLM): An Example of a Constructivist Learning Model

There has been a number of models of learning in science based on constructivist theories (Appleton, 1997). This section will consider the merits of the *generative learning model* as proposed by Osborne and Wittrock (1985), in which the learner has to generate her/his own learning and concepts. It is shown in Figure 3.3.2. The generative learning model is familiar to the researcher, makes sense to him in the context of his own and his students' learning and acted as an initial stimulus for the development of the teaching model discussed in chapter four.

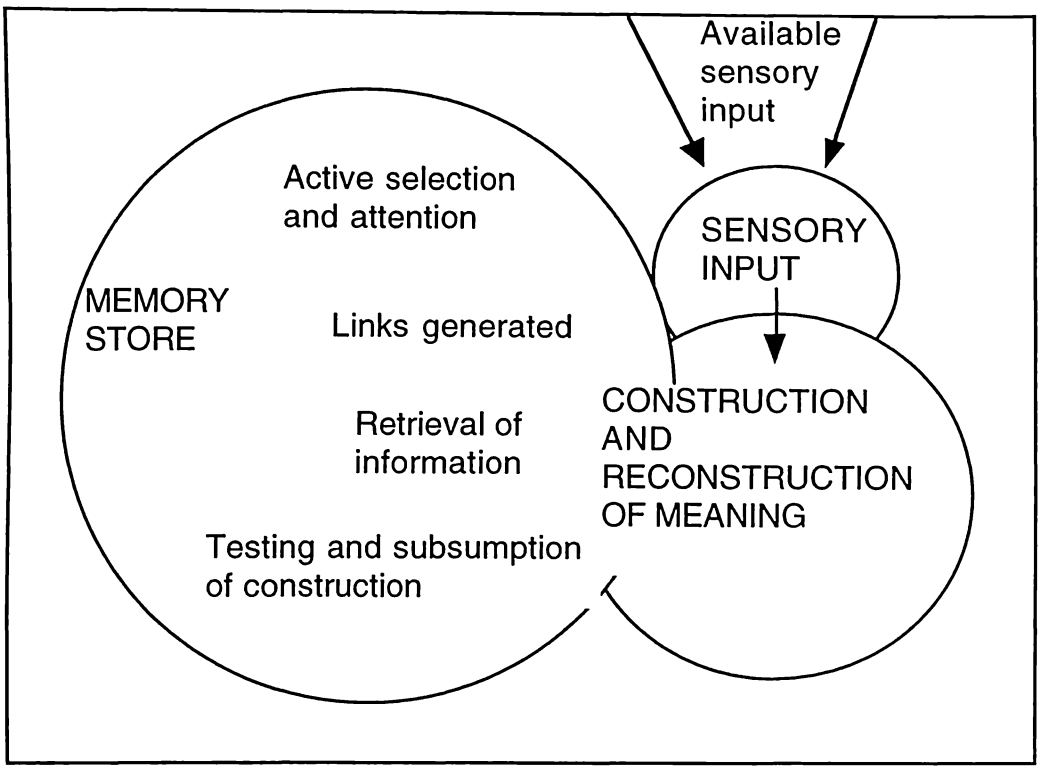


Figure 3.3.2: Osborne and Wittrock's (1985) Generative Learning Model

The key features of the generative learning model are:

* the learner selects sensory input from all the possible ones around the learner;
* the learner gives attention to the chosen sensory input;
* the learner generates links between stimuli and aspects of memory store;
* the learner constructs meaning from the chosen sensory input;
* the learner retrieves information from his/her long-term memory;
* the learner evaluates meanings and possibly subsumes them.

(Osborne and Wittrock, 1985).

Referring to the first point, there has to be an active filtering by the learner in order that the appropriate stimuli are selected from among the ones competing for attention (Fensham, 1972; White, 1977; Garnett and Treagust, 1992). This filtering is active, whether conscious or not, and is guided by the learner's cognitive structures (Anderson, 1992) before being admitted to short-term memory. A social example of this is the way in which people engage in conversation in a crowded room by filtering out non-related data. Anderson (1992) suggested that humans are, in fact, predisposed towards this filtering ability. The filtering by the learner may, of course, not be the filtering that is intended by the educator (Driver, 1981).

The model requires an entity known as *short-term memory*, in which the selected stimuli are placed (White, 1977; Hendrey and King, 1994). It also requires an entity known as *long-term memory*, in which are intellectual skills and mental images (White, 1977) that are related to the discussion about mental models in chapter two.

Incoming information will be lost by the learner unless the learner processes that information to link it to existing knowledge rather than merely receiving it passively (White, 1977; Osborne and Wittrock, 1983). With the generative learning model, the learner can be said to have constructed the new concept once it has been processed into the *long-term memory*, thereby altering the learner's cognitive structure (Novak, 1976; White, 1977). Hendry and King (1994) add the cautionary note that it is not precisely explained how that process occurs.

Osborne and Wittrock (1985) commented that the model accounts for the finding that children's ideas are often not influenced at all, or are influenced in unanticipated ways, by the teaching. They emphasised that the learner is active, a view emphasised by Larochelle and Desautels (1991) with their observation that learners must be conceptualized as *producer*s of knowledge. In the generative learning model, as with the constructivist approach, learning in science becomes a revision of the learner's cognitive structure (Osborne, 1980). Furthermore, assimilation is better facilitated when the new concept is readily linked to propositions already in the learner's long-term memory (White, 1977), in which case little processing from short-term to long-term memory is required.

The foregoing discussion suggests that the constructivist approach and the generative learning theory have many similar properties. However, further research is required to test claims made for the theory. Berger (1979) wrote of critical research problems, including:

* the need for practical application to science classroom practice; and
* feedback to adjust the learning model in light of research findings.

Overall, the role of the learner in the generative learning model is to construct meaning and to generate and test tentative solutions (Osborne and Wittrock, 1983), which is itself a reflection of science research processes and constructivist approaches.

3.3.10 Summary of Section 3.3

Section 3.3 has examined the features required of a learning model if it is to be described as reflecting constructivist approaches. It has been argued that such a learning model must allow for and facilitate the seven features indicated at the beginning of section 3.3. In particular, the generative learning model closely mirrors, or allows for, most of those features, as shown in Table 3.3.1.

The feature that is missing from the GLM is the social nature of learning, because the GLM was initially a personal learning model rather than a social one. However, the GLM encompasses the social aspect to learning if one assumes that sensory input can include input from others within the social group of the learner.

Table 3.3.1: Generative Learning Model and the Features of a Constructivist Approach to Science Learning

Number	Constructivist Feature	Feature in the GLM
1	Meaningful learning rather than rote learning.	Reference to construction and reconstruction of meaning.
2	Pupils come to classes with prior knowledge.	Reference to pupils' existing memory store.
3	Pupils learn in an active way.	Reference to pupils' active selection and attention and to processing of information.
4	Information new to pupils is either (a) assimilated; or	Reference to linking new concepts to those already in the learner's cognitive structure.
	(b) accommodated.	Reference to altering the learner's existing structure.
5	Pupils need to become dissatisfied with their non-science concepts before they can accommodate currently accepted scientific concepts.	This occurs if the new concept is not readily assimilated into the learner's existing memory store - if the learning is to be meaningful rather than by rote.
6	Pupils are more likely to adopt new science ideas if those ideas are intelligible, plausible and fruitful.	Acceptance into long-term memory requires that concepts be intelligible, plausible and fruitful.
7	Learning is a social activity.	

As was noted in section 3.3.9, the GLM is familiar to the researcher and appears to be successful within the context of his own learning and that of his students. For the researcher, the GLM makes sense in terms of:

* dissatisfaction with the learning outcomes when previously accepted models were utilised;
* intelligibility in that it is understood;
* plausibility in that it relates to the researcher's and others' learning difficulties and successes;
* fruitfulness in that it explains previous learning successes and difficulties while predicting future enhanced learning.

The GLM thus acted as an initial stimulus for designing the proposed astronomy intervention. That is, pupils' prior astronomy mental models and concepts need to be articulated and shared among members of small groups and the whole class. While each idea is likely to be intelligible to its holders it is expected that a number of different ideas will emerge from this process, which will encourage a degree of conceptual conflict. For meaningful learning to occur, the different ideas must be subjected to a process by which the competing mental models and concepts can be critiqued in terms of their intelligibility, their plausibility, their fruitfulness and their acceptability in the social setting of the classroom.

3.4 TOWARDS TEACHING ASTRONOMY

3.4.1 Introduction

Section 3.4 reviews teaching models which have arisen in the constructivist tradition, especially with regard to their potential utility in a process-driven approach to astronomy education. A teaching-learning approach will be described and advocated in this section that takes as an important starting point that learners' prior views must both be ascertained and acted upon. Also, it needs to be appropriate for the emerging features of the planned astronomy intervention. The discussion will be in the following sequence:

* the role of the science teacher (section 3.4.2);
* general features of constructivist-based teaching (section 3.4.3);
* some constructivist-based teaching models (section 3.4.4);
* A constructivist-based teaching model for the astronomy intervention (section 3.4.5).

3.4.2 The Role of the Science Teacher

From a constructivist perspective, the role of the teacher changes from a more transmissive mode (Dykstra, Boyle and Monarch, 1992; Davis, McCarty, Shaw and Sidani-Tabbaa, 1993; Hand and Vance, 1995) to one that encourages pupils to re-construct their own meanings closer to the currently accepted scientific idea (Bell, 1994; Leach and Scott, 1995). This involves a change in teachers' professional beliefs and practices rather than merely applying a new strategy (Ritchie, 1994) as they become responsible for providing the learning environment that best facilitates the restructuring process (Walters and Boldt, 1970; Zuzovsky, 1994; Ritchie, 1994) through a method of inquiry (Hand and Vance, 1995).

For that, the teacher must act as a mediator of learning between the world of science and the pupils' world (Adey, 1992; Ritchie, Tobin and Hook, 1997) so that the teacher becomes a facilitator of learning (Watts and Pope, 1989; Dykstra, Boyle and Monarch, 1992; Vance, Miller and Hand, 1993; Krueger, 1994). Correspondingly, the teacher must know both those worlds (McElwee, 1991) in order to be alert to pupil conceptual difficulties (Milkent, 1977) and to provide a safe, non-threatening and supportive learning environment (Lloyd and Wallace, 1996) which encourages pupils to put forward and discuss their own ideas (Appleton and Asoko, 1996) and allows time for the reflection process to occur (Ebenezer and Gaskell, 1995; Hand and Vance, 1995).

That is, teachers have to provide opportunities for pupil input into what is learned and how it is learned (Hand and Vance, 1995), for pupils to become aware of their own ideas and those of their classmates and for pupils to modify their own ideas when necessary (Watts and Pope, 1989; Ritchie, Tobin and Hook, 1997).

Bell (1993a) summarised the above ideas to outline the multi-faceted role of the constructivist teacher as being to:

* create a supportive and caring environment;
* motivate pupils to learn;

* find out what the pupils think about the topic;
* accept pupils' ideas;
* help pupils clarify and reflect on their own ideas;
* promote inter-pupil discussion;
* give feedback;
* challenge pupils' concepts;
* help pupils change their concepts towards the scientists' concepts;
* be a co-researcher and learner;
* provide resources;
* be a manager and organiser;
* plan the curriculum.

3.4.3 General Features of Constructivist-based Teaching

Finding and Comparing Pupils' Prior Concepts

Constructivist teaching-learning approaches propose that school science should begin with a determination by the teacher of the science concepts held by pupils in her or his classroom (Hewson, 1981a; Osborne and Wittrock, 1983; Osborne, 1984; Ridgeway, 1988; Bishop and Anderson, 1990; Loudon and Wallace, 1990; Hill and Edwards, 1992; Krueger, 1994; Hand and Vance, 1995; Hennessy, Twigger, Driver, O'Shea, O'Malley, Byard, Draper, Hartley, Mohamed and Scanlon, 1995a; Perales and Nievas, 1995; Appleton and Asoko, 1996; Ebenezer and Erickson, 1996; Lloyd and Wallace, 1996; Osborne and Simon, 1996; Palmer, 1996; Pereira, 1996; Taber, 1996; Christidou and Koulaidis, 1996; Ritchie, Tobin and Hook, 1997). This process is to provide a sound base on which to help pupils build the scientists' concepts (Nussbaum, 1981; Clough and Driver, 1985; Wildy and Wallace, 1995).

The elicitation of pupils' concepts is based on the assumption that those concepts are identifiable and stable (Clough and Driver, 1986). While West and Fensham (1974) noted that misconceptions in learning can be explored, Sutton (1980) pointed out that there are difficulties in doing so, and Dykstra, Boyle and Monarch (1992) noted that concepts can only be identified indirectly.

Concept analysis needs to identify the presence or absence of the critical attributes that determine any concept (Herron, Cantu, Ward and Srinivasan, 1977; MacGuire and Johnstone, 1987). In addition, any procedure that is advocated as a process for eliciting pupils' concepts must satisfy the criteria of validity, reliability and usability (Gronlund, 1971). Also, no one method is likely to reveal the complex, and probably changing, concepts of pupils (Dykstra, Boyle and Monarch, 1992).

In practice, diagnosis of pupils' concepts is rarely carried out as part of regular teaching (Fetherstonhaugh and Treagust, 1992) because it is difficult and time-consuming (Tobin and Fraser, 1988). For this, teachers need training in diagnosing pupils' concepts (Nussbaum, 1981). An alternative would be teacher use of learner concepts revealed by research, such as the astronomy concepts discussed in section 2.5. However, caution is

required when transferring findings from a general population, or from research on a class in a specific context, to the particular class being taught (Song and Black, 1991).

In addition, the instruments should be appropriate to the cognitive stages of development of the pupil (Stanbridge, 1990), research should not be undertaken in a vacuum of presuppositions (Sutton, 1980), assessment items must be conceptually focused (Hand and Vance, 1995) and there should be awareness that all measurements perturb the object of measurement (Sutton, 1980), as in Heisenberg's Uncertainty Principle.

The conclusion to be drawn from the above is that teachers and researchers need to utilise a variety of methods to elicit pupils' concepts (Hand and Vance, 1995; Pearsall, Skipper and Mintzes, 1997). The variety of methods is explored further in chapter five, where reasons are offered for the approaches selected for this research.

Expressions of pupil's concepts will lead to comparison with other views in the classroom (Osborne, 1982; Bell, 1993a). Pupils, however, must feel secure before they will voluntarily expose their ideas to possible ridicule. That is, a supportive classroom environment is an important factor in teaching (Pope and Gilbert, 1983; Watts and Gilbert, 1983; Driver, 1989) if intellectual development is to be enhanced (Westbrook and Marek, 1991). On the other hand, such a pedagogical approach is not without its dangers. For example, there may be an almost impossible contradiction for teachers if they talk to the pupils in language familiar to them while at the same time attempting to negate the very concepts explicated by that language (Louisa, Veiga, Costa Pereira and Maskill, 1989).

Challenging Pupils' Prior Concepts

There will usually be differences of viewpoint among pupils, implying that competing concepts have to be evaluated, compared and challenged (Hewson, 1981a; Osborne, 1982; Strike and Posner, 1982; Osborne and Wittrock, 1985; Krueger, 1994; Hennessy, Twigger, Driver, O'Shea, O'Malley, Byard, Draper, Hartley, Mohamed and Scanlon, 1995a; Appleton and Asoko, 1996; Lloyd and Wallace, 1996; Osborne and Simon, 1996). The teacher's aim in challenging pupils' alternate concepts is to encourage conceptual development by tactics such as the promotion of dissatisfaction with the pupils' non-scientists' ideas (Koumaras, Kariotogloy and Psillos, 1996). This is to lower the status of any alternate concepts and to raise the status of the scientists' concept (Lijnse, 1995). A sensitive approach is clearly called for (Taber, 1996). That is, an aim is to generate cognitive development, often by challenging the prior concepts of those pupils holding non-scientists' views (Champagne, Gunstone and Klopfer, 1983; Dibar Ure and Colinvaux, 1989; Wheatley, 1991; Saunders, 1992; Krueger, 1994; Hand and Vance, 1995; Milne and Taylor, 1995; Ritchie, Tobin and Hook, 1997), and to subvert such views (Terry, Jones and Hurford, 1985).

Niaz (1995) noted that such challenges can be induced by use of a result which contradicts pupils' expectations, by the generation of puzzlement or a feeling of unease about an idea, by a conflict in their minds, by simple curiosity, by experiencing a

cognitive gap, or by disequilibria. Appleton (1997) reported that discrepant event strategies often induce cognitive challenges for the learner but pointed out that multiple experiences of accommodation are necessary to encourage major changes to a learner's cognitive structure.

This is not an easy or self-evident task (Head, 1986; White and Gunstone, 1989; Solomon, 1994). Teachers need to provide classroom learning experiences which illuminate inconsistencies and anomalies with pupils' alternate concepts (Strike and Posner, 1982; Osborne and Bell, 1983). That is, what are often described as discrepant events need to be employed by teachers (Hesse and Anderson, 1992; Benson, Wittrock and Baur, 1993; Taber, 1996). An example is when magnesium ribbon is burned and it produces ash that weighs more than the original magnesium.

The challenges proposed by the teacher need at some stage to be resolved by the class with development towards a consensual view (Wheatley, 1991). Hill and Edwards (1992) suggested that an appropriate strategy for this is having pupils operate in small groups and encouraging pupils to propose the questions to be investigated. The teacher then becomes a co-investigator and a model of the scientific process (Strike and Posner, 1982). Adey (1992) noted that such an approach is at the core of the Children's Learning in Science Project, CLISP, adding that the approach encourages pupils to share their current concepts and then to design critical tests of the alternatives revealed. Part of the investigative process is thus handed on to the learners, with appropriate teacher guidance.

Exploring the Implications of Pupils' and Scientists' Concepts

A further necessity in a teaching strategy based upon constructivist ideas is that a phase needs to be included in which pupils predict and explore implications that arise from their initial concepts (Osborne and Bell, 1983; Watts and Gilbert, 1983; Dawson and Rowell, 1995; Koumaras, Kariotogloy and Psillos, 1996). Explorations need to be followed by application of the new ideas to explain phenomena and contexts not previously understood (BouJaoude, 1992; Hand and Vance, 1995; Hennessy, Twigger, Driver, O'Shea, O'Malley, Byard, Draper, Hartley, Mohamed and Scanlon, 1995a; Perales and Nievas, 1995; Palmer, 1996; Lloyd and Wallace, 1996) and in a broad range of situations (BouJaoude, 1992; Dawson and Rowell, 1995).

Overall

In essence, there is a general pattern developing for teaching sequences which resonate with a constructivist view of learning. Attempts are made to elicit the pupils' concepts, and then to challenge those ideas by a variety of interventions which are designed to encourage the learners to find the sense and the fruitfulness in the scientists' concepts. That is, in order to encourage a change from the diverse range of pupils' concepts towards the generally accepted scientists' concept, the teacher utilises a wide range of interactions and experiences which reflect the scientists' view. The introduction of the scientists' concept is only one of the strategies introduced by the teacher. This is a key difference between the constructivist and transmissive approaches to teaching.

However, Adey (1992) cautioned that the teaching approach is difficult for both teachers and pupils. Current research does not offer clear guidance to classroom teachers on how to effect cognitive change (Cross and Pitkethly, 1991). Much of the relevant research has been conducted in small groups and researchers are less sure about the effectiveness of the approach when teaching a whole class (Millar, 1989). Thus teachers who apply teaching methods based on constructivist theories are themselves researchers and learners (Davis, McCarty, Shaw and Sidani-Tabbaa, 1993).

3.4.4 Some Constructivist-based Teaching Models

A variety of constructivist-based teaching models has been generated. Some of these are shown in Table 3.4.1, with brief outlines of their structure.

Table 3.4.1: Some Constructivist-based Teaching Models

Year	Reference	Brief Description
1979	Erickson	Experiences - clarification - anomaly - restructuring.
1983	Rowell & Dawson	Find pupils' prior views - introduce scientists' ideas - teach new idea by linking to prior ideas.
1985	Bell, Watts & Wilson	CLISP: pupils' prior ideas - explore - reflect - reformulate ideas.
1986	Pines & West	Awareness - disequilibrium - reformulation.
1988	Van Hise	Pupils' ideas - intervention - application.
1988	Faire & Cosgrove	Interactive Teaching Sequence (ITS): pupils' before views - exploratory activities - pupils' questions - investigations - pupils' after views - reflection.
1990	Appleton	Pupils' prior ideas - focus - challenge - application.
1990	Gunstone	Predict - Observe - Explain (POE).
1991	Utting	Reformulation of ITS model.
1992	Tasker	Generative Teaching Model (GTM): preparation - exploration - pupils' questions - investigations - reflection.

A constructivist approach was at the heart of the LISP teacher education programme (Bell, 1993a and 1993b), both in the focus on pupils as learners who construct their own knowledge and concepts and in the sense that the teachers involved in this in-service programme would likewise re-construct their own concepts about effective ways of teaching science. Bell reported that two teaching approaches were suggested to the teachers as meeting the requirements of a concept change approach. These were the Generative Teaching Model (GTM) and the Interactive Teaching Sequence (ITS).

Key activities in the ITS model are eliciting and selecting pupils' questions and using them as the starting point for developing investigations (Tasker, 1992; Bell, 1993a and 1993b). While the ITS model was developed with primary teachers in mind (Tasker, 1992), Bell and Pearson (1991 and 1992) reported in-service courses with primary, intermediate and secondary teachers in New Zealand that used and investigated the teachers' use of an interactive teaching approach. The teachers generally reported favourably about 'better learning', more pupil co-operation, pupil ownership of concepts

and increased motivation and confidence levels among their pupils. However, Bell and Pearson (1992) advise caution in that teachers may equate better learning conditions, such as increased numbers of pupil questions, with better learning outcomes .

3.4.5 A Constructivist-based Teaching Model for the Astronomy Intervention

The Generative Teaching Model (GTM) (Tasker, 1982), as with the generative learning model, is familiar to the researcher, makes sense to him in the context of teaching his students and acted as an initial stimulus for the development of the teaching model discussed in chapter four. Its name indicates a link with the generative learning model discussed in section 3.3. Furthermore it reflects the features introduced at the start of section 3.4, that a constructivist teaching model should include the main features of constructivist learning. That is, the GTM must be seen to include:

* finding and comparing pupils' prior views;
* challenging pupils' prior concepts;
* exploring the implications of pupils' and scientists' concepts.

There is some limited research support for the utilisation of the GTM (Conforto and Mayer, 1984; Barker and Carr, 1989a and 1989b; Fetherstonhaugh and Treagust, 1992). That is, the GTM may be an appropriate stimulus towards an approach for teaching astronomy.

Adoption of the GTM as the stimulus for constructing an astronomy intervention necessitates that the proposed intervention must include the following features:

* a **focus** phase in which pupils' astronomy concepts are articulated;
* a **challenge** phase in which each astronomy concept is made public within the group and whole class situation. Then the intelligibilty and plausibility of each concept are examined with a view to the adoption of the one that is most meaningful to the groups and class;
* an **application** phase in which groups of pupils explore the fruitfulness of the astronomy concepts that appear to be the most meaningful.

In addition, the astronomy intervention must:

* address the perceived difficulties in teaching and learning astronomy (see section 2.4);
* address the alternative astronomy concepts that pupils come to school with (see section 2.5);
* address the role of models in developing astronomy mental models and concepts (see section 2.6);

3.4.6 Summary of Section 3.4

Section 3.4 has considered possible approaches to teaching astronomy that are based on the generative learning model selected in section 3.3, which is itself based on constructivist approaches to teaching science. However, little research appears to have

been conducted in regard to their efficacy within normal classrooms, particularly with regard to teaching astronomy.

The GTM approach reflects features of both constructivist theory and the guidelines of the generative learning model. Furthermore, it is a familiar model within the researcher's research community. It serves, then, as the basis for the proposed astronomy intervention, with modifications to cater for the researcher's special needs in designing an astronomy intervention to help pupils construct their astronomy mental model by way of a process-based approach.

A cautionary note is required in that much more research is required, in all areas of the science curriculum and across all age groups, before the efficacy of the generative learning model and its associated generative teaching model approach can be properly evaluated. This study will add to that data.

3.5 PUPILS AND MENTAL MODEL BUILDING

3.5.1 Introduction

Section 2.6 outlined the role of mental models in helping astronomers generate theories and explanations. It also commented on how, conversely, mental models are rarely used in astronomy education. The section also noted the close relationship between mental model making and the development of concepts. It also discussed the essential use of models in this process by both scientists and science teachers. However, research into their effective use in science teaching was limited, particularly in astronomy education. This section considers the possibility that astronomy mental models can be constructed by pupils with the aid of appropriate models. Much of the literature uses a variety of overlapping terms in this area. As in section 2.6, the term *mental model* denotes the way related concepts are organised in a learner's cognitive structure and the term *model* denotes the way in which the mental model is overtly expressed.

Discussion in this section is presented in the following sequence:

* models available to astronomy teachers (section 3.5.2);
* learners, mental models and models (section 3.5.3);
* effective use of models in science teaching (section 3.5.4);
* bridging strategies (section 3.5.5);
* teaching using models (section 3.5.6).

3.5.2 Models Available to Astronomy Teachers

Tables 3.5.1 and 3.5.2 were constructed from a literature review which determined the types of model available to science teachers. It states examples of each type. For instance, an example of a verbal model is the Bohr model of the atom, described as being like a miniature solar system.

Table 3.5.1: Types of Model Available to Science Teachers: Part A

Name	Example	Reference	Year
Physical	Half-life and tossing coins.	Treagust, Duit, Joslin & Lindauer	1992
	Air compressibility & bath sponges.	Treagust, Duit, Joslin & Lindauer	1992
	Ball and stick models of atoms.	Gabel & Sherwood	1980
Verbal	Electric current and trains.	Dupin & Johsua	1989
	Electric current and water.	Stocklmayer & Treagust	1996
	Mole and reams of paper.	Thiele & Treagust	1991
	Electron clouds & propellors	Treagust	1993
	Bohr atom model and solar system.	Thagard	1992b
	Atomic energy levels and vertical book case.	Treagust	1993
Personal	Energy transfer in electric circuits by passing of a biscuit round a circle of pupils.	Treagust	1993
	Pupils as atoms in chemical bonding.	Treagust	1986
Models	Wave motion & ripple tanks.	Lunetta & Hofstein	1981
	Chromosomes as pop-bead models.	Treagust, Duit, Joslin & Lindauer	1992
	Atomic models of toothpicks and marshmallows.	Dyche, McClurg, Stepans & Veath	1993
	Potential Difference and nail model.	Turley	1994a
	Standing waves model.	Turley	1994b
	Protein synthesis models.	Mensch & Rubba	1991

Tables 3.5.1 and 3.5.2 show that there is a variety of models available to educators. Section 2.6 noted, however, that they are not widely used in astronomy education. The two tables illustrate that models in astronomy education feature mainly in the area of computer simulations. However, other proposed uses of models in astronomy education include the celestial sphere and planetaria such as 'Star Lab' (Tebbutt, 1994) and scaled pencil-and-paper models of the solar system (Joslin, 1988). However, it is not possible to visually model the solar system in a classroom using the same size and distance scales, so the use of that particular model could mislead pupils.

Table 3.5.2: Types of Model Available to Science Teachers: Part B

Name	Example	Reference	Year
Pictures	Hydrological cycle.	Koran & Koran	1980
	Periodic table of elements.	Lehman, Koran & Koran	1984
	Electrochemistry.	Alesandini & Rigney	1981
	Food chain.	Winn	1980
Computer	Modular physics.	Gillis, Sinclair & Swithenby	1996
	Menstrual cycle.	Hartley	1976
	Waves.	Hartley	1976
	Raft Away River.	Oliver & Okey	1986
	Cat Genetics.	Kinnear, Martin & Novak	1982
	Volume and displacement.	Choi & Gennaro	1987
Computer Spreadsheet	Planetary orbits.	Bridges	1995a
	Jupiter's moons.	Bridges	1995b
Computer Databases	Ecology.	Maor	1990
Videos	Kinematics.	De Yong	1983
	Chemical reactions.	Lynch & Shadbolt	1988
Films	PSSC Physics.	Woodman	1972
Games	Scientific Inquiry.	Romesburg	1979
	Life Sciences.	Lunetta & Hofstein	1981
	Biology.	Spraggins & Rowsey	1986

Literature reviews about the educational effectiveness of models have not been encouraging and Lunetta and Hofstein (1981) were of the view that direct experiences for learners are preferable to indirect ones. However, as noted in section 2.6, many of astronomy education's fundamental mental models are not amenable to experimental manipulation. Consequently, astronomy relies on modelling and model-based reasoning to explain and to predict (Raghavan and Glaser, 1995). Indirect methods must often be utilised to help learners develop astronomy concepts.

Astronomy education, then, uses physical models such as the orrery for pupils to explore features of the mental models of the Sun-Earth-Moon system. It also uses diagrams such as ones of the phases of the Moon, and computer simulations such as those that provide time-lapse illustrations of the effects of the Sun and Moon on tides.

3.5.3 Learners, Mental Models and Models

Scientists and researchers use many models, physical and otherwise, to build mental models which interpret and explain their world (Weck, 1995). That is, modelling is a fundamental science activity by which people simplify the complexities of the real world (Paton, 1996). In education, models appear to be valuable tools in conceptual change learning (Treagust, Duit, Joslin and Lindauer, 1992) in that they are believed to provide visualisation of abstract concepts by comparing similarities between learners' existing concepts and the new concept and by increasing motivation (Treagust, 1993).

Duit (1991) stated that there is an abundance of empirical evidence that the use of models often fails because learners do not properly understand or appreciate them. He said that models were only employed by learners when they felt that it was necessary to use them to help their understanding. Stocklmayer and Treagust (1996) concluded that learners use very few meaningful models.

Osborne and Gilbert (1980b) noted that some learners tended to think that models such as solar system ones were scale models of reality. Teaching with models has limitations if learners (or teachers) take the model literally (Zeitoun, 1984). In South Africa and Namibia, Smit and Finegold (1995) surveyed 196 secondary science student teachers to elicit their ideas about models. Almost half the student teachers saw models as representing mental models and about a third saw them as helping in the development of knowledge. But most of them had the view that models are merely a copy of a real thing. Such a view would clearly attenuate a teacher's attempts to use models to develop learners' concepts.

Osborne and Gilbert (1980b) and Gilbert and Osborne (1980) reported that the effect was due to the fact that learners may lack awareness of the boundaries between the model and the reality the model is representing. Dyche, McClurg, Stepans and Veath (1993) supported this in observing that many middle grade pupils in the USA remembered a solar system model rather than the concept it represented.

Treagust, Duit, Lindauer, and Joslin, (1989) pointed out that model-based reasoning is only effective if learners see the models in the way intended by the teacher. In addition, many learners may learn the model rather than the concept it is meant to illustrate (Thiele and Treagust,1991) and learners sometimes become unable to separate the model from the topic being learned. Other pupils forget the topic and only remember the model, while others focus on unwanted aspects of the model to form wrong conclusions (Treagust, 1993). Thus ill-considered use of models may actually aid the generation of alternative concepts (Stavy, 1991; Treagust, 1993).

3.5.4 Effective Use of Models in Science Teaching

A helpful teaching sequence which uses models, then, becomes an attempt to convince pupils that some situations which they already understand are analogous to other situations which they misunderstand (Stavy, 1991). That is, an effective tactic is to utilise a model which facilitates access to the misunderstood concept by emphasising the similarities between the model and the idea being taught (James, 1983; Treagust, 1993). Duit (1991) argued that advantages of using models include that they:

* assist in conceptual change learning;
* assist in understanding of abstract ideas;
* provide visualisation of abstract ideas;
* motivate pupils.

Teachers ought to encourage pupils to note not only the strengths of a model but its

limitations (Hesse, 1966). Yet this can also be a source of difficulty for some pupils in that the unshared attributes are often a cause of misunderstandings for learners (Thiele and Treagust, 1991). For example, transmissive use of an orrery could encourage pupils to think that we experience solar and lunar eclipses every month.

Teachers may include a variety of models in an attempt to overcome such difficulties, but this can also be a source of confusion to pupils when they see the same target concept replicated in different forms (Osborne and Gilbert, 1980a). An example of this is when atomic structure is first represented as a miniature solar system and later by a rotating propellor.

Clearly it is important that researchers examine how models can promote learners' acquisition of mental models and concepts. Although most of the research so far has been conducted without any explicit consideration of possible alternative concepts by pupils (Brown, 1994), there has been limited indicative and promising research (Lunetta and Hofstein, 1981; Gabel and Sherwood, 1984; Friedel, Gabel and Samuel, 1990; Thiele and Treagust, 1991; Treagust, 1993; Gilbert, 1994). For example, Treagust (1993) commented that when in-service science teachers were systematically taught to use models in their teaching their pupils' science understanding subsequently became more compatible with scientists' views.

In particular, there has been very little research into models in astronomy education. In the USA, Atwood and Atwood (1995) investigated night and day concepts of fifty primary student teachers. The student teachers, who were observed using models to demonstrate the concept, reported positive effects of the use of models in teaching astronomy.

An observation made by Raghavan and Glaser (1995), after using their Model-Based Analysis and Reasoning (MARS) approach with grade six children in the USA, was that the approach required more class teaching time than is usually spent in covering topics. This conclusion was supported in the UK by Hennessy, Twigger, Driver, O'Shea, O'Malley, Byard, Draper, Hartley, Mohamed and Scanlon (1995b) and by Doerr (1997) in the USA, who estimated that a unit which normally was completed in 10 to 12 lessons needed 35 lessons when teaching via a mental model-building approach.

There is no universal agreement as to the effectiveness of models in promoting science learning. Nevertheless, Duit (1991) was of the view that there is substantial support that model-based reasoning can, given the right conditions, facilitate meaningful learning. In agreeing, Brown (1994) noted mounting evidence that models play an important role in facilitating pupil learning.

3.5.5 Bridging Strategies

The role of the teacher, then, is to provide an interpretive bridge between pupils' prior knowledge and the science concept to be developed (Zeitoun, 1984). Such a bridge can be introduced more meaningfully by use of models (Thiele and Treagust, 1991; Treagust,

1993). Duit (1991) noted that research results as to their effectiveness were promising and that the approach was generally based on a constructivist framework, but cautioned that the use of bridging strategies is not an easily learned skill. The procedure is for teachers to use models that are already familiar to the pupils and to make clear the correspondence between the models and the target (Thagard, 1992b). Hesse (1966) adds that the non-correspondences also should be made clear.

Research by Brown (1994) and by Kaufman, Patel and Magder (1996), although not in astronomy education, suggest that a bridging approach using models may have potential in helping the development of pupils' astronomy concepts.

3.5.6 Teaching Using Models

Weller (1970) proposed that models have a legitimate role to play in teaching. However, they can just as easily be used in a transmissive way as in a way reflecting constructivist approaches. For example, an orrery can be used by the teacher to describe and explain the Sun-Earth-Moon system or it can be used by pupils to investigate it.

If a constructivist model of teaching using models is to be developed from the above research and theory then the parameters need to be clearly elicited. One such parameter is that pupils not yet familiar with using models in their learning should be given an introduction to them (Zeitoun, 1984; Friedel, Gabel and Samuel, 1990). Thagard (1992b) and Albanese, Neves and Vicentini (1997) noted the importance of the teacher making clear to pupils the correspondences between the model and the target. Gilbert and Osborne (1980), Hesse (1966), Thiele and Treagust (1991) and Thagard (1992b) advocated that where the target and model do not overlap also needs to be made clear to pupils.

Gilbert and Osborne (1980) developed a model-based approach to teaching. It included the aspect of eliciting pupils' prior views but suggested only a small role for pupils in examining a model for its positive and negative features. There need to be more classroom discussions of models to increase awareness of their limitations (Venville, Bryer and Treagust, 1994; Ritchie, Tobin and Hook, 1997).

After noting that there was no common view for teaching with models, Zeitoun (1984) proposed his General Model of Analogy Teaching (GMAT). A key feature was based on constructivist teaching-learning approaches in that whenever pupils encounter a new topic they attempt to interpret it in terms of their existing concepts. His model included a step in which pupils' prior ideas are elicited, but the teacher, rather than pupils, identifies the positive and negative attributes of the model.

Similarities between the concept to be developed and what is already known must be drawn, preferably by the pupils (Duit, 1991), and teaching should preferably be based on models generated by the pupils rather than by the teacher or texts (Lind, 1980). To this end, Wong (1993) suggested a teaching plan based on constructivist approaches to help pupils generate their own models.

Many of the ideas in the models of Osborne and Gilbert, Zeitoun and Wong were incorporated into the model (see Table 3.5.3) proposed by Glynn at the University of Georgia in 1991.

Table 3.5.3: Glynn's 1991 Model of Constructivist Teaching Using Models

1	Introduce the target concept to be learned.
2	Cue the pupils' memories of the analogous situation.
3	Identify the relevant features of the target concept and the model.
4	Map out the similarities between the target concept and the model.
5	Draw conclusions about the target concept.
6	Indicate where the model breaks down.
	(Treagust, 1993)

Glynn's model appears to be transmissive in style. Pupils' prior or post concepts are not elicited, the teacher appears to tell the pupils the positive and negative features of the model and the essential parts of intelligibility, plausibility and fruitfulness are absent. Item 6, however, could be used to develop cognitive conflict.

There is little research to validate or otherwise the Glynn model, although Treagust (1993) and Treagust, Harrison and Venville (1996) reported that this teaching approach was effective in enabling Year 10 Australian pupils to better understand refraction of light. Also, Lin, Shiau and Lawrenz (1996) reported that learning of density and pressure by 225 Year 8 pupils in Taiwan was enhanced by using Glynn's approach.

Harrison and Treagust (1994) reported that their research with the systematic use of models in teaching science suggested fruitfulness in reducing pupil misconceptions and in enhancing their understanding. While supporting Glynn's model in most respects, particularly in that pupils were more comfortable with their concepts after the teacher had identified the shared attributes of the model used, they found that steps 2, 4 and 5 were not effective with respect to pupils' understanding.

Treagust (1993) utilised Glynn's idea of model teaching by using the rotating propellor model to represent electrons around a nucleus. He noted that those teachers who had used models most effectively had reversed steps 5 and 6 of Glynn's model. Thus he adapted the model to a simpler and apparently more effective and efficient three-phase model shown in Table 3.5.4. There is a clear resemblance to the GTM.

Table 3.5.4: Treagust's 1993 Adaptations of Glynn's Model of Constructivist Teaching Using Models

FOCUS		
	CONCEPT	Is it difficult, unfamiliar or abstract?
	PUPILS	What ideas do they already have about the concept?
	MODEL	Is it something the pupils are familiar with?
ACTION		
	LIKES	Discuss the features of the model and the science concept. Draw similarities between them.
	UNLIKES	Discuss where the model is unlike the science concept.
REFLECTION		
	OUTCOMES	Was the model clear and useful, or confusing?
	IMPROVEMENTS	Refocus as above in light of the outcomes.
		(Treagust,1993)

The Focus, Action and Reflection phases were to help teachers maximise the advantages and minimise the disadvantages of models when used in teaching (Treagust, 1993). This model appears to be more discovery-orientated in nature than constructivist although it introduces the potentially valuable Reflection phase. While it includes the ideas of eliciting pupils' prior concepts, it suggests that it is the teacher's role to draw out the positive and negative features of any model introduced.

3.5.7 Summary of Section 3.5

Section 3.5 has considered the use of models in astronomy education. While there is limited research into their effective use with respect to astronomy education, there is some encouraging evidence as to their usefulness in other areas of science education. It appears that pupils' construction of astronomy mental models may be facilitated by the use of models which bridge the gap between the pupils' prior ideas and astronomers' mental models and concepts. Furthermore, the approach is not inconsistent with constructivist-based approaches in general. Treagust's amended version of Glynn's model has promise in assisting pupils' development of mental models. However, an approach for this study needs to pay more attention to pupils' competing concepts and their resolution by way of reasoned pupil debate in light of each idea's intelligibility, plausibility and fruitfulness.

The above also suggests that the process of using models to help pupils construct scientists' mental models might be a bridge between extreme positivist and constructivist viewpoints. That is, the positivist view that there are knowledge and concepts 'out there' to be learned can be integrated with the constructivist view that individuals generate their own unique concepts. Models such as the orrery have a part to play in this process.

3.6 ASTRONOMY TEACHING AND *SCIENCE IN THE NEW ZEALAND CURRICULUM*

3.6.1 Introduction

Section 3.6 inquires whether *Science in the New Zealand Curriculum* does, in fact, permit and/or encourage an effective approach to teaching astronomy, as developed in the preceding sections of chapter three. The proposed astronomy intervention needs to be congruent with the official curriculum document if its findings are to be acceptable to New Zealand teachers. This section, then, investigates the extent to which an effective teaching approach is explicit and implicit in *Science in the New Zealand Curriculum*. It further discusses the extent to which a constructivist-based approach could enhance delivery of the document. The discussion is presented in the following sequence:

* constructivism and the science curriculum (section 3.6.2);
* investigations and the science curriculum (section 3.6.3);
* the Generative Teaching Model and *Science in the New Zealand Curriculum* (section 3.6.4);

3.6.2 Constructivism and the Science Curriculum

The word *constructivism* is not mentioned in *Science in the New Zealand Curriculum* (Ministry of Education, 1993b). However, in light of the discussion in sections 3.2 to 3.5, the phrase *Making Sense of...* for all four of the contextual strands and one of the two integrating strands is seen by the researcher to have a similar meaning. In addition, the document specifically refers to science being constructed by people (p.9), both historically and philosophically (p.11).

This impression is supported by the frequent references to learners and their learning rather than to them receiving knowledge and concepts from teachers. Every achievement aim is stated in terms of what ideas the learners might construct or develop. For example, the overall Achievement Aim for the astronomy part of Planet Earth and Beyond is:

> In their study of planet Earth and beyond, students will use their developing scientific knowledge, skills, and attitudes to:
>
> 3 investigate and understand relationships between planet Earth and its solar system, galaxy, and the universe;

(Ministry of Education, 1993b, p.106)

The above figure shows that the learning is to be meaningful rather than by rote, in that pupils are to "investigate and understand". In addition, on page 9 there is a reference to pupils' development of "a coherent understanding" of science rather than just science knowledge or even merely an understanding of science. Elsewhere in the document there is reference to "successful learning" (p.11) and "effective learning" (p.17). In addition, the document points out that the teaching-learning is based on "findings from recent research into learning in science", much of which has been described in sections 3.2 to 3.4 as being constructivist in nature.

3.6.3 Investigations and the Science Curriculum

Further evidence of the implied support for a constructivist-based learning approach is to be found in the extent to which the document recommends that the pupils find and generate knowledge and ideas by investigations rather than by having information transmitted to them. While the term *investigations* does not explicitly support the learning and teaching approach outlined in earlier sections, it clearly suggests a more interactive approach than is expected with a transmissive or a guided discovery approach. The term *investigate* was used in the overall Achievement Aim for astronomy and it recurs in every group of Achievement Aims for every strand. That is, a major aim of *Science in the New Zealand Curriculum* is that pupils "develop skills for investigating" (p.9), which are seen as being essential for successful learning in science (p.11) because science is seen as an integration of investigation skills and ideas (p.14). That is, it is clear that the document is not considering a guided discovery or a process model of teaching-learning, although it does not specifically exclude those models.

3.6.4 The Generative Teaching Model and *Science in the New Zealand Curriculum*

The teaching-learning model described in sections 3.3 and 3.4 reported that the necessary conditions for pupils to change their prior ideas towards scientists' ideas include that the pupils' ideas will be made explicit and then challenged. After that, the scientists' idea has to be seen as being intelligible, plausible and fruitful for its acceptance.

Science in the New Zealand Curriculum (p.10; p.11; p.12; p.21) encourages enhancement of learning by the process of all pupils stating their prior ideas in an atmosphere of mutual respect. The pupils are then to be encouraged to share their prior ideas (page 10) from the full range of perspectives within the class (p.11).

The concept change approach of modification of concepts towards scientific understandings is encouraged on page 10 within contexts which are familiar to the pupils to enhance the possibilities of plausibility. Intelligibility is also to be encouraged (p.11; p.12).

A further condition for concept change, fruitfulness, is advocated on page 17, with a recommendation that new concepts and skills should be applied first to familiar contexts, and later in other *novel situations* (researcher's emphasis).

3.6.5 Summary of Section 3.6

Science in the New Zealand Curriculum emphasises interactive approaches in which the pupils investigate phenomena to build their astronomy mental models and concepts from their shared prior ideas and experiences. Section 3.6 has shown that at the very least there is no conflict between *Science in the New Zealand Curriculum*'s achievement aims and achievement objectives and constructivist-based approaches to learning described in sections 3.3 to 3.4. It appears that a teaching approach developed from the impetus of the

Generative Teaching Model has potential to enhance delivery of the astronomy strand of *Science in the New Zealand Curriculum*. In addition, the level four astronomy achievement objective 3(b) specifically indicates that the development of pupils' ideas might be better facilitated by the use of models. Particular models proposed, as discussed in section 3.5, may include the orrery, computer simulations and diagrams.

3.7 CHALLENGES TO EFFECTIVE TEACHING OF ASTRONOMY

3.7.1 Introduction

Sections 1.5 and 2.4 discussed challenges faced when teaching astronomy in traditional ways. This section discusses some of the particular difficulties that arise when teaching science in general, and astronomy in particular. The difficulties are discussed in the following sequence:

* teachers' science concepts (section 3.7.2);
* teachers' astronomy concepts (section 3.7.3);
* teacher acceptance of constructivist-based approaches (section 3.7.4);
* astronomy investigations in the New Zealand curriculum (section 3.7.5).

3.7.2 Teachers' Science Concepts

Stofflett (1994) interviewed 17 primary school teacher trainees in the USA and found that most of them not only lacked confidence in science but also disliked it. While Bell (1994) wrote that teachers' knowledge of both science education and science helps them to maximise pupils' learning, the reverse implies that a shortfall in knowledge and skills in either science or science education would make the process of concept challenge and development more problematical. It raises the issue of the amount of content knowledge that is required in order to teach science effectively (Osborne and Simon, 1996).

Primary Teachers' Science Concepts

Table 3.7.1 summarises research into science concepts held by primary teachers and primary student teachers. The emphasis on research into physical science concepts is noticeable. The research revealed many concepts alternative to those of scientists in all the topic areas tabulated and showed there is often a similarity between primary teachers' views and those of their pupils (Birnie, 1989; Kruger and Summers, 1989; Kruger, 1990; Ryan, 1990), including the presence of anthropomorphic views. However, Hope and Townsend (1983) found that New Zealand student teachers' concepts were more developed towards the scientists' views than were those of their pupils.

Teachers' alternative concepts make it unlikely that they will recognise pupils' misconceptions and they may even place little credence on pupils' concepts that are in agreement with scientists' views. Thus they are not likely to be in a position to challenge pupils' alternative concepts in their role of helping pupils make sense of the currently accepted scientific idea (Bell, 1994). Nor is it likely that many of the investigative skills objectives in science curricula could be facilitated by those teachers (Kruger and Summers, 1989; Kruger, Palacio and Summers, 1992).

Table 3.7.1: Primary Teachers' and Student Teachers' Science Concepts

Year	Researchers	Country	Topic	Student or Teacher
1983	Hope & Townsend	New Zealand	Forces Friction Living Plant Animal	Students
1989	Birnie	Australia New Zealand	Physics	Teachers
1989	Kruger & Summers	UK	Evaporation Materials	Teachers
1990	Kruger	UK	Energy	Students
1990	Ryan	UK	Purity States of Matter	Students
1990	Rollnick	South Africa	Air pressure	Teachers
1992	Heller & Finley	USA	Electricity	Students
1992	Kruger, Palacio & Summers	UK	Forces, Energy	Students
1992	Summers	UK	Forces, Friction	Students
1993	Bendall, Goldberg & Galili	USA	Light	Students
1995	Abell & Roth	USA	Food chains	Teachers
1997	Turner	UK	Food and Health	Teachers

Secondary Teachers' Science Concepts

Table 3.7.2 summarises research into science concepts held by secondary teachers and secondary student teachers. Again, the emphasis on the physical sciences is noticeable. Alternative concepts were found among secondary teachers and student teachers, who, unlike primary teachers, usually have academic qualifications specific to their teaching subjects. Some researchers (Ameh and Gunstone, 1985; Stromdahl, Tullberg and Lybeck, 1994) commented on the similarity between alternative concepts of the secondary teachers and those found among their pupils. Ameh and Gunstone (1985) thus questioned some teachers' effectiveness in developing the scientists' concepts among their pupils and also wondered if teachers might not actually be a source of erroneous concepts in their pupils, a concern shared by Sanders (1993).

Table 3.7.2: Secondary Teachers' and Student Teachers' Science Concepts

Year	Researchers	Country	Topic	Student or Teacher
1981b	Gunstone & White	Australia	Electricity Plants	Student teachers
1985	Ameh & Gunstone	Australia	Electricity Forces Friction Animal Living	Student teachers
1986	Ameh & Gunstone	Australia Nigeria	Light Particle Nature	Student teachers
1989	Birnie	Australia	Physics Chemistry	Teachers
1989	Palacios, Cazorla & Cervantes	Spain	Light	Student teachers
1991	Banerjee	India	Chemical reactions	Teachers Student teachers
1993	Bendall, Goldberg & Galili	Israel	Light	Student teachers
1993	Sanders	South Africa	Photosynthesis	Teachers
1994	Stromdahl, Tullberg & Lybeck	Sweden	Mole Stoichiometry	Teachers
1995	Demastes, Good & Peebles	USA	Evolution	Student teachers
1996	Adamczyk & Willson	UK	Energy	Student teachers
1996	Willson & Williams	UK	Chemistry	Student teachers
1997	Trumper	Israel	Energy	Student teachers

3.7.3 Teachers' Astronomy Concepts

Table 3.7.3 summarises research into astronomy concepts held by both primary and secondary teachers.

Table 3.7.3: Teachers' and Student Teachers' Astronomy Concepts

Year	Researchers	Country	Topic	Student or Teacher	Level
1983	Hope & Townsend	New Zealand	Gravity	Student teachers	Primary
1985	Ameh & Gunstone	Australia	Gravity	Student teachers	Secondary
1992	Ojala	Finland	Seasons	Student teachers	Primary
1993	Barba & Rubba	USA	Space	Student teachers	Secondary
1994	Skam	Australia	Moon phases Tides Stars Comets Gravity	Student teachers	Primary
1996	Atwood & Atwood	USA	Seasons	Student teachers Teachers	Primary
1997	Ojala	Finland	Planets	Student teachers	Primary

As might be expected, a similar pattern to those illustrated in tables 3.7.1 and 3.7.2

emerged in that concepts alternative to those of astronomers were found among student teachers and practising teachers, both primary and secondary, in all the astronomy areas surveyed. Many of the teachers' and student teachers' ideas were little different to those of the pupils. Thus there is a danger of teachers being a source of alternative astronomy concepts among their pupils. However, an approach within which the teacher and pupils jointly investigate their shared ideas towards discovering those that make sense to the whole class would allow the teacher to research and learn in partnership with the pupils.

3.7.4 Teacher Acceptance of Constructivist-based Approaches

The above findings raise a variety of concerns which impact on the likelihood of constructivist-based approaches being accepted and implemented by teachers. It appears self-evident that teachers at all levels require an adequate knowledge of the material they are to teach (Gunstone and White, 1981b; Osborne and Simon, 1996). Difficulties arise when teachers have misconcepts which are not distinguishable from those held by their pupils. In such cases, as noted above, the teaching may become the source of pupil alternative concepts (Rollnick, 1990; Ojala, 1992; Sanders, 1993).

Teachers themselves come to the teacher education process with prior views and those with a positivist epistemology and pedagogy are likely to resist implementing constructivist approaches (Milne and Taylor, 1995). All views will need to be explicated, shared and challenged if teachers are to experience conceptual change and construct a science education concept that is intelligible, plausible, and fruitful to them in that it enhances classroom learning (Ebenezer and Gaskell, 1995; Wildy and Wallace, 1995). That is, constructivist approaches cannot simply be transmitted to teachers (Adey and Shayer, 1988).

Fears expressed by teachers about implementing constructivist approaches include that pupils (and parents) may not co-operate in a novel approach that is markedly different from traditional approaches (Krueger, 1994; Wildy and Wallace, 1995), that effective pre-planning is not possible (Krueger, 1994; Hand and Vance, 1995; Appleton and Asoko, 1996), that teacher language may reinforce pupils' alternative concepts (Sprod and Jones, 1996) and that there is often a very complex inter-linking of mental models and subordinate concepts not normally acknowledged in more traditional teaching (Hogan and Fisherkeller, 1996). The latter is particularly the case with astronomy concepts. For example, one cannot begin to make sense of the causes of the monthly phases of the Moon if one thinks that the Moon orbits Earth once every day.

A major problem for science teachers in implementing constructivist approaches is that there is currently little advice on how to teach different topics (Fensham, Gunstone and White; 1994; Lijnse, 1995). The case may be particularly acute for astronomy education. In addition, it is not clear which science concepts are appropriate for various age ranges (Osborne and Simon, 1996) and very few articles describe how to translate constructivist principles into practice or have documented such attempts (Krueger, 1994).

A major need, then, is the development of science curriculum materials which are based on current learning research and which assist teachers in implementing the curriculum (Ebenezer and Erickson, 1996).

3.7.5 Astronomy Investigations in the New Zealand Curriculum

Sections 1.5 and 2.4 explored the practical difficulties of teaching astronomy in ways which include significant use and development of investigative skills. Astronomy is widely seen as an example of a topic area for which laboratory work is very difficult and which includes processes which cannot be replicated (Driver, Leach, Millar and Scott, 1996). This view does not consider the wide range of investigative skills described on pages 42 to 51 of *Science in the New Zealand Curriculum* (Ministry of Education, 1993b). The investigative skills emphasise the central role of the pupils in *focusing and planning* investigations, in *information gathering*, in *processing and interpreting* the information *they* have gathered and in *reporting* their *own* findings to the rest of the class. After all, astronomy information and concepts had to be initially ascertained and developed and they continue to be developed. That is, investigation by astronomers continues to occur and should occur in classrooms when these topics are taught.

McComas (1996) pointed out that, along with other astronomers, neither Copernicus nor Kepler performed laboratory-type experiments and that the major investigative skill used in astronomy has been extensive observation. Astronomers, nevertheless, utilise other investigative skills such as selecting and interpreting information, drawing inferences from that information and modelling (both mental and physical) to test out ideas for plausibility and fruitfulness. These aspects can be introduced into astronomy classes, as they need to be in other areas of the science curriculum. The proposed astronony intervention unit will need to include these investigative skills objectives and suggested activities.

3.7.6 Summary of Section 3.7

Section 3.7 has considered some possible barriers to the implementation of effective approaches to teaching science in general and astronomy in particular. Key difficulties appear to include the fact that many teachers' science and astronomy concepts are themselves often not in sympathy with those of scientists, that many teachers, parents and pupils do not understand or value constructivist-based approaches and that many teachers fail to see how such approaches can be implemented, particularly with respect to investigative skills and building mental models for astronomy education.

The above issues need to be addressed if more effective astronomy education is to gain wider currency. That is, specific curriculum materials, including assessment guidance, need to be provided for teachers. In addition, in-service education needs to be offered to teachers for them to examine the proposed approach to teaching astronomy, to make explicit and have challenged their prior views about the approach, to experience the approach and to be encouraged to evaluate it in terms of its intelligibility, plausibility and

fruitfulness. There is clearly a need for a research programme in this area. The proposed astronomy intervention is designed to provide experience, information and guidance in these key aspects.

3.8 SUMMARY and CONCLUSIONS

Chapter three explored new possibilities with respect to teaching and learning in science in general and astronomy in particular.

A number of learning theories arising from positivist and relativist epistemologies was reviewed and contrasted in section 3.2. The researcher's conclusion was that there is objective science knowledge to be learned, but each person will make his or her own mental construction of that knowledge dependent on her or his experiences, including interactions within social groups. Thus the learning theory which made most sense to the researcher with respect to the development of an astronomy intervention was a constructivist-based approach in which pupils as members of a group construct their own mental models to explain and predict theirs and others' astronomy observations.

Section 3.3 examined the features required of a learning model that is to be consistent with the epistemological model selected in section 3.2 such that learners are engaged in meaningful learning, rather than rote learning, in which they construct for themselves their concepts and mental models. It briefly described the Generative Learning Model (GLM) as an example of such a constructivist learning model and explained why it was chosen as an initial stimulus for the development of the proposed astronomy intervention.

A review of some constructivist-based teaching models that facilitate meaningful learning of concepts and mental models was the focus of section 3.4. It described the Generative Teaching Model as an example of such an approach and explained why it offered promise as a an initial stimulus for the development of the proposed astronomy intervention.

Section 3.5 discussed the use of models in developing pupils' astronomy mental models. It concluded that such approaches were compatible with a constructivist-based teaching-learning approach. In addition, it was suggested that the orrery might be a suitable bridging model in that sense and that it may also serve as a bridge between the positivist and relativist views of astronomy and learning.

Section 3.6 reviewed *Science in the New Zealand Curriculum* to evaluate its commitment to the more effective approaches to astronomy education discussed in previous sections. It concluded that the astronomy section is, in general, in sympathy with such approaches, although the support is more implicit that explicit. That is, the development of an interactive astronomy teaching-learning unit will, at the very least, not be inimical to the aims and objectives of *Science in the New Zealand Curriculum.*

Section 3.7 reviewed the particular challenges that a constructivist-based approach has for astronomy education. These partly mirrored the concerns expressed in section 2.4, noting

that teachers themselves often appear not to share the astronomers' concepts and that teachers may be resistant to the adoption of the new approach in general and the conducting of astronomy investigations in particular. Such concerns will have to be addressed in the proposed intervention.

In summary, the possibilities illuminated by this chapter's review are that the astronomy intervention will possess the following central features:

* a constructivist-based pedagogy;
* a focus on mental model building;
* progressive critiquing and refining of mental models of and within the solar system;
* attention to teachers' resistance to the new approach, particularly the use of investigations as required in the *Developing Scientific Skills and Attitudes* strand of *Science in the New Zealand Curriculum*;
* *Science in the New Zealand Curriculum*'s implicit empathy with the proposed approach to teaching astronomy.

Chapter four will list and discuss the guiding principles and the specific features of the proposed astronomy intervention. It will then describe the development of a research-based astronomy teaching-learning intervention designed to facilitate pupils' construction of astronomy mental models and concepts.

CHAPTER FOUR: FORMULATING THE ASTRONOMY INTERVENTION

4.1 INTRODUCTION

The need to develop a new approach to teaching and learning astronomy has been developed in chapters two and three. It has been established that learners' concepts in astronomy are often different to those of astronomers, even after teaching, and that the predominant approach to teaching is transmissive. Yet world-wide, recent science curricula often encourage an investigative approach as well as encouraging the development of astronomy concepts.

It has also been established that a constructivist-based approach has potential with respect to astronomy education. The research support for constructivist approaches to teaching in general has been discussed. The Generative Teaching Model (GTM), which has been developed in the constructivist tradition, but does not appear to have been utilised in astronomy education, offers promise as the starting point for this investigation.

It was further established that the development of astronomy concepts requires that astronomers construct generalised mental models. It was postulated that learners of astronomy would benefit from the same process of mental model building.

Chapter four describes the development of a research-based astronomy teaching-learning intervention designed to facilitate pupils' development of astronomy mental models and astronomy concepts. Section 4.2 outlines the guiding principles and the specific features of the approach to astronomy education, upon which the intervention was constructed. Section 4.3 outlines the intervention in detail, showing how the constructivist-based features and mental model building were incorporated. The chapter concludes with a summary of the findings from each section.

4.2 THE GUIDING PRINCIPLES AND THE SPECIFIC FEATURES OF THE ASTRONOMY INTERVENTION

4.2.1 Introduction

Section 4.2 considers the formulation of an approach to mental model building in astronomy. It is based on four guiding principles and seven specific features. The discussion is presented in the following sequence:

* the guiding principles of the intervention (section 4.2.2);
* the specific features of the intervention (section 4.2.3);
* the Generative Teaching Model and mental model-building (section 4.2.4).

4.2.2 The Guiding Principles of the Intervention

Four guiding principles in the design of the intervention are shown below. Each principle derives from discussion in the earlier chapters, as indicated.

G1. **Astronomy education, as described in *Science in the New Zealand Curriculum*, requires that attention be given to:**

(a) learner knowledge outcomes (as stated in the contextual strand, *Making Sense of Planet Earth and Beyond*)

(b) learner investigative skills and attitudes (as stated in the integrating strand, *Developing Scientific Skills and Attitudes*)

(c) an understanding of the nature of science itself.
(as stated in the integrating strand, *Making Sense of the Nature of Science and its Relationship to Technology*)

These were discussed in sections 2.3 and 3.6.

G2. **Progressive critiquing and refining of mental models of the solar system, a key investigative skill among astronomers themselves, should be a crucial learner skill in astronomy education.**
This was discussed in sections 2.6 and 3.5.

G3. **A constructivist-based approach to learning astronomy should create an appropriate classroom climate in which this investigative skill of model building can flourish.**
This was discussed in section 3.2.

G4. **The repertoire of constructivist teaching skills - elucidating, comparing and challenging pupils' concepts - can promote this approach to astronomy learning.**
This was discussed in section 3.4.

4.2.3 The Specific Features of the Intervention

Seven specific features of the intervention derived from earlier discussion, appropriately in the order in which they appear in the intervention, are shown below.

F1. **The intervention must address the traditionally cited difficulties in classroom astronomy education, such as the lack of practical work and night-time activities.**
This was discussed in section 2.4.

F2. **The intervention needs to include an early discussion about what scientists consider models to be and how they critique models.**
This was discussed in sections 2.6 and 3.5.

F3. **A considerable part of each lesson will need to be devoted to constructivist-based learning approaches, such as consideration of new data, brainstorming and conjecture, to give pupils themselves opportunities to become familiar with model critiquing.**
This was discussed in sections 2.5, 3.2 and 3.3.

F4. **Opportunities for teacher professional support will be needed for those who are unfamiliar with this approach.**
This was discussed in sections 2.4 and 3.7.

F5. **To accommodate the progressive critiquing of models, the intervention needs to be structured according to a form of constructivist teaching model which has cyclical components within its structure.**
This was discussed in section 3.4.

F6. **As a key example of a model in astronomy, the orrery should emerge centrally in the intervention.**
This was discussed in section 3.5.

F7. **The design of the intervention needs to ensure that the focus on investigative skills generates both astronomy content knowledge and knowledge about scientists' concept of models. Pupil assessment needs to reflect this dual emphasis.**
This was discussed in sections 1.2 and 3.6.

4.2.4 The Generative Teaching Model (GTM) and Mental Model Building

Table 4.2.1 shows the mental model building approach which is proposed for teaching astronomy in New Zealand schools. It is based on the GTM plus the addition of a *Reflection* phase. There are also some changes to the terminology to better reflect that the pupils' construction of mental models is the key feature of the learning process. This helps to facilitate G2. Key similarities and differences between the mental model building approach and the GTM, itself developed from Osborne and Freyberg's (1985, pp. 109-110) Generative Learning Model, are discussed below.

In the proposed astronomy intervention, the *Focus on the Mental Model* phase (see Figure 4.2.1) will see the teacher and pupils engage in topics appropriate to the *Making Sense of Planet Earth and Beyond* strand. They will make explicit to themselves, to their group members and to the teacher their mental models about the structure of the Sun-Earth-Moon system (the key feature in the intervention), its related concepts such as days, years, seasons and tides and their views on how scientists use models. Examples of models will be introduced at this stage and critiqued by the class. This phase closely parallels the *Focus* phase in the GTM. For example, Bell (1993a) suggested that a typical focus phase might begin with brainstorming about the topic. The teacher would record the suggestions on the chalkboard or overhead projector transparency in exactly the same words used by the pupil. The teacher might ask questions for clarification. The ideas would be shared with the whole class, thus illuminating different points of view.

In the *Mental Model Building and Critiquing* phase (which parallels the *Challenge* phase in the GTM), the teacher will introduce the scientists' mental model of the Sun-Earth-Moon system and the orrery as its model. The orrery will be critiqued by the pupils with respect to its representation of the mental model. The teacher will facilitate the sharing of pupils' views about those astronomy concepts which are subordinate to the mental model, introduce the astronomers' concepts if they have not been introduced by any pupils and engage the pupils in repeatedly critiquing (as per Hesse, 1966) the orrery

Table 4.2.1: The Mental Model Building Approach

Phase	Teacher Activity	Pupils' Activity
Preparation	Ascertains pupils' views from the literature; finds out astronomers' views; interviews sample of class. Surveys all class.	Sample of class is individually interviewed. All in the class complete survey.
Focus On The Mental Model	Establishes the context. Provides motivating experiences. Probes and interprets pupils' prior mental models. Probes pupils' views on how scientists use models.	State their prior mental models. Compare their prior astronomy ideas within their group and within the class.
Mental Model Building and Critiquing	Explains scientists' approach to representing and testing mental models (Hesse, 1966). Asks pupils: How can we find out which mental model makes the most scientific sense? Facilitates exchange of views among the pupils, ensuring all pupils' mental models are considered. Suggests activities if required.	Consider positive, negative and neutral aspects of representing an example of a mental model. Consider the views of the other pupils in their group and in the whole class. Design activities to find out, in turn, which supporting mental models make the most scientific sense in terms of their positive, negative and neutral aspects. Conduct the activities. Interpret the evidence in light of its positive, negative and neutral aspects in choosing the 'most explanatory' mental models.
Using the Mental Model to Solve Problems	Selects activities in which the 'most explanatory' mental model is applied to solve different situations, puzzles, games, predictions and problems. Informs the groups of their obligation to defend their findings to the rest of the class. Assists the groups of pupils as necessary.	In groups, use the 'most explanatory' mental model to solve problems novel to the pupils. The problems are investigated via the Focus-Challenge-Review cycle. Prepare to report their findings to the rest of the class.
Reflection	Facilitates group presentations of their solutions to the problems. Encourages the rest of the class to critically evaluate the solutions and explanations where necessary. Sums up and gives an overview.	Groups report their findings to the rest of the class, using an interactive approach, on how the 'most explanatory' mental model best explains the data and solves the problems. Rest of class critically evaluates the solutions and explanations.

as to its facility in representing those concepts. That is, the variety of astronomy concepts is to be challenged not by the more traditional method of appealing to an authority figure, such as the teacher, but by the pupils designing tests of various concepts and by

researching the extent to which the orrery explains those concepts. The aim for the end of this phase is that the pupils will be able to make sense of the astronomers' mental model (G1) after using their investigative skills (G2). The development of the pupils' astronomy mental models will be conducted in group learning situations (G3), during which the repertoire of constructivist teaching skills will be used to promote the learning (G4).

The *Using the Mental Model to Solve Problem* phase parallels the *Application* phase of the GTM in that it involves groups of pupils in applying the astronomers' mental model of the Sun-Earth-Moon system to resolve problems new to the pupils. Each group will attempt to reach a consensus, with respect to its activities, by debating the merits of the various explanations. An example will be to describe what days, years and seasons would be experienced by someone inhabiting a planet other than Earth. Another example will be to describe the effects on Earth if Earth had two moons. At least two groups will attempt each activity but all groups are not expected to complete all activities.

Finally, the *Reflection* phase is seen as a key component of the approach. While it does parallel some aspects of the *Application* phase of the GTM, its separate status highlights the interactive nature of the reporting back by the groups of pupils to the rest of the class. Each group will take on the role of interactive teacher and will defend its consensual ideas to the teacher, to pupils who may not have completed that activity and also to groups who have completed the same activity but might have arrived at different conclusions and explanations. The *Reflection* phase introduced into this model is seen as a vital sharing and further exploration of ideas that were developed in the previous two phases. Sharing is a common activity in New Zealand primary schools, and the *Reflection* phase develops this further in that the rest of the class will not passively listen but will evaluate the findings reported to them. That is, the *Reflection* phase further facilitates the four (G1 to G4) guiding principles of the intervention.

4.2.5 Summary of Section 4.2

The four guiding principles and the seven specific features of the astronomy intervention have been described in sections 4.2.2 and 4.2.3. This was followed in section 4.2.4 by a description of the mental model building approach as it will be applied to an astronomy intervention designed for pupils to construct the scientists' mental model of the Sun-Earth-Moon system. The key features of the astronomy intervention are summarised in Table 4.2.2.

An intervention based on mental model building should be a rich and varied approach to meet both the specific and wider aims of *Science in the New Zealand Curriculum*. In essence, the emphasis will be on the pupils building their own mental models about selected aspects of the universe.

Table 4.2.2: The Key Features of the Astronomy Intervention

Aspect	Feature of the Astronomy Intervention
Astronomy education.	Developing mental models that explain observed facts.
Theory of Learning.	Constructivist: initiated from prior learning, pupils construct * facts and concepts; * successively more explanatory models.
Major teacher activities.	Successive provision of current model-relevant information to facilitate pupil sharing of ideas and research.
Major pupil activities.	1. Successive critiquing of the pupils' and scientists' models. 2. Development of their own mental model. 3. Group and class interactions.
Major learning outcomes.	1. Facts and concepts about the universe. 2. Enhanced model building skills. 3. An understanding of the role of model building in astronomy and science.
Curriculum strands addressed.	1. Making Sense of Planet Earth and Beyond. 2. Developing Scientific Skills and Attitudes. 3. Making Sense of the Nature of Science and its Relationship to Technology.
Assessment techniques.	Interviews and surveys about: * facts and concepts; * mental models.

4.3 THE STRUCTURE OF THE ASTRONOMY PILOT INTERVENTION

4.3.1 Introduction

Section 4.3.2 will outline and describe the specific structure of the proposed astronomy intervention. Furthermore, it will describe how the intervention accommodates the guiding principles and the specific features discussed in section 4.2, indicating on the structure where they influenced it. The intervention is described lesson by lesson in Appendix A, and discussed in more detail in chapters six and seven.

4.3.2 The Structure of the Astronomy Intervention

Figure 4.3.1 shows the structure of the astronomy intervention, which consists of twelve lessons. The cyclical nature (specific feature five) is illustrated by the the fact that most lessons will include a cycle of focus, challenge and review. The lessons themselves are part of the larger pattern in which the pupils' mental models about the solar system are developed through a four-phase process of *Focus on the Mental Model*, *Mental Model Building and Critiquing*, *Using the Mental Model to Solve Problems* and *Reflection* (guiding principle two).

In lesson one, the pupils focus on the class' response to the pre-survey, which reveals their knowledge and mental models about the solar system. These are discussed as a whole class. Lesson one facilitates guiding principles G1, G3 and specific features F1, F3 and F7. Also in lesson one, there is a discussion about the roles of models in general, using a map of the London Underground system to elicit that models can be critiqued using Hesse's (1966) positive, negative and neutral features. This facilitates guiding

principle G2 and specific features F1 and F2.

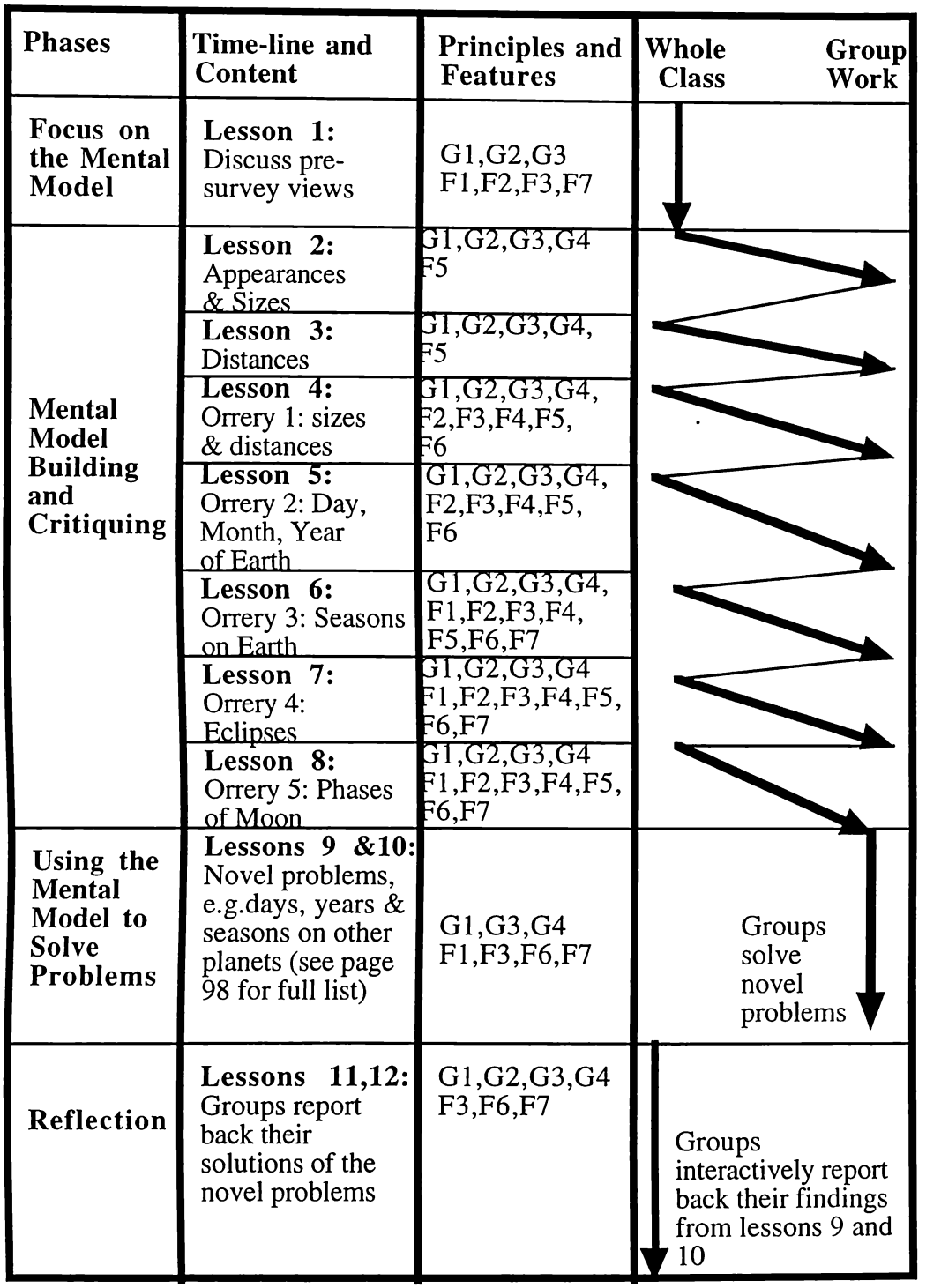


Figure 4.3.1: The Astronomy Pilot Intervention

In lesson two, each group of pupils is challenged to construct a scale model of the solar system object which is the same as their group name. That is, there are eleven groups, each of about three pupils. The pupils work within their group during the whole of the intervention, thus facilitating guiding principle three. The whole class gathers at the beginning of the lesson to focus on the problem and at the end of the activity to review the findings and the mental models proposed for the Sun-Earth-Moon structure.

Lessons two to eight constitute the *Mental Model Building and Critiquing* phase of the intervention. Throughout this phase the role of models, as perceived by scientists and in an everyday sense, is analysed and a particular model, the orrery, is introduced by the teacher. The orrery is observed and described by the pupils and then used to articulate and investigate their mental models about aspects of the Sun-Earth-Moon system. Also, they critique the orrery in terms of its capacity to accurately model those aspects: a scale model of the Sun-Earth-Moon system, days on Earth, months and years on Earth, seasons on Earth, lunar and solar eclipses and phases of Earth's moon.

The cyclical nature of the activities is seen in that each lesson consists of a group based focus, challenge, review sequence within the overall *Mental Model Building and Critiquing* phase. Within that sequence, the pupils focus on the problem, share and challenge each other's views. In the review part of the sequence, the results of the challenge activity are used to critique both the scientists' Sun-Earth-Moon mental model and the orrery. The pupils also operate as a whole class in the *Mental Model Building and Critiquing* phase, during which the orrery is used both as a model and in mental model building. They investigate ideas both with the orrery and with class-designed activities to investigate conflicting concepts. That is, the *Mental Model Building and Critiquing* phase facilitates guiding principles G1, G2, G3 and G4. It also facilitates specific features F1, F2, F3, F5, F6, F7, although only specific feature five (F5) is facilitated in every lesson in this phase.

The guiding principles G1 to G4 are facilitated in each lesson from lesson three to lesson eight. In lesson three, the pupils as a whole class attempt to build a scale model of the solar system in their classroom. They use the same scale for distances that was used for sizes. Each group decides the position of its solar system object and attempts to place it at that position relative to the position of the Sun.

The orrery is introduced by the teacher in lesson four and used in each of lessons four to eight to facilitate specific features F2 and F6. The pupils then critique the orrery in terms of its modelling of the sizes and distances of the Sun, Earth, Moon and Venus, and compare that with their mental model of those aspects, thus facilitating guiding principle G1.

The pattern is followed in lesson five, in which the orrery is investigated in terms of its representation of day, month and year on Earth. Again, the pupils critique the orrery, this time in terms of its modelling of the rotations and revolutions of the Earth and Moon, and then compare that modelling with their mental model of those aspects. This lesson facilitates the same guiding principle and specific features as in lesson three, but with different knowledge outcomes. As before, pupils work in groups, facilitating guiding principle three.

In lesson six, pupils, both in groups and as the whole class, investigate scientists'

concepts about seasons. Their prior ideas are made public and the pupils are encouraged, with guidance where necessary, to design and conduct an experiment to allow them to decide which concept most closely fits their observations. The orrery is then critiqued with respect to its and the mental model's representation of the causes of seasons. That is, this particular lesson facilitates guiding principles G1 and G2 and specific features F1 and F7.

The orrery also features prominently in lesson seven, in which pupils' concepts about lunar and solar eclipses are elicited and compared and then modelled on the orrery. Again, the orrery is critiqued, both in groups and in the whole class, this time with respect to its representation of the causes of eclipses. This lesson further facilitates guiding principles G1, G2 and G3 and specific feature F1.

Lesson eight is the last in the *Mental Model Building and Critiquing* phase. In this lesson, the pupils' ideas about the phases of the Moon are elicited and compared. The orrery is then used to model the phases of the Moon and then critiqued. Again, the pupils work in groups, then as a whole class and finally in groups again to review what they have learned. This lesson facilitates guiding principles G1, G2, G3 and G4 and specific features F1, F2, F3, F6 and F7.

Lessons nine and ten are intended to help the groups of pupils consolidate for themselves the scientists' mental model of the Sun-Earth-Moon system by using it to solve problems that are novel to them (see below). The pattern of focus-challenge-review continues to be utilised in each of the activities. Not all pupils complete all the activities but at least two groups of pupils undertake each activity. The activities in this phase of the intervention are:

(a) using the orrery and a table of data to describe days, years and seasons on Mercury.
(b) using the orrery and a table of data to investigate whether the same faces of the Moon and Mercury always face their parent body.
(c) speculate about the effects on Earth if we had zero moons or two moons.
(d) using graphical data about high tide times and Moon-set times to investigate whether the Moon affects tides on Earth and whether it is the only cause of those tides.
(e) using graphical data about high tide times and times of phases of the Moon to investigate whether or not the Sun affects tides on Earth.
(f) using a table of data to describe days and years on other planets.
(g) using a table of data to describe seasons on other planets.

That is, these lessons are designed to further facilitate guiding principles G1, G3 and G4, and specific features F1, F3, F6 and F7.

The *Reflection* phase of the cycle is conducted in lessons eleven and twelve. This phase

is to help the pupils further consolidate their mental model of the Sun-Earth-Moon system. Groups of pupils report back their findings to the rest of the class, using charts and aids such as the orrery where applicable. These lessons are to be interactive, in that different reporting groups may have different interpretations, any of which may be inconsistent with ideas others in the class hold. The rest of the class are encouraged to ask questions and not to accept the reports at face value. The teacher will have previously informed the groups that he or she might have some difficult questions, so preparations need to be thorough. Thus lessons eleven and twelve facilitate guiding principles G1, G2, G3 and G4 and specific features F3, F6 and F7.

Specific feature F4, which refers to opportunities for professional teacher support, is the only one not mentioned as being facilitated in the sequence of lessons. This feature was catered for by the researcher, who included appropriate advice in the written teachers' guide material and also worked closely with the teacher before and during the implementation of the intervention. The researcher met the teacher to discuss the format and approach of the intervention, provided the teacher with a copy of the intervention unit plan, amended the plan where necessary after discussion with the teacher, provided all resources necessary to teach the unit and met and supported the teacher between each of the astronomy lessons.

4.3.3 Summary of Section 4.3

Section 4.3 outlined the structure of the proposed astronomy intervention. Furthermore, it linked parts of the intervention to show how it encompasses the guiding principles and specific features that were described in section 4.2. The guiding principles and the specific features pervade the whole intervention. Some examples where they are particularly evident are cited respectively in Table 4.3.1 and Table 4.3.2.

Tables 4.3.1 and 4.3.2 illustrate that all the guiding principles and specific features described in section 4.2 are reflected in the structure of the proposed pilot astronomy intervention.

4.4 SUMMARY AND CONCLUSIONS

Chapter four described how the recommendations made in chapter three were utilised to construct the guiding principles for the development of the proposed astronomy intervention. Section 4.2 considered those guiding principles and the specific features of the proposed astronomy intervention. It concluded with Table 4.2.1, which outlined the teacher and pupil activities within the teaching approach, and Table 4.2.2, which listed the key features of the intervention.

Section 4.3 described the structure of the pilot astronomy intervention and identified the lessons in which the general principles and specific features would be facilitated in that structure.

Thus chapter four combined the aspects raised and discussed in chapters two and three to form the structure of a proposed astronomy intervention. Specific research questions and the research methodology will be described in chapter five.

Table 4.3.1: Examples of the Guiding Principles in the Intervention

Guiding Principle	Example in the Intervention
1. Astronomy education, as described in *Science in the New Zealand Curriculum*, requires that attention be given to:	
(a) learner knowledge outcomes;	In lesson 8 pupils learn that the Moon's phases are caused by our changing view from Earth of a constantly half-illuminated Moon. Earth is orbiting the Sun. Phases are not caused by Earth's shadow, a commonly held view.
(b) learner investigative skills and attitudes;	In lesson 9 and 10, pupils use graphical data to infer that the Moon is not the only cause of Earth's tides, as is commonly believed, and that the Sun is also a major cause.
(c) an understanding of the nature of science itself.	Astronomers construct mental models of the Sun-Earth-Moon system. Mental models are repeatedly critiqued to see how they explain observed phenomena. An example is lesson 2.
2. Progressive critiquing and refining of mental models of the solar system, a key investigative skill used by astronomers themselves, should be a crucial learner skill in astronomy education.	In lesson 4, pupils critique the orrery scale sizes and distances.
3. A constructivist approach to learning astronomy can create an appropriate classroom climate in which this investigative skill of mental model building can flourish.	Pupils work in groups in using a table of data to reach consensus in describing days years and seasons on other planets. - lessons 9 & 10.
4. The repertoire of constructivist teaching skills - elucidating, comparing and challenging pupils' concepts - can promote this approach to astronomy learning.	Pupils' ideas about the causes of the seasons are challenged. Then the pupils devise and conduct an activity to test those ideas. - lesson 6.

Table 4.3.2: Examples of the Specific Features in the Intervention

Specific Feature	Example in the Intervention
1. The intervention must address the traditionally cited difficulties in classroom astronomy education, such as the lack of practical work and night-time activities.	Pupils attempt to construct a scale model of the solar system in the classroom and then in the school fields. - lessons 2 & 3
2. The intervention needs to include an early discussion about what scientists consider models to be, and how they critique models.	Pupils critique a map of the London Underground for its positive, negative and neutral features as a model. - lesson 2
3. A considerable part of each lesson needs to be devoted to constructivist learning procedures, such as consideration of new data, brainstorming and conjecture. This gives pupils opportunities to become familiar with mental model critiquing.	The pupils operate in their groups for parts of each lesson 2 to 8 and lessons 11-13. They will operate solely in their groups in lessons 9 to 10. Each group compares individual views and attempts to reach a consensus view based on discussion and data.
4. Opportunities for teacher professional support is needed for those who are unfamiliar with this approach.	The researcher provides many materials to the teacher and offers continual guidance and reassurance.
5. To accommodate the progressive critiquing of models, the intervention needs to be structured according to a form of constructivist teaching model which has cyclical components within.	Lessons 2 to 10 each include a cycle of focus-challenge-review during which a sub-concept within the larger mental model of the Sun-Earth-Moon is investigated. e.g. eclipses in lesson 7
6. As a key example of a model in astronomy, the orrery should emerge centrally in the intervention.	The orrery is introduced in Lesson 3 and used and/or investigated in all subsequent lessons.
7. The design of the intervention needs to ensure that the focus on investigative skills generates both astronomy content knowledge and knowledge about scientists' concept of models. Pupil assessment needs to reflect this dual emphasis.	Pupils learn about the structure and operation of the Sun-Earth-Moon system, learning that the mental model used by astronomers helps us to better understand ideas that cannot be directly observed. Assessment reflects this in interviews and written surveys.

CHAPTER FIVE: THE RESEARCH METHODOLOGY

5.1 INTRODUCTION

Chapter two noted that astronomy has recently been re-introduced into the science curricula of many countries, including New Zealand. These curricula emphasise learning processes and the development of investigative skills, whereas research reveals that most astronomy teaching has focused on knowledge outcomes. This is in contrast to the practice of astronomy itself, which builds and critiques mental models. Much more research is needed into whether and how pupils develop astronomy mental models.

Chapter three discussed implications for the classroom of such a mental model building approach and considered the role of models in that process. It showed that more research is needed into the process by which pupils use models to construct and repeatedly critique their astronomy mental models and modify them towards astronomers' mental models. A constructivist-based teaching approach was suggested as the framework within which to construct an astronomy teaching-learning package, the astronomy intervention.

Chapter four considered the guiding principles and the specific features of the proposed astronomy intervention, and how they were to be facilitated in the overall structure, which comprises four phases:

* pupils propose mental models of the solar system;
* pupils successively critique and re-build their mental models of the solar system in terms of the mental models' capacity to explain and predict subordinate astronomy information and concepts;
* pupils apply the scientifically accepted mental model of the solar system to solve problems that are new to them;
* pupils reflect on the scientifically accepted mental model of the solar system.

Research is needed to help determine whether the proposed four phases will help pupils to construct astronomy mental models which are similar to those of astronomers.

In summary, the overall research question which has emerged is:

> *What happens when a constructivist pedagogy is used to give Year 7-8 pupils the opportunity to generate and critique astronomy mental models?*

Chapter five considers the research methodology for this study. To that end, section 5.2 describes the specific research questions which arise from the overall research question and section 5.3 considers an appropriate interpretive research methodology to be utilised. Section 5.4 describes and explains the particular data-gathering methods to be adopted, while overall considerations of reliability, validity and triangulation are considered in

section 5.5, which also discusses ethical considerations and the role of the researcher. The research programme is outlined in section 5.6. Section 5.7 profiles the teachers of Year 7-8 pupils who were interviewed, while section 5.8 describes contextual considerations such as the school, the pilot teacher and the intervention teacher. In section 5.9 the pilot intervention and trial intervention classes are briefly described, as are the classrooms in which the pilot and trial interventions were conducted. Chapter five is completed with section 5.10, which is a summary of the research strategy.

5.2 THE RESEARCH QUESTIONS

There were five specific research questions related to the overall research question:

1. How effective was the intervention in developing pupils' ideas about the role of scientists' models? This question relates to chapter three.

2. Are pupils able to construct the scientists' mental model of the Sun-Earth-Moon system? This question refers to chapter two.

3. How effective are models in promoting mental model building by New Zealand pupils? This question relates to chapters two and three.

4. What are the astronomy conceptual learning and teaching difficulties experienced, respectively, by New Zealand pupils and teachers? This question relates to chapter two.

5. How effective was the intervention in promoting the astronomy knowledge and concepts in *Science in the New Zealand Curriculum*? This question relates to chapter three.

5.3 AN INTERPRETIVE METHODOLOGY

As noted above, the purpose of this research was to gain insights into learning and teaching when learners are engaged in constructing and critiquing their mental models and the models which represent those mental models. It is not possible to gather information about all the events that occur in busy and dynamic environments such as classrooms, especially in complex science lessons which include practical activities in small groups and discussions in both small and large groups. This would be so even if the researcher acted only as an observer. This is particularly so if the researcher is called upon to be an occasional participant.

An interpretive methodology (Lather, 1992; Maxwell, 1992; Cohen and Manion, 1994) was adopted, in which the researcher attempts to understand learners' interpretations of their world. That is, a multi-faceted approach to data-gathering is necessary, in which the researcher is in the classroom working with both the teacher and pupils and gathering data

about classroom interactions in as many ways as time and resources permit. Thus the researcher cannot be construed as a totally objective observer and recorder of classroom events in that he/she may well influence those events in unanticipated ways by her/his interactions with individuals or groups, both planned and unplanned. Nevertheless, the researcher attempts to be as objective as possible in ascertaining the developing understandings of the pupils' and teacher's interpretations of classroom events.

As is usual within an interpretive framework, the present study uses both qualitative and quantitative methods because neither approach is sufficient on its own to record both the learning outcomes and the processes by which the learning occurred. Quantitative methods tend to reflect the positivist epistemology, regarding the researcher as separate from the research and as a reporter of variables over which he/she has little or no influence. Quantitative methods are necessary in this research to establish changes in the pupils' constructions of astronomy concepts and mental models.

On the other hand, qualitative methods, the approach most used in science education (Rennie, 1998), more closely reflect the relativist epistemology (Niaz, 1997). With qualitative methods, the researcher constructs meanings from her/his involvement and acknowledges that involvement by the researcher is likely to have an effect on the data. Qualitative methods are necessary in this research to investigate the processes by which pupils construct astronomy concepts and mental models.

Each approach has its own advantages and limitations (Griffin, 1985; Banet and Nunez, 1997; Mellado, 1997). The aspects from each approach that are most appropriate to the particular research should be selected, as should the instruments (Rennie, 1998). The next section will describe the data-gathering methods that were adopted in this research.

5.4 DATA-GATHERING METHODS ADOPTED IN THIS RESEARCH

5.4.1 Introduction

Within a constructivist approach to helping pupils build astronomy mental models, it is important that pupils' concepts are accurately elicited both before and after the teaching (Sutton, 1980; Osborne and Bell, 1983; MacGuire and Johnstone, 1987; Goh, Khoo and Chia, 1993; Hand and Vance, 1995; Gutwill, Frederiksen and Ranney, 1996; Maskill and Pedrosa de Jesus, 1997). Although the main emphasis in the present study was on pupils' thinking processes, it was also considered important to ensure that these do not occur in the intervention at the expense of the usual aim of acquiring astronomy concepts (compare research questions 2, 3 and 5).

There is a large variety of methods available to researchers and teachers who wish to elicit learners' concepts (Sutton, 1980; Posner and Gertzog, 1982; Douvdevany, Dreyfus and Jungwirth, 1997). These are represented by the researcher in Figure 5.4.1, in which the techniques have been broadly grouped as talking to learners, or asking learners for written responses, or observing in classrooms. For example, talking to learners usually includes

interviews with them, either loosely structured or clinical, or Interviews About Instances or Interviews About Events. Similarly, written responses by the learners include free responses to open-ended questions, drawing concept maps, completion of Likert scales and choosing responses from multiple choice questions, which could be either one-level or two-level. This research will use methods from all three groups.

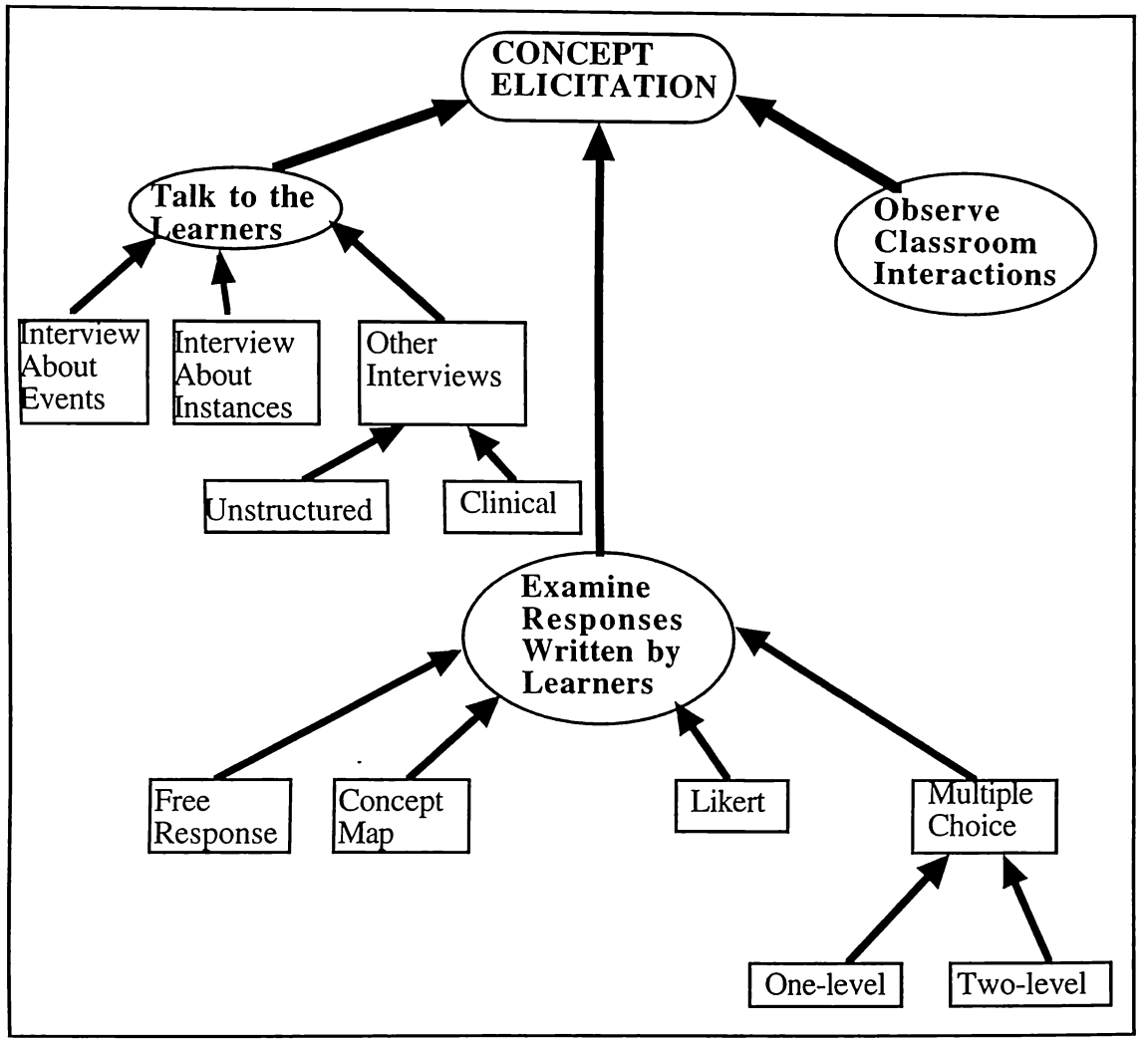


Figure 5.4.1: Methods of Concept Elicitation

Section 5.4 will consider a variety of ways in which data can be gathered and will describe the reasons for the methods adopted in this study. The discussion is in the following sequence:

* interviews (section 5.4.2);
* multiple choice surveys (section 5.4.3);
* lesson transcripts (section 5.4.4);
* pupils' work books (section 5.4.5).

5.4.2 Interviews

Background

The interview technique, pioneered by Jean Piaget (Posner and Gertzog, 1982; Solomon, 1983; Solomon, 1992), is defined as a purposeful conversation to elicit specific kinds of

information (Posner and Gertzog, 1982) and to determine pupils' cognitive structures and concepts (Nussbaum, 1979; Nussbaum and Sharoni-Dagan, 1983; Anderson, 1992; Brody, 1994). Pupils must feel comfortable that the process is not one of assessment (Osborne and Gilbert, 1980a). For that, interviewers must be accepting of the pupil responses, must not offer clues as to the 'correctness' or otherwise of the learner's viewpoint and must be good listeners. In addition, they must utilise the pupil responses by asking probing questions to ascertain the real meanings behind their responses (Posner and Gertzog, 1982).

Interviewing is highly flexible when used by skilled researchers (Posner and Gertzog, 1982). On the other hand, there are limitations to the utilisation of interviews in encouraging pupils to talk freely while also probing the basis of their reasoning (Sutton, 1980). Also, the interviewer has to be skilled in the art of questioning (Posner and Gertzog, 1982) and knowledgeable in the area of research (Stead and Osborne, 1980). Furthermore, interviewing, transcribing the audio tapes and analysing them is time-consuming (Stead and Osborne, 1980; Sanders, 1993; Bloom 1995; Yip, 1998). Further major considerations are that the concepts revealed in an interview might be very different from those on the same pupil's mind in a classroom learning situation (Maskill and Pedrosa de Jesus, 1997), that pupils may be unable to fully articulate what they think (Rye and Rubba, 1998) and that the usually small sample means it is not easy to generalise findings to larger populations (Sadler, 1991).

Teacher Interviews

In view of the reservations expressed by overseas teachers about the difficulties of teaching astronomy, and in order to gain insights into New Zealand teachers' views, twelve teachers of Year 7-8 pupils were individually interviewed prior to the construction of the pilot astronomy intervention. A semi-structured format was used, following the guidelines of Bell, Osborne and Tasker (1985). Reasons for selecting Year 7-8 pupils are considered in section 5.6. An aim of the interviews was that the planned intervention would address the strengths and challenges of astronomy education as perceived by these teachers. The interviews also made it possible to compare New Zealand and international teachers' views about teaching astronomy.

Accordingly, the researcher wrote to principals of schools that teach Year 7-8 pupils. The schools included five intermediate schools (Year 7-8), one middle school (Year 7-10), and two full primary schools (Years 0-8). The letter outlined the purposes of the research and of the interviews. It asked each principal to seek up to three volunteers in his or her school who would agree to being interviewed and to forward their names to the researcher. In the event, there were twelve volunteers, three each from three intermediate schools and three from the middle school. The trial intervention teacher was among the ten women and two men teachers interviewed in this preparatory phase.

An interview schedule, shown in Appendix B (page 313), was developed. It was based on both the findings from the international research outlined in section 2.4 and on the

objectives of *Science in the New Zealand Curriculum.* The researcher put the interviewees at ease by introducing himself, outlining the purpose of the interview and asking a few appropriate personal-professional questions. They were then asked what they saw as the good aspects about teaching astronomy and what they saw as the main challenges when teaching astronomy. They were also asked how they thought astronomy education could help pupils towards the achievement objectives of both the contextual strand *Making Sense of the Planet Earth and Beyond* and the two integrating strands in *Science in the New Zealand Curriculum.* Prompting questions were also prepared in case the questions or responses needed clarification.

The interviews were individually conducted at each teacher's school at a convenient time, either after school or at lunch time, and in a quiet room that was unlikely to be disturbed. Each interview took about twenty minutes. Before the interviews, each teacher was asked if it was acceptable to audio-tape the interviews. At the conclusion, the respondents were thanked for their contributions and asked if they would like to receive a copy of their transcript which they were free to amend so that it accurately reflected their views. All interview tapes were transcribed verbatim on the evening of each interview. They were then typed and analysed as described by Wildy and Wallace (1995) and by Ebenezer and Gaskell (1995).

All the teachers asked to see their transcripts and these were forwarded to them for comment. Two made no alterations, six made corrections to the typing, two made minor amendments and the other two made more substantial alterations to the wording to clarify their position on particular questions. One of the latter added that she realised that she did not really know or understand the Achievement Objectives in *Science in the New Zealand Curriculum* and felt that she ought to, while the other teacher in the latter group wanted her conversational responses to be recorded more formally. For example, "There's oodles (of resources) out there..." was changed to "There is a great number of resources available." The researcher is of the view that the interviews accurately reflect the opinions of these teachers.

The pilot and trial intervention teachers were interviewed before and after the intervention according to the schedule shown in Appendix C (page 315). The same procedure as with the above interviews was adopted (Shepardson and Moje, 1994). In addition, the trial intervention teacher was briefly interviewed after eight of the lessons to ascertain his views about how those lessons went.

Pupil Interviews

A representative sample of the class was interviewed three days before and one day after both the pilot and trial interventions. The interview protocol, shown in Appendix D, was constructed with the view that the interviewees needed to be as much at ease as is possible in the potentially stressful situation of being interviewed by a stranger from the university. Accordingly, the interviews were conducted in a quiet corner of the school library and the

interviewer began by thanking the pupils for helping the researcher. Each pupil interview took about 20 minutes.

The pupils were assured of confidentiality in that only they and the researcher would know the results of the interview. Permission was asked for the interviewer to use the audio-tape to avoid "having to write like crazy". Each pupil was given the opportunity to listen to the audio-tape, receive a copy of the transcript and make any changes they wanted to make. No pupils asked to hear the tape or read the transcript.

The interviews then went on to explore the pupils' knowledge and concepts about the astronomy recommended for level four science in the *Planet Earth and Beyond* contextual strand. That is, content validity was assured in that the questions investigated the pupils' mental models of the solar system and the Sun-Earth-Moon system, and effects of the Sun-Earth-Moon system such as tides, eclipses, phases of the Moon, days, months, seasons and years. Their ideas about models in science were also elicited. Optional prompt questions were used when necessary to explore pupils' ideas further. The interviewer concluded by asking the pupils if they had any questions, and by thanking them for helping him. Every audio tape was transcribed and typed within three days of the interview.

5.4.3 Multiple Choice Surveys

Background

Multiple choice surveys have been widely used by both researchers and teachers because of their ease of administration and because they allow for a wider sampling than is usually possible with interviews. They should be developed after wide use of qualitative approaches that determine pupil alternate concepts (Gilbert, 1977; Treagust, 1986), which then constitute the distractors (Stead and Osborne, 1980; Tamir, 1990). Unless this procedure is followed, multiple choice items may fail to reveal what pupils actually know about a topic (Griffiths and Barman, 1993; Bell, 1993a). While they might elicit the proportions within a given population who subscribe to one of the views expressed in the distractors, they do not elicit any other sincerely held views and they force participants to choose between predetermined views (Dawson and Rowell, 1995; Palmquist and Finley, 1997) They also fail to ascertain the reasoning processes that lead to the choices being made (Yip, 1998) and they rely on pupils' interpretations of the wording of the questions (Driver, Leach, Millar and Scott, 1996).

In addition, multiple choice approaches are now so widely used in an assessment capacity that it cannot be known whether respondents are stating their own views or are looking for the 'best' answer, an approach which is widely advocated for completing multiple choice tests. Furthermore, there is a 25% chance of guessing the correct response in a typical four-item multiple choice question.

Gilbert (1977) suggested that a good multiple choice question requires the addition of a space for pupils to explain their choice. This suggests the need for two-level multiple

choice questions, of which there are two types. The first type is one described as multiple choice plus justification (Treagust, 1986). Tamir (1990) investigated the utility of such two-level multiple choice items and found a correlation of only 0.65 between the total multiple choice score and the total justification score. In addition, he noted that many pupils were unable to adequately explain their choices but that they provided a rich source of pupils' alternate concepts.

Based on the 1981 work of Tobin and Capie, Treagust (1991) developed a two-level multiple choice format as a method open to both teachers and researchers to ascertain pupils' science concepts. This was supported as one way to address the problem of time constraint (Goh, Khoo and Chia, 1993). Rather than the respondents adding their own reason for each selection of response, they also select one of four stated reasons for that response (Peterson, Treagust and Garnett, 1986; Treagust, 1991; Goh, Khoo and Chia, 1993). Answers are only considered correct if the pupil selects both the correct content choice and the correct reason (Peterson, Treagust and Garnett, 1986).

Peterson and Treagust (1989) investigated and evaluated the utility of such two-level instruments. They reported that their Covalent Bonding instrument provided a feasible approach for evaluating pupils' understanding and for identifying alternate concepts. Goh, Khoo and Chia (1993) repeated the process in Singapore, with the addition of a fifth option in the reason part of each item to provide a channel for the pupils if they did not agree with any of the reasons given. They concluded that the two-level multiple choice questions were suitable and useful for classroom teaching (Goh, Khoo and Chia, 1993).

The conclusion drawn from the above discussion is that two-level multiple choice instruments have potential for use both by teachers and by researchers who wish to obtain more extensive data than can be accomplished by interviews. They are reliable tools for both teachers and researchers (Sadler, 1991) and thus will be used in this research.

A constructivist framework requires that data collection occur before, during and after teaching (Shepardson and Moje, 1994) and the design becomes one of utilising pre-, post- and post-post surveys (Hennessy, Twigger, Driver, O'Shea, O'Malley, Byard, Draper, Hartley, Mohamed and Scanlon, 1995b). Estimation of concept change requires that each of the surveys be identical (Gutwill, Frederiksen and Ranney, 1996), although there is the danger that the pupils may become alerted to the questions. However, the use of different survey questions at the different stages would raise doubts about their comparability.

Pupil Multiple Choice Surveys

A survey instrument, whose trial version is shown in Appendix E (page 318), was developed by the researcher. Content validity was established by carefully analysing the astronomy parts of the level four Achievement Objectives of the contextual strand, *Making Sense of Planet Earth and Beyond*. From this analysis, a list was drawn up of the knowledge and concepts that Year 7-8 pupils were expected to develop from a study

of this topic. These include basic ideas about the members of the solar system, mental models of the solar system and of the Sun-Earth-Moon system, phases of the Moon, eclipses of the Moon, eclipses of the Sun, the seasons, days, months, years, tides and scientists' use of models (the orrery in particular). Then single-level and two-level questions were developed that reflected those concepts and knowledge.

The instrument was examined and successively refined until every question was unambiguous. In addition, each distractor was stated clearly and, based on the international research findings discussed in section 2.5, likely to make sense to some of the pupils.

To gain a picture of the pupils' knowledge and concept development, a pre-survey was administered three days before lesson one of the intervention, an identical post-survey was administered the day after the last lesson of the intervention and an identical post-post survey was administered several weeks later.

The surveys were conducted by the class teacher in normal class time. The pupils were asked to have a reading book available if they finished early. The teacher was asked to read the instructions on the survey form and explain to the pupils that the survey results would not affect their course grades. They were also asked to leave a question unanswered, rather than guess, if they did not know the answer. The surveys were analysed by the researcher on the day they were administered.

5.4.4 Lesson Transcripts

Observations and transcripts of classroom interactions are recommended by Louisa, Veiga, Costa Pereira and Maskill (1989), Kempa and Ayob (1991) and Woodruff and Meyer (1997). The researcher adopted the role of participant observer (Cohen and Manion, 1994; Shepardson, 1997), taking on a role that was familiar and acceptable to the pupils and teachers. The researcher observed during the whole-class phases and moved around the class in the small-group phases, occasionally talking to the pupils. These approaches were adopted in an attempt to elicit learners' concepts about astronomy, their ideas about models and how they went about mental model building.

Each lesson was audio-taped by the researcher. In the whole-class phase, the focus was the teacher and in the small-group phase the focus was one of the eleven groups, after their permission had been granted. Different groups were recorded on different occasions. Each audio tape was transcribed on the same day as the lesson was taught, for later analysis.

5.4.5 Pupils' Work Books

Each of the eleven groups responded to directions, activities and questions by co-operatively completing a work book provided by the researcher. A copy of the trial version of the work book is shown in the blue, yellow and red pages of Appendix A (page 236). It consists of a title page, an opening statement and instructions to the groups

for each of the lessons. Each lesson instruction, printed on blue paper, has spaces in which the group was asked to write their individual and group responses to questions.

Tables of data and graphs were provided, where necessary, to assist the groups in responding to the questions. For ease of identification, these were printed on yellow paper and placed immediately following the appropriate lesson. Red critique forms were provided for those lessons in which the groups were to record their critiques of the orrery as a model for the Sun-Earth-Moon mental model. In addition, a map of the London underground was provided which the pupils critiqued as another type of model. The work books were used by the teacher to aid his analysis of the intervention.

5.4.6 Summary of Section 5.4

Section 5.4 considered a number of ways in which research data can be collected. For the purposes of this study it was decided that data would be collected in the form of interviews with 12 teachers of Year 7-8 pupils, pre- and post-interviews with the intervention teachers, after-class interviews with the intervention teachers, pre- and post-interviews with a representative sample of pupils in the intervention classes, pre-, post- and post-post pupil surveys and classroom observations.

5.5 OVERALL CONSIDERATIONS

5.5.1 Introduction

This section discusses how aspects of the methodology were taken into consideration in the development of the research methodology. The aspects are discussed in the following sequence:

* reliability, validity and triangulation (section 5.5.2);
* ethical considerations (section 5.5.3);
* the role of the researcher (section 5.5.4).

5.5.2 Reliability, Validity and Triangulation

Research methods and their data-gathering instruments, whether qualitative or quantitative, need to satisfy the demands of validity and reliability (Johnson and Gott, 1996). *Reliability* is a measure of the consistency with which a data collection device measures whatever it is that the device measures, whereas *validity* measures how well an observation measures what it is supposed to measure (Hopkins, 1980). Reliability was to be ascertained by two approaches. First, a sample of the pupils would be interviewed and their interview responses compared to their survey responses. Second, several concepts were to be investigated by more than one question in the survey instrument. The responses to such questions would be compared and contrasted.

The validity of the survey instrument was established in terms of its design. A suitable survey instrument did not exist that matched the achievement objectives for level four astronomy in *Science in the New Zealand Curriculum*. Hence one was designed, mainly

utilising one-level and two-level multiple choice questions. The achievement objectives were analysed and items written to closely reflect them. These were critically examined with regard to content validity and construction. The cycle of analysis, construction and examination was repeated until the survey was thought likely to reveal the astronomy knowledge and concepts of the pupils in the intervention class. The validity of the pupil interview protocol was developed in a similar way to the development of the pupil survey.

Validity and reliability of data is enhanced by the process of *triangulation*, which is an essential process for qualitative research (Cohen and Manion, 1994; Demastes, Good and Peebles, 1995; Johnson and Gott, 1996). Because several methods are required to gain understanding of a concept or process (Solomon, 1992), triangulation uses two or more methods of data collection (Milne and Taylor, 1995; Shepardson, 1996; De Posada, 1997) to enhance plausibility and to contrast pupil responses (Hopkins, 1993). This is because pupils may answer questions differently in different contexts such as surveys and interviews. With triangulation, then, the researcher gains greater confidence in any data gathered. In this research, pupils' astronomy concepts were investigated by:

* interviews with a representative group of pupils;
* specially-designed one-level multiple choice questions in the survey instrument;
* specially-designed two-level multiple choice questions in the survey instrument;
* analysis of transcripts of lessons.

5.5.3 Ethical Considerations

All researchers at the University of Waikato are required to gain approval for their research proposal by submitting it to an Ethics Committee, a process which ensures that no research participants will be exposed to acts which could harm them or diminish their self esteem. This procedure was followed for this research. The pupils were informed that they were taking part in research in an attempt to improve astronomy teaching, an approach similar to the one adopted by Farenga and Joyce (1997). They knew they were being audio-taped, they were told of their right to withdraw at any time and they were offered transcripts of all interviews, which were conducted only after gaining the permission of themselves and their care-givers (Rye, Rubba and Wiesenmayer, 1997).

Furthermore, as advocated by Douvdevany, Dreyfus and Jungwirth (1997), it was made clear that the anonymity, privacy and confidentiality of all participants would be observed. Thus the school and all participants in the research were allocated pseudonyms. In addition, the intervention teachers were not shown their pupils' survey or interview responses, which were taken away for transcription and analysis by the researcher (Langley, Ronen and Eylon, 1997).

As noted above, pupil interviews were conducted during normal class times and the interventions, both pilot and trial, were taught in the times during which astronomy had previously been scheduled. That is, there was minimum change to the classroom programme.

5.5.4 The Role of the Researcher

Researchers have an empirical role in gathering data while being sensitive to the classroom environment, noting the inter-relatedness between the means and ends of the research, accepting that their presence is likely to affect classroom discourses (Ritchie, Tobin and Hook, 1997) and in adopting a flexible approach to changing circumstances. In addition in this case, the researcher designed the astronomy intervention package, provided support for the intervention teacher in terms of a source of suggestions and additional help in the classroom (Appleton and Asoko, 1996) and was present in the classroom during each of the lessons.

The researcher was responsible for the validity of the research. He has many years of experience in education, at all levels from Year 7 to tertiary, 29 years of that time in the city in which the research was conducted. He has interacted with the research school for many of those years and is regarded as an authority on science education in general and on astronomy education in particular. He is well aware of the daily challenges, distractions and rewards of classroom life.

The researcher was responsible for all aspects of conducting and reporting the research. This included audiotaping all lessons and interviews, observational accounts of each lesson, triangulating, analysing the data, considering alternative explanations for results, setting respondents sufficiently at ease so that they responded honestly and reporting the results. The researcher provided and discussed the astronomy unit with the intervention teachers, who were then free to interpret it within the framework.

5.5.5 Summary of Section 5.5

Section 5.5 discussed how the procedures adopted in this study were effected to ensure the validity and reliability of the data. In addition, ethical considerations were outlined and the role of the researcher was made explicit.

5.6 THE RESEARCH PROGRAMME

The context chosen for the intervention was a typical classroom in a New Zealand intermediate school (Years 7-8). An intermediate school was chosen because they are the end-point of primary school education (years 1 to 8). Thus any findings will give important information about astronomy mental models and concepts at the stage prior to beginning high school (Years 9 to 13). Furthermore, Year 8 is the last year in which pupils are mostly taught by general rather than specialist teachers, so findings are likely to be meaningful to a wide range of teachers.

A further pragmatic consideration was that intermediate schools are more flexible in their timetabling than are high schools, thus research access is more easily facilitated. In addition, the researcher has more frequent professional and collegial relationships with intermediate schools than he has with secondary schools.

The astronomy intervention was constructed by the researcher in accordance with the guiding principles and specific features outlined in chapter four, with an emphasis upon individuals co-operating in groups to construct mental models (Hand and Vance, 1995) that reflect the level four astronomy achievement objectives in *Science in the New Zealand Curriculum.* Because it had to meet school requirements, the intervention was to consist of twelve lesson plans which included teacher moves, pupil moves, pupil work books and tables of data needed by the pupils for the activities. The researcher provided all the pupils' and teachers' written materials, as was the procedure for Hennessy, Twigger, Driver, O'Shea, O'Malley, Byard, Draper, Hartley, Mohamed and Scanlon (1995b). The trial version of these is shown in Appendix A.

Pilot studies are often considered desirable (Boyes and Stanisstreet, 1997; Marques and Thompson, 1997; Palmer and Flanagan, 1997). In this case, the approach was similar to that of Banet and Nunez (1997). That is, the pilot intervention was conducted to gauge the effectiveness of the package for the teacher and pupils and to inform the researcher of the practicability of the package, the data-gathering and its analysis. The whole intervention procedure was piloted with a year two teacher and her Year 7-8 class in the time already scheduled for teaching astronomy.

The pilot intervention was thoroughly analysed, critiqued and modified as necessary into a final trial intervention which reflected what was learned during the pilot intervention. Because much of what occurred during the pilot intervention was similar to the trial, the former is not reported in full in chapter six. Instead, emphasis is placed on two aspects: the lessons learned from it about conducting the research and findings about New Zealand pupils' prior views about astronomy, models and their mental models of the Sun-Earth-Moon system (refer to Figure 5.10.1).

The latter is important because the pilot was designed using data about pupils' prior astronomy concepts gained from the international literature. The trial, however, could then be based on New Zealand pupils' views established in the pilot intervention. The trial intervention will be fully described in chapter seven. It occurred one year later with a different Year 7-8 class and a different year two teacher. As with the pilot, the trial intervention was conducted in the time previously scheduled for teaching astronomy.

In summary, the data collection for the study consisted of interviews with twelve New Zealand Year 7-8 teachers about their views of teaching astronomy; interviews with the two intervention teachers; pre- and post-interviews with a representative sample of pupils in the intervention classes; pre-, post- and post-post pupil surveys and lesson transcripts. The data collection is outlined in Table 5.6.1.

Table 5.6.1: Data Collection During the Research

	Time	Group	Methods	Reference
Preparatory	March 1995	12 Teachers of Year 7-8 Pupils	Interviews with Teachers	Chapter 6
Pilot Intervention	November 1995	Pilot Intervention Teacher plus 32 Year 7-8 Pupils	Pupils: Surveys, Interviews, Lesson Transcripts	Chapter 6
Before Trial Intervention	October 1996	Trial Intervention Teacher plus 33 Year 7-8 Pupils	Trial Teacher Interview plus Pupil Pre-survey and Interviews	Chapter 7
During Trial Intervention	October 1996	Trial Intervention Teacher plus 33 Year 7-8 Pupils	Trial Teacher Interviews plus Lesson Transcripts	Chapter 7
Post Trial Intervention	October 1996	Trial Intervention Teacher plus 33 Year 7-8 Pupils	Pupils: Surveys, Interviews, Lesson Transcripts	Chapter 8
Post-post Trial Intervention	November 1996	33 Year 7-8 Pupils	Post-post survey	Chapter 8

5.7 PROFILES OF THE INTERVIEWED TEACHERS

The twelve interviewed teachers of Year 7-8 pupils were allocated codes (T1 to T12) to preserve anonymity. The pilot intervention teacher is not among these twelve teachers but T4 was the trial intervention teacher. The teacher profiles are shown in table 5.7.1.

Table 5.7.1 reveals there was a wide range of teaching experience among these teachers, both in the primary school system in general and at the Year 7-8 level in particular, ranging from three beginning teachers to two teachers who each had almost 18 years of experience. Primary teachers in New Zealand may teach at all levels from Year 0 to Year 8, so T7 is unusual among the more experienced teachers in having spent the whole of her teaching career teaching Year 7-8 pupils. On average, these teachers had spent more than half their careers teaching Year 7-8 pupils.

None of these teachers had studied astronomy since leaving school, and only three of them had studied any science at tertiary level (one 100-level paper each). T4 and T5 had studied one biology paper and T12 had completed one earth science paper which did not include any astronomy topics. All the interviewed teachers had completed an introductory science education course in their Diploma of Teaching or Bachelor of Education courses.

Despite astronomy being a compulsory part of *Science in the New Zealand Curriculum*, which is itself compulsory in New Zealand schools, only seven of these twelve teachers had previously taught astronomy. T10 had taught it to three different age levels, T12 had taught it to two different age levels and T2, T6, T7, T9 and T11 had each taught it to one age level. The term *level* is used in the same way as in *Science in the New Zealand Curriculum*. Only five of these teachers, T2, T7, T9, T10 and T12, had previous experience in teaching astronomy to Years 7-8 pupils.

Table 5.7.1: Profiles of the Twelve Teachers of Year 7-8 Pupils

Code	Teaching Qualifications			Teaching Experience			
	Teacher Education Qualifications	Science Papers in the Qualification	Astronomy Papers in the Qualification	Total Teaching Years	Years Teaching Years 7-8	Prior Astronomy Teaching Experience	Levels of Prior Astronomy Teaching Experience
T1	Dip.Tchg.	None	None	0.8	0.8	None	None
T2	B.Ed.	None	None	0.8	0.8	Yes	Years 7-8
T3	B.Ed.	None	None	0.8	0.8	None	None
T4	B.Ed.	One	None	2.8	1.8	None	None
T5	B.Ed.	One	None	2.8	2.8	None	None
T6	B.Ed.	None	None	5.8	2.8	Yes	Years 1-2
T7	Dip.Tchg.	None	None	10.8	10.8	Yes	Years 7-8
T8	B.Ed.	None	None	11	4.8	None	None
T9	B.Ed.	None	None	12	6.8	Yes	Years 7-8
T10	Dip.Tchg.	None	None	14	2.8	Yes	Years 3-8
T11	Dip.Tchg.	None	None	17.8	1.8	Yes	Years 4-5
T12	Dip.Tchg.	One	None	17.8	14.8	Yes	Years 1-2 & 7-8
Mean				8.1	4.3		
S.d.				6.6	4.4		

Note: Dip.Tchg. = Diploma of Teaching, the minimum trained teacher qualification
B.Ed. = Bachelor of Education

Comment

As the teachers were self-selected in that they responded to a request to be interviewed, the extent to which they are representative of Year 7-8 teachers in New Zealand is not

known. It seems apparent that these teachers, in general, are not sufficiently prepared for teaching astronomy as suggested by *Science in the New Zealand Curriculum*. That conclusion is based on the assumption that adequate preparation includes:

* background knowledge in the subject - none of these teachers had studied astronomy beyond their own schooling.
* science education preparation - none of these teachers had studied science education beyond the introductory level, and most of their studies had occurred before the introduction of *Science in the New Zealand Curriculum.*
* astronomy education preparation - none of these teachers recalled astronomy being part of their science education course.
* previous experience in teaching astronomy - very few had taught astronomy before, other than very short units of work.

5.8 CONTEXTUAL FACTORS: THE SCHOOL, THE PILOT TEACHER AND THE TRIAL TEACHER

5.8.1 Introduction

This section briefly describes the school and the teachers who co-operated in the research. They are considered in the following sequence:

* a description of the school (section 5.8.2);
* a description of the pilot intervention teacher (section 5.8.3);
* a description of the trial intervention teacher (section 5.8.4).

5.8.2 A Description of the School

The particular intermediate school where the pilot and trial interventions were held was chosen because:

* of its proximity to the university which employs the researcher;
* good professional relationships between the school and the researcher have been established over a period of many years;
* pupils in Normal schools are used to people coming in to the school to observe and/or teach them.

(Normal schools in New Zealand are primary and intermediate schools that have a close relationship to their nearest teacher education facility. Student teachers regularly teach small groups of Normal school pupils as part of their teacher education programme).

The school is a state co-educational Normal intermediate school with a roll of about 600 pupils. It has eighteen teachers plus a principal, deputy principal and assistant principal. It is situated in an inland city which serves a large rural area. Most of the school's Year 7-8 pupils live locally and most of them previously attended one of four Years 0-6 schools. However, a small minority travel to the school from across town or from neighbouring rural areas.

The principal of the intermediate school was very supportive of the research and arranged a meeting with five teachers at the school who had shown an interest in the research. At that meeting, three teachers withdrew because they had no plans to teach astronomy in the near future. Of the other two teachers, one (Ms T) was planning to teach it in the latter half of 1995 and the other (Mr T) was planning to teach it in the latter half of 1996. Thus it was agreed to pilot the intervention with Ms T in 1995 and conduct the trial intervention at a similar time in 1996 with Mr T. Mr T is T4 among the twelve New Zealand Year 7-8 teachers who were interviewed.

5.8.3 A Description of the Pilot Intervention Teacher

Ms T was nearing the end of her second year of teaching at the time of the pilot intervention, both of those teaching years at the same intermediate school. She had no formal qualifications in science content, including astronomy, beyond her own schooling, but she had studied curriculum science papers to 300-level as part of her B.Ed. degree. She had no previous experience of teaching astronomy. She was outgoing, energetic and creative.

5.8.4 A Description of the Trial Intervention Teacher

Mr T was nearing the end of his second year of teaching at the time of the trial intervention, both years at the same school. He was in his mid-thirties and was trained as a generalist primary school teacher, attaining B.Ed. qualifications, during which he studied one biology paper and one curriculum science paper, both at the 100-level. He had a particular interest in computers and science and, subsequent to the research, he was made responsible for the science education programme in the school. He had no previous experience of teaching astronomy but had taught two science topics.

5.9 CONTEXTUAL FACTORS: THE CLASSES AND THE CLASSROOMS

5.9.1 Introduction

This section briefly describes the pilot and trial classes and the classrooms in which the astronomy intervention was taught. They are considered in the following sequence:

* the pilot and trial intervention classes (section 5.9.2);
* the intervention classrooms (section 5.9.3).

5.9.2 The Pilot and Trial Intervention Classes

All classes at the school are composite Year 7-8 classes of about 30 pupils, chosen to be as equivalent as possible. To this end, before being allocated to their classes, pupils are rated according to their academic, sporting and leadership qualities, as well as compatibility, gender balance and balance between Year 7 and Year 8 pupils. The classes are re-grouped at the beginning of each year. As with all classes in the school, the pilot and trial classes were taught the whole curriculum by the same teacher, except for technology and art, which are taught by specialist teachers.

Ms T's pilot intervention class of 32 pupils consisted of seven Year 8 girls, eight Year 8 boys, nine Year 7 girls and eight Year 7 boys. They had not studied any science during that year. Mr T's trial intervention class of 33 pupils consisted of eight Year 7 boys, eight Year 7 girls, eight Year 8 girls and nine Year 8 boys. Because of the re-grouping, one Year 8 boy, Ian, had been in the previous year's pilot intervention class. However, the intervention teacher was of the view that Ian was a low achiever with a low attention and retention span. He doubted if last year's experience would perturb this year's experience for Ian. The trial intervention class had studied two science topics prior to the astronomy intervention. Very few of the pupils in either class had studied astronomy before.

All pupils in the pilot and trial astronomy intervention classes were randomly allocated individual aliases by the researcher.

5.9.3 The Intervention Classrooms

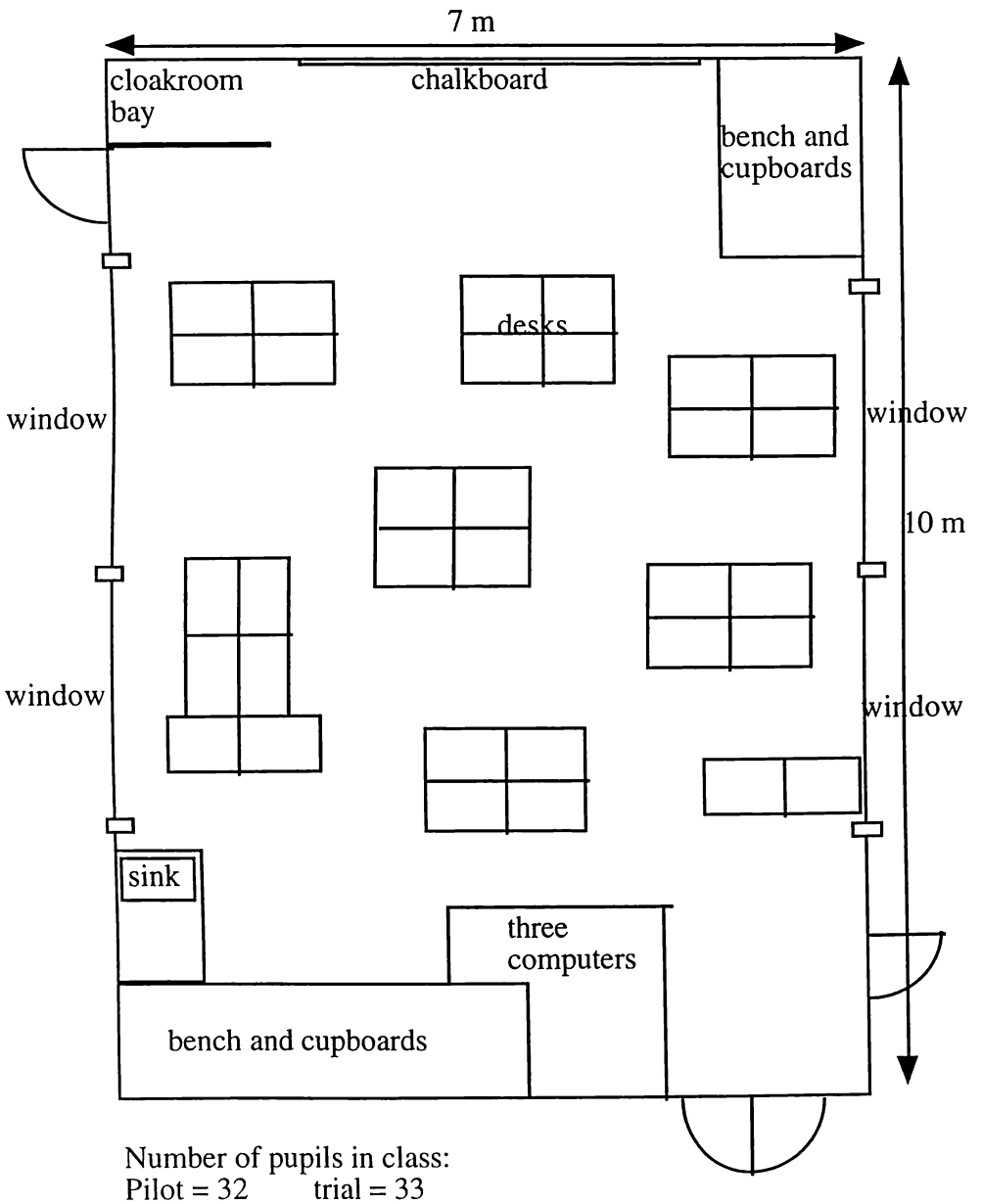


Figure 5.9.1: The Classroom Plan

The pilot and trial intervention classrooms were typical for the school, reflecting the school's group-based approach to teaching all subjects in the curriculum. A plan of the intervention classrooms is shown in Figure 5.9.1. They were essentially identical, being supplied with desks, a chalkboard, a sink, some cupboard space, an overhead projector (but no whiteboard) and computers. As shown, the seating was in groups, chosen by the teacher, so the arrangement varied from class to class. The arrangement shown in Figure 5.9.1 is that chosen by the trial intervention teacher, Mr T.

However, the pilot classroom had only one computer whereas the trial classroom had three computers. The computers were available for teaching, for projects and for game-playing during breaks from teaching. One computer in the trial classroom was connected to the Internet.

5.10 OVERVIEW: THE RESEARCH STRATEGY IN CONTEXT

Figure 5.10.1 is a diagram of the research programme. As shown, the programme consists of three phases - the Initiation Phase, the Data-gathering Phase and the Reflection Phase.

The Initiation Phase was reported in chapters one to three. It consists of:

* international pupils' difficulties with astronomy concepts;
* an international survey of the history of astronomy;
* international classroom astronomy research;
* science teaching and learning theories;
* New Zealand and international previous and current astronomy curricula;
* a literature survey which examined international teachers' views about the challenges of teaching astronomy.

The above facets each contributed to the design of the pilot intervention. In addition, the international teachers' views about the challenges when teaching astronomy were compared to the New Zealand teachers' views in designing the pilot intervention. Similarly, the international pupils' astronomy concepts were later compared with the New Zealand pilot intervention pupils' concepts in redesigning the pilot intervention to the trial intervention.

The Data-gathering Phase is reported in chapters six and seven. The data from the pilot intervention consisted of pupil interviews, pupil surveys and classroom observations. These were analysed in terms of the pilot intervention's practicability and its effectiveness in facilitating pupils' building and repeatedly critiquing their mental models of the solar system in general and of the Sun-Earth-Moon mental model in particular. Data as outlined in section 5.4 were collected. The pilot intervention was evaluated and redesigned to become the trial intervention, which was conducted almost one year after the pilot intervention and during which similar data, as outlined in section 5.3, were collected.

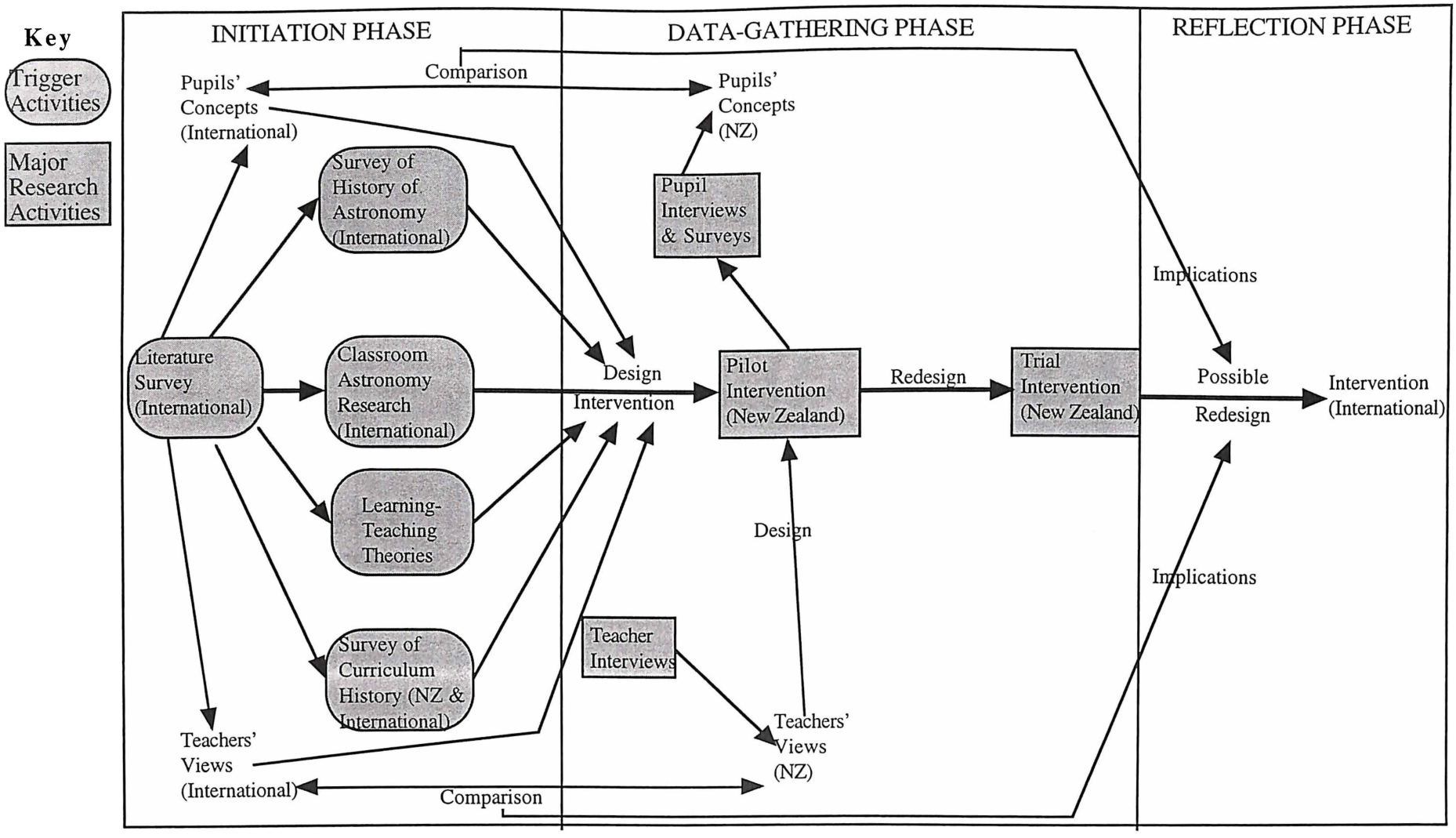


Figure 5.10.1: A Flow Diagram Showing the Development of the Research Programme

The Reflection Phase will be reported in Chapters eight and nine. A possible redesign of the trial intervention was considered in view of the evaluation of the conduct and outcomes of the trial intervention, a comparison between New Zealand teachers' and international teachers' views about the challenges of teaching astronomy and a comparison between New Zealand pupils' and international pupils' experiences in constructing astronomy concepts. This critique indicated a possible further redesign towards an astronomy intervention, to be made available internationally, which would help to facilitate pupils' construction and repeated critiquing of their astronomy mental models.

Section 5.2 listed the five questions that this research addresses. The interpretive methodology adopted for the research was described in section 5.3, and the data which were collected were described in sections 5.4 and 5.5. Section 5.6 described the research programme, and section 5.7 profiled the Year 7-8 teachers who were interviewed. The school and the pilot and trial intervention teachers were described in section 5.8, while section 5.9 described the intervention classes and the pilot and trial intervention classrooms. Finally, in section 5.10, the overall research strategy was described, showing how the individual parts linked within it.

Chapter six will describe the preparatory research. It will describe and evaluate the interviews with the New Zealand Year 7-8 teachers, and will critique the pilot astronomy intervention.

CHAPTER SIX: PREPARATORY RESEARCH: THE YEAR 7-8 TEACHER INTERVIEWS AND THE PILOT INTERVENTION

6.1 INTRODUCTION

Chapter six outlines the preparatory research in three parts. Part One reports the interviews with twelve teachers of Year 7-8 classes, which were conducted to explore New Zealand teachers' views about teaching astronomy (section 6.2) and to assess implications for the design of the pilot intervention (section 6.3).

Part Two of chapter six concerns the pilot intervention, which was conducted to ascertain the intervention's practicability in terms of both research and classroom applicability. Because the trial intervention will be fully described and analysed in chapters 7, 8 and 9, only two aspects of the pilot intervention will be described in this chapter. Part Two also reports interviews with New Zealand pupils (section 6.4), which were conducted prior to the pilot intervention - see Figure 5.10.1. Section 6.5 then describes the implications for the trial intervention which could then be modified to include New Zealand pupils' views in addition to those of overseas pupils.

Section 6.6 (Part Three) reports how the pilot intervention was then redesigned to become the trial intervention. The chapter concludes with a summary of the findings from the teacher interviews and the pilot intervention.

PART ONE

6.2 THE NEW ZEALAND TEACHERS' ASTRONOMY INTERVIEWS

6.2.1 Introduction

Section 6.2 is an analysis of interviews with twelve generalist Year 7-8 teachers in New Zealand. The interview schedule is shown in Appendix B. These teachers were asked to state their views about teaching and learning the specialist area of astronomy, which is part of the *Planet Earth and Beyond* contextual strand in *Science in the New Zealand Curriculum*. The interviews also reflect the fact that *Science in the New Zealand Curriculum* suggests that each contextual strand has to incorporate the integrating strands of *Developing Scientific Skills and Attitudes* and *Making Sense of the Nature of Science and Technology*. The interview data will be presented and analysed accordingly.

The responses to the interview questions are reported in the following sequence:

* New Zealand teachers' general views about teaching astronomy (6.2.2);
* New Zealand teachers' views about the curriculum contextual aspects of astronomy education (6.2.3);
* New Zealand teachers' views about the curriculum integrating aspects of

astronomy education - developing scientific skills and attitudes (6.2.4);

* New Zealand teachers' views about the curriculum integrating aspects of astronomy education - making sense of the nature of science (6.2.5);
* teacher interviews: a summary of section 6.2 (6.2.6).

6.2.2 New Zealand Teachers' General Views About Teaching Astronomy

This section reports the teachers' views about teaching astronomy. It will describe what they consider to be the positive aspects about teaching astronomy and their perceived challenges when teaching it.

Positive Views About Teaching Astronomy

Eight of these teachers were generally enthusiastic about teaching astronomy and showed a learner-centred orientation in stating that its main attraction was that their pupils find it interesting (*I enjoy teaching astronomy because I know the children are motivated... They'd like to do* it [T7]). They felt that astronomy is popular with Year 7-8 pupils because *Kids have a fascination with space and stars and things like that. It's an interest that they can talk about* [T6], which *makes it easier for teachers* [T12]). This emphasis on working from the pupils' interests suggested teacher support for a more interactive approach to astronomy education. Also, pupils at this age are beginning to look beyond themselves: they *like to know where they are and where they fit into the main scheme of things*[T9].

Challenges When Teaching Astronomy

On the other hand, four of these teachers were generally not enthusiastic about teaching astronomy, largely because they felt *Somewhat inadequate. Somewhat struggling for models or concepts to get the ideas across. And to make the children understand* [T11]. Astronomy teaching, compared to other subject areas, was also seen as demanding for teachers (*I find that teaching of science really hard. Yeah. And in astronomy, I guess, the same way* [T3]). They felt the need for teaching approaches that would involve the pupils more than transmissive approaches do (see below).

Figure 6.2.1 shows the twelve teachers' responses when asked what they saw as the main challenges when they teach astronomy. Most frequently mentioned was their own lack of knowledge (*my lack of astronomy knowledge. And being able to find that knowledge quickly* [T11]). This view that astronomy teaching is mainly knowledge transmission was because of a limited view of suitable alternatives rather than because of a commitment to that approach, as shown by T1's comment that *There's not much hands-on stuff.*

Other less frequently mentioned challenges were about finding good teaching ideas and the limited number of astronomy places to visit. Individual teachers expressed views that teaching astronomy is expensive, that it occurs only at night and that pupils have

difficulties with its three-dimensional representations. In addition, one teacher stated a personal lack of interest in astronomy.

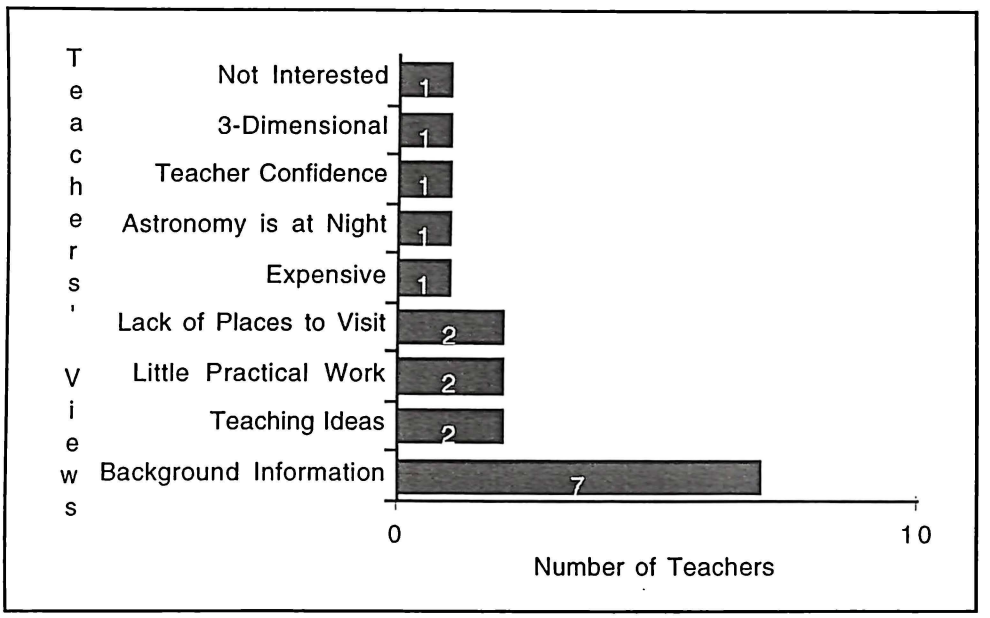


Figure 6.2.1: Teachers' Views of the Challenges in Teaching Astronomy

These teachers' generally pragmatic approach to teaching was indicated in that 75% of them said that they would teach astronomy in whatever time was available to them (*I think if you give yourself 2-3 weeks or 3-4 weeks you build your unit around that time frame. You have to, because you've always got other things to go on with* [T5]). It was seen as requiring no more time than other curriculum areas (*I can't see why it would take any longer or should be any shorter than any of the other subjects* [T1]). On the other hand, two teachers expressed the view that astronomy needs more time than other curriculum areas because *You might have to allow a little bit more, especially when you're doing investigations and displaying and sharing* [T6].

6.2.3 New Zealand Teachers' Views About the Curriculum Contextual Aspects of Astronomy Education

This section expands on the teachers' perceptions about the level of astronomy knowledge they need and the extent to which astronomy has to be taught in a transmissive way. Their views about the availability of resources, about using the specialist language of astronomy and whether pupils have difficulties with the large numbers used to express astronomy sizes and distances are also described.

Teachers' Astronomy Knowledge and Understanding

Nine of the twelve teachers thought that their astronomy knowledge was not sufficient for teaching astronomy: *The teachers themselves needing background information to teach it* [T7]. This contributed to a lack of confidence about teaching it (*Teacher confidence - whether they think they know enough about the topic* [T12]) and even to

its total avoidance by some (*It's probably why I shied away from it last year. I felt incompetent* [T11]), even though it is a compulsory part of *Science in the New Zealand Curriculum*. Table 5.7.1 has already revealed that five of these teachers had not taught any astronomy at all and only five had taught it at the Year 7-8 level.

Nevertheless, three teachers did not see their background knowledge and understanding in astronomy as being a challenge because teachers cannot be expected to know everything. They had a pragmatic approach that teachers can research information before teaching it (... *science isn't a strong area for me. So I'd have to do a lot of research and investigation* [T3]) or they can learn the material along with their pupils (*I think that you're not to be scared to say in a class that you don't know. Can someone help you to find out? Or how can we find out*? [T9]).

Transmissive Nature of Astronomy Teaching

Teaching astronomy is perceived by many of these teachers as being more difficult than teaching other science topics because it is seen as essentially transmissive in nature (*I find scientific explanations hard to teach. And I find it hard to get the children to come to the scientific explanation* [T3]). This is especially so when the explanations require an understanding of three-dimensional structures (*Explaining and concepts, three dimensional concepts to the children* [T11]). However, one teacher saw advantages in having to teach astronomy tranmissively because *it's more or less facts and things, it's not as hard to teach. So I wouldn't find it as hard as what I would experimental-type scientific teaching* [T3].

Lack of Resources

Eight of the teachers did not think that availability of resources posed problems when teaching astronomy. This was because they did not perceive a resources shortage (*I've found we just had so many... the observatory... speakers into the classroom... Oodles! There's oodles out there. Wall charts, yeah. Book resources, CD Roms, information. It's all there* [T10]), or because they simply expected that resources would be readily available when needed (*I haven't gone out to look for them because I haven't had to come across teaching it yet. I think they're there if you want them* [T3]), or because of a pragmatic acceptance of using whatever was available (*Sometimes we just have to be thankful with what we've got. But I think if you draw from the children and their parents. And quite often I ask my kids to come up with the resources* [T7]).

Only four teachers thought that there was a lack of resources, particularly models, for teaching astronomy in that *It's not easy to compare something that's so vast. You need resources that can actually pull it down to something smaller and much more manageable, so the kids can actually understand it* [T1]. One teacher was of the view

that any shortage of resources was due to their high cost (*Well, I know planispheres and those sorts of things are reasonably expensive. And you'd need one each or one between a pair or something. To get the equipment, telescopes, is way out for most schools* [T12]).

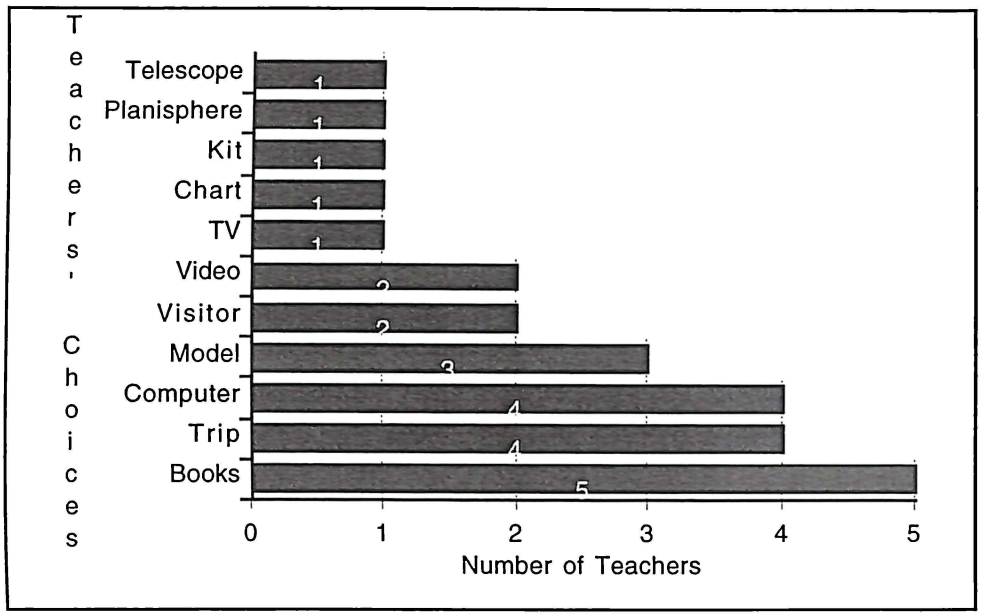


Figure 6.2.2: Teachers' Preferred Astronomy Resources

Figure 6.2.2 shows the teachers' responses when they were asked which resources they would like to have to teach astronomy. It supports the inference that fact-based transmissive teaching is favoured among these teachers. Of the 25 responses offered, 72% of them (books, computers, models, visitors, videos, TVs and charts) are mainly information-transmissive, although it is possible to use investigative approaches with them. Only one teacher mentioned resources (telescopes and planispheres) that pupils could use to gather astronomy information for themselves. However, four of these teachers would like opportunities to take their pupils on trips to such places as observatories, where they would get the opportunity to look through a telescope.

Language

Seven teachers thought that the specialist language used in astronomy would not pose any particular difficulties for Year 7-8 pupils, although *All the children were different, I guess. They picked it up and got different things from it* [T2]. In fact, some of the pupils *like to explore new language* [T6]. It was thought that most pupils *would sort of accept it. They might not be able to spell it, but that's what it's called* [T12]. This is probably *because of TV. It's actually part of their language, although it's not everyday language* [T10]. The teachers' pragmatism is again evident in that they would introduce the specialist language gradually (*If you did it slowly and introduced terms in each lesson, I don't think terminology is a difficult task for children to learn* [T3]).

However, four of the teachers expected some difficulties because *Oh, personally I find that quite confusing. So I'm sure they will* [T1], especially the less able pupils (*The average kids and the below average kids would find it quite hard* [T7]). This was because astronomy language is used nowhere else (*I think a lot of them, sort of, it's a bit mind boggling; we don't use light years usually for anything else than talking about astronomy* [T11]).

The Scale of Things

The large scale of sizes and distances in astronomy was seen by nine of the twelve teachers as *Totally mind-blowing* [T1] and a *major problem* [T11] for Year 7-8 pupils. These concepts were seen as *hard to comprehend, I suppose, for anyone* [T3], while T4 was of the view that *those sorts of numbers go straight over their heads.*

However, three of the teachers did not think that astronomy sizes and distances were a problem in astronomy. For T2 it was because *They like large numbers. Kids in my class love big numbers* and T5 would use scale models to better explain the sizes and distances (*But you know how you can put it to scale... And they can look at the scale and you can put that in another dimension* [T5]). T5 seemed to be unaware that no such scale model of the solar system exists and, furthermore, that is a valuable concept to develop with pupils.

6.2.4 New Zealand Teachers' Views About the Curriculum Integrating Aspects of Astronomy: Developing Scientific Skills and Attitudes

This section reports the teachers' views about the integrating strand *Developing Scientific Skills and Attitudes* when teaching astronomy. It will consider their perceptions of the role of practical work in astronomy education, of Year 7-8 pupils' ability to conduct astronomy observations and of Year 7-8 pupils' understanding of the role of models in astronomy education.

The Role of Practical and Investigative Work

These teachers tended to have a view that investigative skills are limited to information gathering from media, shown by T5's comment that *I find a lot of children when you send them off to do that, they haven't actually learned how to gather information and take their own notes. So there's a lot of plagiarism,* or they consider that astronomy investigations are limited to *planning and reporting really. Astronomy does lend itself to that* [T12]. Seven of the teachers lamented a perceived paucity of practical work in astronomy education, with T2 noting that a difficulty in using investigative skills was that *I guess I don't really know how to set that up.* T7 wanted *some more hands-on sort of practical sorts of activities*. Their lack meant that astronomy teaching often *became too language based* [T2].

However, the other five teachers did not see investigative skills in astronomy as a problem because they could teach them to the pupils (*But if you set the guidelines first, OK, and model them. And then going to the kids OK, now you're going to do your own investigation...* [T7]). An advantage, in fact, was seen in that *those skills can also be used in other areas* [T7].

Pupils' Ability to Conduct Astronomy Observations

Only one teacher responded that her Year 7-8 pupils *would be capable of doing the observations themselves* [T6]. Two more teachers saw observing as a *great idea, 'cos if you see it, it would stick in their mind* [T2]. Contrariwise, two teachers thought that their pupils would not have the skills to conduct astronomy observations. T10 reported *That is an area that we've specially included in our programme. And it was a Moon watch. And even things like that were very difficult* [T10]. T11 agreed and added *But I might be wrong. I mean, I lack the skills there* [T11].

Nevertheless, the other nine teachers thought that observing astronomy events would be valuable but not really worth the effort involved because *it's quite hard to organise things like that. And it depends on lots of things within our school* [T7]. Also, astronomy events occur mainly at night *And that's when we don't have access to the kids unless you're on a school camp or something like that* [T6]. T5, in fact, regarded night observing as an imposition on her because *that sort of requires staying over at night and I'm a bit reluctant to use up my personal time for school things.* A further perceived challenge to organising astronomy observations was that the organisation can be confounded by factors exemplified by *We went up to the observatory. But we are determined once again by the weather and then also relying on other people* [T9].

Pupils' Understanding of Models

Eight of the twelve teachers considered that Year 7-8 pupils can understand how scientists use models because they *tend to be able to relate better to visual than to reading in a book* [T3]. Also, *they use them to show what they've found out* [T9] when they *create their own models of things. Creating the models and relationships in space. To make it observable* [T6], and because models help pupils *to sort of scale down something and see it. It's actually there and physical.* [T1].

Only two of the teachers thought that Year 7-8 pupils would not understand how scientists use models, *unless they're making them themselves. They don't really get any great insight into it* [T10]. However, the teachers' comments reveal that they themselves have a limited view of models only as three-dimensional scale representations of reality: *I think astronomy would definitely help kids to understand about using models... to scale down something and see how vast it is* [T1]. No teacher mentioned

the role of mental models or other representations of reality such as pictures.

6.2.5 New Zealand Teachers' Views About the Curriculum Integrating Aspects of Astronomy: *Making Sense of The Nature of Science*

This section reports the teachers' views about pupils' abilities with respect to the nature of science part of the integrating strand *Making Sense of the Nature of Science and its Relationship to Technology*. It will consider the teachers' perceptions of Year 7-8 pupils' ability to critically evaluate astronomy ideas and processes and to understand that astronomy ideas change over time.

Ability To Critically Evaluate Astronomy Ideas

The teachers were almost evenly split about the abilities of year 7-8 pupils to critically evaluate astronomy ideas. While the media were seen positively in this respect (*I would suspect that they'd do it reasonably well because there's been a lot of information coming across the news about astronomical things* [T4]), the teachers acknowledged that they would need to specifically teach this skill (*You're going to have to take them through the process, I think, to get them to do that by themselves. I think it is within their capabilities, for this age group* [T5]).

However, seven of the teachers thought that such skills would be limited for Year 7-8 pupils (*Personally, I don't think it's really that feasible* [T10]). This was because *I don't know whether they've got the knowledge. I think that that's a difficult skill for them to achieve* [T6] or the skill was limited to *older children, and the more mature thinking children* [T2]. It was also thought that some pupils would be reluctant to be critical because of their personal values: *Sometimes the kids don't want to be critical, because sometimes it can be seen as being rude* [T7].

Ability To Critically Evaluate Astronomy Processes

Seven teachers thought that this would be a limited objective for most Year 7-8 pupils because *they struggle to criticise and make fair tests in other areas* [T11]. It was felt the pupils would just accept ideas put to them (*I think they think that obviously if it's written down, or if they're getting their data from a computer, then obviously some-one's put it in. I mean, it's been published so it's obviously right. I think that's sometimes how they feel* [T7]). However, teachers might not have previously encouraged this skill (*When I sort of look back at what I'd done, I felt it could have been as much my teaching as anything else* [T4]). In fact only two of these teachers thought that Year 7-8 pupils would be able to attain this skill because *A lot of children at intermediate* (school) *are really inquisitive about things. I think they're ready* [T2].

An Awareness that Astronomy Ideas Change Over Time.

Ten teachers responded that Year 7-8 pupils could understand that astronomy ideas

change over time, the media being a key factor in this (*I think everyday TV situations, space shuttle and "Beyond 2000", you know, those sorts of programmes* [T10]), as were pupils' personal experiences (*Yeah, I think that they'd be more readily able to grasp that one. They can see things changing for themselves* [T8]). Also, pupils *can draw comparisons with, I guess, what their parents knew and what they know. And they can see the changes into... as to what people thought in the past and what they think now* [T2]. The awareness could be taught through a broad knowledge of history (*If you just went back into history a little bit and did a bit of what they used to believe and that the Earth was the centre of the universe and all that sort of thing. I personally think Years 7 and 8 could easily cope with that* [T12]).

The other two teachers expressed reservations about this objective. For example, T1 thought that *I imagine they'd be sort of, like, taken aback, and say "Hang on". I think it'd be just like any amount of change... any idea. Be a bit off-putting* [T1].

6.2.6 The Teacher Interviews: A Summary of Section 6.2

This section is a summary of the views expressed by the twelve New Zealand teachers. They are tabulated in the same sequence reported in sections 6.2.2 to 6.2.5.

Astronomy: the contextual strand

In general, many of these teachers:

* felt quite positive about teaching astronomy;
* thought that Year 7-8 pupils are interested in astronomy;
* felt quite inadequate about their content knowledge for teaching astronomy;
* saw astronomy teaching as being essentially transmissive;
* perceived that teaching astronomy was more difficult than teaching other science topics;
* wanted knowledge of teaching approaches that involve the pupils more than transmissive approaches do;
* wanted resources that help them to more efficiently explain astronomy concepts to their pupils;
* wanted better and more up-to-date information sources;
* saw no problem with the time available to teach astronomy.

Astronomy and models

Many of these teachers:

* thought that the large sizes and distances in astronomy were a major problem for pupils, although a minority felt that the pupils would enjoy trying to understand them;
* thought that Year 7-8 pupils were able to understand how scientists use models;
* had a limited view of the role of models in astronomy;
* saw models only as three-dimensional scale representations of reality.

Astronomy and investigative skills and attitudes

Many of these teachers thought that:

* investigative skills in astronomy are almost exclusively to do with information-gathering directly from media such as books, computers and videos;
* the difficulties in observing astronomy events are not worth the effort involved;
* astronomy events occur mainly at night;
* organising astronomy observations is difficult and time-consuming.

Astronomy and the nature of science

With respect to the nature of science, many of these teachers:

* thought that only the higher ability pupils are able to cope with the specialised vocabulary used in astronomy;
* were undecided on whether Year 7-8 pupils are able to critically evaluate astronomy ideas;
* felt that Year 7-8 pupils, other than the high ability ones, are not able to critically evaluate science processes;
* thought that Year 7-8 pupils can understand how astronomy ideas change over time.

The overall impression from the New Zealand teacher interviews

The overall impression gained from the interviews with these New Zealand teachers is that they:

1. are very classroom orientated in response to questions. Many questions of a general nature were responded to by reference to what the teachers either had specifically done with their classes or might propose to do.
2. are very receptive to basing their teaching around pupils' interests, which are seen as being strong in the case of astronomy. This emphasis on working from the pupils' interests suggests support for a more interactive approach to astronomy education.
3. are orientated towards a content-transmissive approach rather than to pupils' thinking skills or their investigative skills. However, this is because of a lack of knowledge of alternatives rather than because of a commitment to that approach.
4. mainly limit their view of resources to content-transmissive media such as books, videos and CD Roms.
5. are not sufficiently conversant with the nature of science aspects in *Science in the New Zealand Curriculum* despite the fact that it is a required integrating strand.
6. have little understanding of how astronomers use models. They wanted physical models that could better explain astronomy concepts, once more suggesting that a transmissive approach is favoured by these teachers.
7. have little understanding of how astronomers use mental models.
8. are very pragmatic in that:
    * the teachers would plan coverage of a given topic that fitted into the time that the school made available to them;

* astronomy is not seen as a subject area with a greater demand on their time than other areas;
* while accepting their lack of astronomy knowledge, some teachers adopt the approach that teachers can always research the information before teaching it or they can learn the content along with their pupils;
* the perceived lack of resources would be accommodated by using whatever was available in the school and from the pupils and their families;
* while accepting that the specialised nature of astronomy terminology could be a problem, they would introduce the language gradually.

So, difficulties notwithstanding, if the New Zealand teachers are asked to teach astronomy, then they accept that and pragmatically plan for it. This was best summarised by the teacher who commented:

> *But if I had been told this was what I had to do, if it was my job to do, then I guess there's always the advisory. I've used them for other areas.* [T5]

6.3 THE TEACHER INTERVIEWS: IMPLICATIONS FOR THE PILOT INTERVENTION

From the interviews with the twelve New Zealand teachers, four general implications for the pilot intervention emerged.

The contrary views that these teachers feel positive about teaching astronomy, and yet also see it as being more difficult than teaching other science topics because of their lack of knowledge about teaching it in other than a transmissive way, will need to be addressed in the pilot intervention. Firstly, therefore, the pilot intervention will need to include up-to-date astronomy information for the teacher plus guidance in helping the pupils to be actively involved in constructing astronomy concepts (rather than passively receiving them from the teacher or from other media) and to build and successively critique their mental models of the solar system and of the Sun-Earth-Moon system.

Secondly, the teachers' own limited view of the role of models as scaled three-dimensional representations of reality will need to be addressed in the pilot intervention. The intervention will therefore include models, particularly the orrery, which will be critiqued in terms of their ability to describe and explain known astronomy phenomena such as phases of the Moon. The pupils will be assisted to construct the scientists' mental model as new information is accommodated into their existing mental model of the Sun-Earth-Moon system. In addition, an attempt will be made to build a scale model in the classroom of the solar system. The impossibility of this task will also be critiqued.

Science in the New Zealand Curriculum insists that investigative skills be employed

when topics are learned by the pupils. However, the interviewed teachers' views of the investigative skills in astronomy were limited generally to information-gathering from a variety of media and to observing, a skill they are reluctant to engage in. Thirdly therefore, the pilot intervention will clearly state both learning objectives and investigative skills objectives for each lesson. Furthermore, each lesson plan will include detailed suggestions by which the investigative skills objectives and the learning objectives can be addressed by the teacher and pupils.

The interviewed teachers were generally optimistic about Year 7-8 pupils' abilities with respect to the nature of science, except for the skills of critically evaluating astronomy ideas and processes. Thus fourthly, the specialised language of astronomy will not be avoided in the pilot intervention. Critically evaluating (critiquing) astronomy ideas, in the form of pupils' concepts and mental models, is the central focus of the intervention, as outlined above. Thus the pupils will engage in the skill of critically evaluating science processes when they attempt to build the model of the solar system and when they design experiments to test competing concepts uncovered within the class.

PART TWO

6.4 THE NEW ZEALAND PILOT PUPILS' ASTRONOMY INTERVIEWS

6.4.1 Introduction

Interviews with four New Zealand Year 7-8 pupils in the pilot intervention class are reported in section 6.4. These were conducted to enable the trial intervention to be informed by the views of pupils of the school in which the trial will be implemented. The interviews were conducted immediately preceding the pilot astronomy intervention and will be reported in the following sequence:

* pupils' general astronomy knowledge (section 6.4.2);
* pupils' mental models of the Sun-Earth-Moon system (section 6.4.3);
* pupils' astronomy concepts (section 6.4.4);
* pupils' views of models and science (section 6.4.5);
* pupils' views: a summary of section 6.4 (section 6.4.6).

The pilot teacher selected four pupils to be interviewed. They were one Year 7 boy (referred to as B7), one Year 7 girl (G7), one Year 8 boy (B8) and one Year 8 girl (G8). G7 was 11 years old and the other three pupils were 12 years old. No two had attended the same primary school prior to the intermediate school and none of them had previously studied any astronomy in school, except for one who had *looked at some stars on a school camp* [B7]. Three of the pupils were *Not really* interested in astronomy, although G7 showed enthusiasm for the topic by saying *Oh, yeah. 'Cos I don't know much about it so I'm learning it.*

6.4.2 Pupils' General Astronomy Knowledge

The interviewer asked questions about particular planets and the structure of the solar system. These pupils did not understand the term 'the solar system', only one responding correctly by saying that *It's all the planets that go round the Sun* [B8]. Two were unable to answer the question and G7 was confused whether the Sun or Earth was the centre of the orbit (*Like the... like the planets around the Sun. And all those other things that are around the Earth. Like the same distance away* [G7]). Only G7 knew the reason it is called the solar system is because *It's got the Sun - that's like solar. And it's a system which runs by the Sun* [G7].

However, three of the pupils were able to place astronomical objects in order from the smallest to the largest, as shown by *Moon, Pluto, Earth, Jupiter, Sun, Solar System, Galaxy, Universe* [B7]. On the other hand, G8 showed some confusion, taking two attempts to offer *Pluto, Earth, Jupiter, Moon, Sun, Solar System, Galaxy, Universe.*

All except G8, who said *I think it's Mars*, correctly responded that Mercury is the nearest planet to the Sun. Conversely, only G8 correctly answered that *Pluto* is the smallest planet. The other three pupils responded that the smallest planet is *Mercury* [B8]. Three of the pupils answered correctly that the largest planet is *Jupiter* [G7], G8 answering incorrectly that the largest planet was *Saturn.* G8 and B7 were unable to name the planet that is very large and has a big red spot on it, but G7 and B8 correctly responded that the planet is *Jupiter.*

6.4.3 Pupils' Mental Models of the Sun-Earth-Moon System

The interviewer asked questions about which objects orbit around which other objects, and how long the orbits take. These pupils' mental models of the Sun-Earth-Moon system were found not to be in agreement with that of astronomers' views that the Moon takes one month to orbit Earth and Earth takes one year to orbit the Sun. These pupils, then, would apparently be unable to explain related concepts such as days, months, years, seasons, phases of the Moon and tides.

All four pupils had the scientifically accepted view that, for Earth, *We move round the Sun. Yeah, we move round the Sun. All the planets move round the Sun* [B7], but they were all unsure why they thought that. G8 admitted that she had guessed and that it *Could be the other way round*, while two of them just knew it from somewhere, such as *Well, in pictures I've seen and in movies and stuff* [B7]. The teachers' views (section 6.2) about the influence of the media appear to be supported. B7 used an analogy to explain his view in that *Well, the Sun's so big and the Earth's really tiny. So it's like an ant going round the classroom, really* [B7].

When asked how long it takes for Earth to go round the Sun, only B8 responded with

some accuracy that *Well, is it 300... a year?... 300 and something days*? The other responses varied from *24 hours* [G7], through *Maybe a month or a year* [G8] to *About a hundred years maybe* [B7]. When they were asked why they thought that, they were unable to respond.

When they were asked whether the Moon orbits Earth or vice-versa, only G7 and B8 answered correctly. B7 thought that *Earth goes around the Moon, I think*, while G8 showed uncertainty in responding that *I know one of them goes round the other.* Only B7 attempted to provide a reason for his viewpoint, saying that *I'm not too... Don't know how... I just... Well, people just answer me that, ask me that, about the Moon. It's the Earth that moves around the Moon.*

When the pupils were asked how long they thought it takes for their chosen object to get around the other, B7 was not sure and the other three responses were similar to G8's that *Maybe... 24 hours or something.* Three pupils were unable to answer why they thought that, while G7 indicated a belief that related the Moon with night-time by responding *Because that makes 24 hours in a day and about half of that is night- time and half of it is day-time, and if... you see the Moon when it's night-time, and it's 12 hours and it's half the Earth.* A view that the Moon orbits Earth every 24 hours would mean that scientists' explanation of the phases of the Moon would not be understood.

6.4.4 Pupils' Astronomy Concepts

This section reports the pupils' astronomy concepts about day and night, years, seasons, eclipses, phases of the Moon and tides. These concepts are subordinate to mental models of the Sun-Earth-Moon system.

Pupils' Concepts About Day and Night

These pupils generally had a scientifically acceptable view of the causes of day and night. For example, B7 explained the phenomenon by saying *The world spinning round. When you shine a torch on the corner, on the world, only half of it lights up. As the world spins round, the other bit lights up.* All four of them realised that all parts of the world do not experience day-time together. Three of them nominated *Round England and places like that* [B7] where it would be night when it was day in New Zealand. However, non-scientific views were revealed in that G7 appeared to think that Earth's axis of rotation was through its equator rather than through its poles (*No, it's daytime now in New Zealand and the rest of the southern hemisphere and the top half it's night. And when the Earth turns round the Sun it'll be the other way*). Also, B7 was of the view that the Sun and Moon changed places for night and day to occur (*It reflects on the Moon. Reflects on the Moon and the Moon shines down on Earth in places where it's* (otherwise) *dark.* [B7]).

Three of the pupils correctly reported that the Sun was on the other side of the world when it is night in New Zealand. G7 said *It's still there. It's just that... like when it's night-time in New Zealand, on the other side of the Earth it will be daytime because they're facing the Sun.*

Pupils' Concepts About Years

The astronomical basis for the understanding of the concept *year* was not well understood by these pupils. Two of them simply referred to the calendar as an indication of the passing of a year, one referred to the changing months, and G7 attempted to be precise by saying *It's 364 days and a quarter. 366 in a leap year.* G7 showed an incomplete understanding of this concept by being unable to describe what she thought caused years, B7 stated that *I can't really answer that. It's just a year. It's just 12 months* and G8 showed confusion in saying it is *How many times the world goes round. If it goes round... whatever... something to do with the Moon and the Earth and that. Not sure. No idea*. Only B8 correctly explained that a year is the time that Earth takes to orbit the Sun (*Earth has travelled around the Sun. Once* [B8]).

Pupils' Concepts About Seasons

These pupils generally do not have astronomers' ideas of seasons, particularly their cause. All four pupils correctly named the seasons, including the one at the time of the interview as *It's not quite Summer yet... Spring* [B7], and they were all able to describe the seasons. Different seasons were *When it's different temperatures. Hot and cold* [G8], although B8 simply saw each season as being a quarter of a year and B7 described what happens in the different seasons: *Autumn's a season when all the leaves come off the trees. Spring is when they come back. Winter is when we get snow in some places in New Zealand... and others it seems to just rain all the time.*

Three of them understood that all places on Earth do not experience the same seasons at the same time, although one pupil showed uncertainty in saying it would be *Winter or Autumn or something* [G8] in Europe when it is spring in New Zealand. The four pupils each gave different ideas about the causes of seasons. B7 was uncertain and said they might be due to *Clouds? I don't know* and G8 suggested that summer might be due to when *the Sun gets closer it gets hotter*. B8 had a partial scientific concept although he overstated the changing angular relationship between the Sun and Earth: *Summer is when we're getting more sunlight. The Sun goes up higher than the Earth. Like it gets right on top of us really. Then it goes right down on the horizon* [B8]). On the other hand, G7's concept was accurate but incomplete when she said *Oh, the angles at which the Earth faces the Sun and how much light and things it gets. Which would affect things like the weather. Like rain and stuff* [G7].

Pupils' Concepts About Eclipses

Solar eclipses were understood by most of these pupils. While G7 had heard of neither solar nor lunar eclipses, the other three pupils correctly referred to the role of the Moon in solar eclipses that *It's when the Moon goes in front of the Sun and you can't see it* [B8]. On the other hand, lunar eclipses were less well understood, perhaps because of greater media attention to solar eclipses, with B7 responding that they are *When the Sun moves over the Moon.* B8 had the same concept but was less sure, answering in the form of a question: *Does the Sun go in front of the Moon?* yet adding correctly that in a lunar eclipse *There's no light on the Moon. We can't see the Moon* [B8].

Pupils' Concepts About Phases of The Moon

The monthly pattern and causes of the phases of the Moon were not understood by these pupils. This is not surprising in view of the fact that they think the Moon orbits Earth, or vice-versa, every 24 hours.

Two of the pupils associated the Moon only with the night-time sky. The other two thought it was possible, but rare, to see the Moon during the day, but only if it was a new Moon: *Oh, unless it's like the new Moon. You can sometimes see it in different shapes* [G7]. There was clearly confusion about this because, during New Zealand's day-time, G8 thought that *It goes different places, to where the Earth is cloud-covered or something* and the other three pupils thought that the Moon is *on the other side of the Earth* [G7]. This majority view shows that the pupils' idea that the Moon-Earth orbital time is 24 hours (above) is a strongly held concept.

Uncertainty about describing the phases of the Moon was demonstrated in that one pupil did not recognise the term and B7 related phases to eclipses (*Is it like an eclipse? I'm not too sure* [B7]). The other two pupils correctly described the physical appearance of phases, such as When *it's how big the Moon is, like half Moon, full Moon and that* [G8].

Three pupils were able to accurately describe a full Moon. G8 talked about *When it remains full. When it's not covered up or anything* and B7 described it in terms of a face: *It looks like it's got two eyes and a mouth. You could say it's like a whole face. Like it's full face.* G8 was consistent in that she saw a new Moon as occurring *When most of it's covered* [G8]. The other three pupils described new Moons as being very small, with B7 suggesting a sequence for the phases: *Don't you get a full Moon and then a half Moon and then a kind of, like a tiny half of a quarter Moon. It might be one-sixteenth. And then you get a new Moon* [B7]. All four pupils saw a crescent Moon as being somewhere between a full and a new Moon, with G7 describing it in terms of the crescent shape: *Oh, it's just part of the Moon, I suppose. A crescent shape. I don't know the words* [G7]. B7 thought it would be *A half a face I think* [B7] and the

other two pupils were not sure whether its shape would be a *Half or quarter of it* [G8]. None of the pupils had heard of a gibbous Moon.

As expected from their earlier comments, there was uncertainty about the causes of the phases of the Moon. Three different views from the four pupils included a view that the phases were caused by a shadow falling on it and a view that different fractions of the Moon were lighted by the Sun at different times: *The Sun moves and you only see reflection on part of the Moon? So that it's only lighting part of the Moon. So the Sun lights one little bit. It lights it all when we get a full Moon and it lights hardly any of it when we get a new Moon* [B8]. No-one suggested the scientists' view.

Pupils' Concepts About Tides

All the pupils except G8 were able to describe what tides are, a typical comment being that they are *the movement of water* [G7]. B8 answered more specifically that *It's when the sea level drops and rises*. Three of the pupils understood that we get a high tide *every twelve hours* [G7], with only G8 thinking that we get them *Once every day.*

However, the pupils were less sure about the causes of tides, although three of them realised that the Moon had something to do with it, as shown by B7's comment that *Like, when the Moon, the full Moon, the tide comes in. And then it's the half Moon, it might be, the tide goes out. The Moon acts like a kind of magnet.* This response suggested an understanding of a relationship between tides and the Moon's phases. B8's comment that *Tides alter the Moon somehow, I suppose* demonstrated a vague idea of a relationship between the Moon and tides and G8 was even less certain in responding that tides are due to *Things changing. Whatever's meant to be changing to make the tides go different* [G8]. None of them mentioned the Sun as a cause of tides.

None of the pupils could state how they had learned about tides. A typical reply was B8's response that he had just *read it up somewhere, I suppose. Or somebody told me* [B8].

6.4.5 Pupils' Views of Models and Science

This section reports the pupils' general knowledge of the orrery and their concepts about models and how scientists use models.

None of these four pupils had heard of an orrery. The pupils in general saw models only as scale representations of real objects, as in B8's description that *It's a scale model* [B8], from which scientists can learn about the real world (*It might help them understand how the planets move round the Sun.* [G7]).

When they were asked about scientists using models, G8 shrugged and B8 referred to scientists using a *model of our solar system.* The other two pupils each specifically

talked about planetary models (*A model, like, might have all the planets set up like little balls as a model of the planets* [B7]), with G7 suggesting that scientists ... *use models of planets and stuff and see how they work* [G7]. Most of them mentioned models that referred specifically to astronomy and G7 added *and telescopes*, which indicates confusion between instruments and models.

All four pupils thought it was possible to make a scale model of the solar system that can fit into their classroom and be big enough to be seen. Three of them simply responded *Yes*, although G7 was less sure and said *I suppose so*. When they were asked why they thought that, the pupils' unanimous responses were that *You can make a model of anything* [G8].

6.4.6 Pilot Intervention Pupils' Views: A Summary of Section 6.4

The overall impression gained from the interviews with these four New Zealand year 7-8 pupils is that, prior to being taught astronomy, most of their astronomy concepts were different to those held by astronomers yet were similar to those held by international pupils. In particular, they:

* had a good knowledge of the relative sequence and sizes of the planets, but not their relative distances from the Sun;
* had an incomplete mental model of the Sun-Earth-Moon system. Most understood that Earth orbits the Sun, but none knew how long it takes. They were unsure whether Earth orbits the Moon or whether the Moon orbits Earth and the most common view was that the orbital time is 24 hours;
* generally had a scientific concept of the causes of day and night, although a minority view was that Earth's axis of rotation is through its equator rather than through its poles;
* did not understand the concept of the month as an astronomy-based unit of time;
* did not understand the concept of year in terms of Earth's orbit around the Sun;
* could name the sequence of the seasons and their effects on people but did not understand how they were caused;
* had a clear understanding of solar eclipses but not of lunar eclipses;
* could name many of the phases of the Moon, were not certain about the sequence of the phases, tended to relate the phases to a shadow falling on the Moon and considered the Moon as a purely night-time phenomenon (related to the fact that they thought the Moon takes 24 hours to orbit Earth);
* could explain the term tides but were not sure of their frequency. They thought, in a vague way, that the Moon had something to do with tides, but did not think the Sun affected tides;
* had a limited view of what models are and how scientists use them. They saw models as scaled three-dimensional representations of reality which are the consequences of investigation rather than as the tools to investigate reality.

6.5 THE PUPIL INTERVIEWS: IMPLICATIONS FOR THE TRIAL INTERVENTION

The pilot intervention, which was initially designed after consideration of the surveys of overseas pupils' alternative astronomy concepts and of teachers' perceived challenges when teaching astronomy, was modified to take into account the findings from the New Zealand pupil interviews. That is:

* an emphasis on the role of models and mental models in astronomy is appropriate in view of the interviewed pupils' (and teachers') limited understanding of them;
* emphasis needs to be placed on the pupils constructing their own mental models of the Sun-Earth-Moon system;
* emphasis needs to be placed on the pupils attempting to build a physical model of the Solar system;
* the physical model of the mental model of the Sun-Earth-Moon system, the orrery, needs to be repeatedly critiqued in terms of its ability to predict and explain its subordinate concepts. In that way the pupils' limited view of models and their use may be expanded towards that of scientists;
* emphasis needs to be placed on helping pupils build the subordinate astronomy concepts outlined in level four of *Science in the New Zealand Curriculum*. With the exception of day-night, these concepts (months, seasons, years, eclipses, phases of the Moon, tides and the role of models) were not understood by these pupils.

PART THREE

6.6 THE PILOT INTERVENTION REDESIGNED TO THE TRIAL INTERVENTION

6.6.1 Introduction

Section 6.6 describes how the trial astronomy intervention was redesigned in view of what was learned in conducting the pilot intervention. This section will consider:

* redesigning the survey instrument and the pupil interviews (section 6.6.2);
* redesigning the intervention (section 6.6.3).

To save repetition, the pilot intervention will not be described here. The trial intervention will be fully described in chapter seven. What follows are reports about how the survey instrument, the pupil interviews and the intervention were redesigned as a result of lessons learned from the pilot intervention.

6.6.2 Redesigning the Survey Instrument and the Pupil Interviews

The survey instrument

The final form of the survey instrument is found in Appendix E. This subsection documents the changes which were made to the version which was used in the pilot intervention. The pre-survey, which was administered to all members of the pilot class,

supported findings from the pupil interviews that there was a large range of astronomy prior knowledge and concepts in this class, that the class generally had limited understanding of these and that only 26% of the class had a mental model of the Sun-Earth-Moon system similar to that of astronomers.

Only two questions had negative discrimination indexes, only two questions had zero discrimination indexes, and the other survey questions had positive discrimination indexes up to 0.9. The difficulty levels ranged from 9.7% to 93.5%. These levels suggest that the survey reveals real differences in pupil achievement rather than chance factors (Gronlund, 1971). Almost all distractors elicited a response from at least one pupil, suggesting that nearly all the distractors made sense to at least some pupils.

Overall, it was felt that the survey revealed the pupils' concepts about astronomy and that the survey questions were generally well constructed. Nevertheless, it was decided to further analyse each distractor that failed to elicit a response and each question that had a zero or negative discrimination index with a view to improving those questions for use in the trial intervention. Furthermore, the survey was seen to be usable in terms of classroom time in that the pupils completed it in an average time of 20 minutes, with a range of completion times of 15 to 30 minutes.

The pupil interviews

The final form of the pupil interview instrument is found in Appendix D. This subsection documents the changes which were made to the version which was used in the pilot intervention. The interviewees were at ease during the interview and none were reticent about sharing their views. The researcher felt he had contributed to this by his supportive stance.

As a triangulation procedure, the interview responses were compared with the interviewees' pre-survey responses. Table 6.6.1 shows that there was a high percentage correspondence between the interview responses and those survey responses that investigated the same pupil ideas. This suggested high reliability of the survey and interview protocol. However, the interview did not investigate all the pupil ideas that the survey investigated, so the interview structure was amended for the trial intervention to more closely match the survey.

Both the interview and the survey served their purpose in reliably eliciting pupils' astronomy views. This further supports the view that the survey instrument is a valid, reliable and usable method of eliciting pupils' astronomy views at level four of *Science in the New Zealand Curriculum.*

Table 6.6.1: Comparison Between Pupils' Pilot Pre-Survey and Interview Responses for Fifteen Items

Topic	B7		B8		G7		G8	
	S.	Int.	S.	Int.	S.	Int.	S.	Int.
Name of smallest planet	y	n	y	n	y	n	y	y
Name of largest planet	y	y	y	y	y	y	n	n
Description: Moon's phases	n	y	n	n	y	y	n	n
Cause of Moon's phases	n	n	n	n	n	n	n	n
Description: eclipses of Moon	y	y	n	n	n	n	n	n
Cause of Moon eclipses	y	y	n	n	n	n	n	n
Description: eclipses of Sun	y	y	n	n	n	n	n	n
Cause of Sun eclipses	y	y	n	n	n	n	n	n
Cause of summers	n	n	n	n	y	y	n	n
Cause of day	y	y	y	y	y	y	n	y
Length of year	y	y	y	y	y	y	y	y
Cause of year	y	y	y	n	y	y	n	n
Cause of lunar month	y	y	y	n	n	-	n	-
Tides mainly caused by	y	y	y	y	y	y	n	n
Structure of Sun-Earth-Moon	y	y	n	n	y	y	n	n
Number in Agreement	13		12		13		13	
Per cent in Agreement	87		80		87		87	

Key:

S = Survey Response

Int = Interview Response

y = provided correct response

n = provided incorrect response

- = did not respond

6.6.3 Redesigning the Intervention

Table 6.6.2 shows the sequence of the pilot intervention in practice. It shows that, because of classroom exigencies, the pilot intervention programme was not followed in detail. There were only ten lessons instead of the planned twelve and lessons eight and nine were taught together, as were lessons ten and eleven. That is, the programme was shortened by two lessons, with the *Using the Mental Model to Solve Problems* phase and the *Reflection* phase reduced to only one lesson each. Furthermore, the sequence was altered so that lesson twelve was taught before lessons ten and eleven. A further unexpected event was the ill health experienced by Ms T. This resulted in her absence on two occasions and her unwillingness to teach on another occasion. The researcher chose to teach the lessons himself rather than have them not taught at all. Such eventualities, of course, perturb the pilot intervention.

Table 6.6.2: The Pilot Astronomy Intervention in Practice

Date	Lesson Times	Phase	Lesson
25-10-95	-	**Focus on the Mental Model**	Pre-interviews
27-10-95	10.45 - 11.30		Pre-survey
30-10-95	10.45 - 12.30		Lesson 1 - Share Prior Views
31-10-95	1.30 - 2.45	**Mental Model-Building & Critiquing**	Lesson 1 - Planet Sizes & Shapes
01-11-95	1.30 - 2.45		Lesson 2 - Planet Distances
03-11-95	8.45 - 10.00		Lesson 3 - Orrery 1 *See Note*
06-11-95	10.45 - 12.00		Lesson 4 - Orrery 2 *See Note*
07-11-95	1.30 - 2.45		Lesson 5 - Orrery 3
08-11-95	1.30 - 2.45		Lesson 6 - Orrery 4
			Lesson 7 - Orrery 5
13-11-95	10.45 - 12.00	**Using the Mental Model to Solve Problems**	Lessons 8 & 9 combined - Group Applications *See Note*
15-11-95	1.30 - 2.45	**Reflection**	Lesson 12 - Pupils report back (solar system)
17-11-95	8.45 - 10.00		Lessons 10 & 11 combined - Pupils report back (tides)
21-11-95	-		Post-survey
08-12-95	-		Post-post survey (2.5 weeks later)

Note: Taught by researcher because pilot teacher was ill.

The pilot intervention was evaluated in terms of problems noted during its implementation. Problems were identified by analysis of the lesson transcripts and of the pupil workbooks and by interviews with Ms T. Then modifications, shown in Table 6.6.3, were suggested for the trial intervention.

Table 6.6.3 indicates that some identified problems were classroom managerial, some were research managerial while others were more central to the focus of the intervention. Modifications from the pilot to the trial intervention are indicated alongside each of the problems. In addition to the above, other changes that were made to the trial intervention package were:

* the complete package will be issued to the pupils during the initial lesson;
* the complete package will be issued to the trial teacher prior to the intervention;
* a clear-file will be issued to each group to facilitate the storage and easy retrieval of the pupil lessons and their associated work sheets;
* the researcher will provided a large wallchart of Moon observations which the pupils will describe, analyse and interpret;
* the activities of a different group each day will be audio-taped and transcribed;
* the two lessons about tides will be combined and will have an investigative approach.

Table 6.6.3: Suggested Modifications From the Pilot to the Trial Astronomy Intervention

Problems Noted During the Pilot Intervention	Modifications to the Trial Intervention
The structure of the surveys made it difficult to separately analyse pupils' astronomy knowledge, astronomy concepts and ideas about models.	The questions in the surveys will be grouped into astronomy knowledge questions, astronomy concepts questions and questions about pupils' ideas about models.
The pupils often forgot their group number, thus causing management difficulties.	The groups will each be given the name of 'their' solar system object. e.g. Jupiter.
It was time-consuming to locate the required paper in each group's clear-file.	Pupil activities, appendix data and critique sheets will each be in different colours.
It was confusing to locate the relevant astronomy data in the appendices at the back of each group's clear-file.	The relevant appendix data will be placed with the appropriate lesson.
The pupils did not critique the scientists' mental model of the Sun-Earth-Moon system.	Critiquing the scientists' mental model of the Sun-Earth-Moon system will be made more explicit in the the intervention lesson plans.
The pupils did not critique the orrery.	Critiquing the orrery will be made more explicit in the the intervention lesson plans.
The lessons were not as interactive as planned.	The intervention lesson plans will be made more explicitly interactive.
The tides lesson was more discovery-orientated than investigative.	The tides lesson plan will be made more explicitly investigative.
The pupils' questions sometimes interrupted the interactive nature of the teaching-learning process.	At the end of each lesson there will be 5 minutes for pupils' questions.
There were only 10 teaching sessions.	There will be 12 lessons taught.
There was inadequate time (only one lesson) for the Using the Mental Model to Solve Problems phase.	The Using the Mental Model to Solve Problems phase will be two lessons.
There was inadequate time (only one lesson) for the Reflection phase.	The Reflection phase will be two lessons.
Two and a half weeks between the post-survey and the post-post survey was not long enough to assess concept retention.	The time between the post-survey and the post-post survey will be increased to at least four weeks.
The pupils' mental model of the Sun-Earth-Moon system reduced from 74% accurate in the post-survey to 66% in the post-post survey.	The scientists' mental model and the orrery will be critiqued more often.
Three lessons were taught by the researcher instead of the pilot teacher.	All lessons will be taught by the intervention teacher.

As a result of the modifications, the trial intervention outline became as shown in chapter seven. The trial intervention package is found in Appendix A (page 236).

6.7 SUMMARY AND CONCLUSIONS

Chapter six has briefly described the development and implementation of the pilot intervention for teaching the astronomy part of *Science in the New Zealand Curriculum* to Year 7-8 pupils.

Section 6.2 described the interviews which elicited the views of twelve New Zealand teachers about teaching astronomy to Year 7-8 pupils. It revealed that those New Zealand teachers had generally taught little or no astronomy in the past but were quite relaxed about the prospect of teaching it since it has become a compulsory part of *Science in the New Zealand Curriculum*. In general, they had a pragmatic approach with regard to the constraints of time and resources. They were very practical and classroom-orientated rather than developing approaches from the current education philosophies in that they tended to see teaching astronomy as being transmissive and fact-orientated. They placed little emphasis on investigative skills development or constructing and critiquing mental models.

The implications for the pilot intervention were described in section 6.3, which summarised the support to be provided to the trial intervention teacher in terms of initiating an investigative approach to help pupils build and successively critique their mental models of the Sun-Earth-Moon system.

The pre-pilot intervention interviews with four Year 7-8 pupils from the pilot intervention class were described in section 6.4, with implications from them described in section 6.5. The interviews indicated that New Zealand pupils have many astronomy concepts that do not agree with astronomers' current thinking. In addition, several conceptual difficulties were revealed in these interviews that had not been previously reported. Knowledge of the New Zealand pupils' conceptual difficulties was used in revising the pilot intervention.

The pilot intervention was critiqued in section 6.6 in light of the pupil survey, the pupil interviews and experiences during the trial intervention itself. Analysis of the survey revealed that it was a valid, reliable and usable instrument but some individual items needed further development to better elicit astronomy concepts held by pupils. Similar conclusions were drawn for the interview protocol. In addition, it was revealed that the interview schedule revealed similar concepts to the survey. Changes to the interview format were suggested to better match the survey instrument and to better support the triangulation process.

A positive feature of the pilot intervention that was retained into the trial intervention was the overall sequence of the *Focus on Mental Models* phase, the *Mental Model-Building and Critiquing* phase, the *Using the Mental Model to Solve Problems* phase and the *Reflection* phase. These, including the Focus-Challenge Review cycle within the *Mental Model-Building and Critiquing* phase, had proved to be practicable and valuable. A

further positive feature was that the pupils generally retained their astronomy concepts intact between the time of the post-survey and the time of the post-post survey. However, negative features of the intervention were identified and changes were proposed for the trial intervention, as shown in Table 6.6.3.

Overall, with the recommendations instituted, it is felt that the proposed trial intervention to teach astronomy to Year 7-8 pupils both matches the objectives in *Science in the New Zealand Curriculum* and reflects a constructivist approach to facilitating pupils' mental model building. The pilot intervention and its analysis suggests that the amended trial version has the potential to facilitate significant pupil construction of the Sun-Earth-Moon mental model and its subordinate concepts among Year 7-8 pupils in New Zealand.

Chapter seven will describe how the astronomy trial intervention was put into effect to facilitate the Year 7-8 pupils constructing their mental model of the Sun-Earth-Moon system. It will then respond to research questions one, two and three.

CHAPTER SEVEN: THE TRIAL INTERVENTION OUTCOMES 1: THE PROCESS OF BUILDING AND CONSOLIDATING MENTAL MODELS IN THE TEACHING AND LEARNING OF ASTRONOMY

7.1 INTRODUCTION

Chapter seven describes how the intervention proceeded. It considers the processes and outcomes of the pupils considering, building and consolidating their mental model of the Sun-Earth-Moon system and also their developing concepts of the role of models in science. This chapter responds to research questions one, two and three, which were listed in section 5.2 :

1. How effective was the intervention in developing pupils' ideas about the role of scientists' models?

2. Are pupils able to construct the scientists' mental model of the Sun-Earth-Moon system?

3. How effective are models in promoting mental model building by New Zealand pupils?

Section 7.2 defines the main terms to be used in this chapter, describes the overall structure of the intervention in practice and gives a brief description of what occurred in each of the intervention lessons. This is followed in section 7.3 by a comparison of the pupils' initial and final views about scientists' models. Section 7.4 describes the *Focus on the Mental Model* phase, in which the pupils considered models in general and the building of a model of the solar system in particular. The *Mental Model Building and Critiquing* phase is described in section 7.5, during which the orrery was introduced and critiqued with respect to its own structure and with respect to its ability to illustrate and explain astronomy concepts which are subordinate to the scientists' mental model of the Sun-Earth-Moon system. Section 7.6 describes the pupils' consolidation of their mental models of the Sun-Earth-Moon system during the *Using the Scientists' Mental Model to Solve Problems* phase and during the *Reflection* phase. Section 7.7 describes the extent to which the pupils did, in fact, build the scientists' mental model of the Sun-Earth-Moon system and the chapter concludes with section 7.8, a summary of the findings from chapter seven with respect to research questions one, two and three.

7.2 DEFINITIONS AND THE TRIAL INTERVENTION

7.2.1 Introduction

Section 7.2 describes how the trial intervention proceeded. Discussion is presented in the following sequence:

* definitions of terms used (section 7.2.2);

* the trial intervention lessons (section 7.2.3).

7.2.2 Definitions of Terms Used

This research uses the terms "mental model", "model" and "critiquing" as central features of the intervention. The following are the researcher's definitions of the above terms that were used in this research. They were also discussed in chapter two.

1. A *mental model* is a human cognitive construction which is used to describe and explain phenomena which cannot be experienced directly. It is usually a 'big idea' which represents the interplay between a number of subordinate concepts.
   It continually develops through repeated investigation and analysis of its subordinate concepts.
   Examples include mental models of the universe, atoms, ideal gases, electric circuits, genes, the economy and 'good teaching practice'.
   An explanation of mental models to children would include how they would picture something in their mind that they cannot see, such as what is going on inside an electric circuit.

2. *Models* may be scaled miniatures or scaled enlargements or working models, each of which represents a mental model in some, but not all, properties. Examples of scaled miniatures include model cars and aeroplanes and an example of a scaled enlargement is a visible model of an atom. It is *not* a condition, however, that models are scaled representations. For instance it is not, in fact, possible to make a visible scale model of the solar system.
   Models may be working or static. Examples of working models include orreries to represent parts of the solar system, water circuits to represent electric circuits and ripple tanks to represent and investigate properties of light and sound waves. An example of a static model is a representation of our solar system's planets in which each planet is suspended from the ceiling.
   An explanation of models to children would include the ideas that they are usually larger than objects that are too small to be seen or smaller than objects that are too big to fit into a classroom. They might be static, such as a model of a racing car, or might be a working model, such as a Lego model of a funfare ride.
   An instrument or a tool, such as a microscope or an epidiascope, is not an example of a model.

3. A model's relationship to the mental model it represents can be judged by Hesse's (1966) method of *critiquing* it. To critique a model, one lists its positive, negative and neutral features, where its *positive* features are those which both the model and mental model share, its *negative* features are those attributes that are not common to both the model and mental model, and its *neutral* features are those attributes that have not yet been determined as either positive or negative. The neutral attributes are often the areas of further research.
   For example, the ripple tank working model has the positive features that it can

show the wavelength, diffraction and interference effects of waves. A negative feature is that both the wavelength and velocity of water waves are dependent on the depth of the water, whereas this is not the case for light or sound waves. A neutral feature is that water waves do not address the dispersion effects of light.
An explanation to children of critiquing the orrery is:
'positive' is equivalent to 'things the orrery accurately represents'
'negative' is equivalent to 'things the orrery represents inaccurately'
'neutral' is equivalent to 'things the orrery does not mention'

7.2.3 The Trial Intervention Lessons

Figure 7.2.1 shows the overall sequence of the intervention. It expands the box labelled "Trial Intervention (New Zealand)" in Figure 5.10.1 and shows the time sequence for:

* the interviews with the teacher;
* the interviews and surveys for the pupils;
* the intervention lessons.

Figure 7.2.1 shows that the pupil pre-interviews (six pupils) and the pre-survey (the whole class) were conducted during the week prior to the intervention, the intervention was conducted over a period of 16 days, the pupil post-survey was conducted one day after the last intervention lesson, the pupil post-interviews were conducted four days after the post-survey and the post-post survey was conducted 26 days after the post-interviews. That was the latest time that it could be administered prior to the special end-of-year school activities.

The figure also shows that the teacher pre-interview was conducted on the same day as the pupil pre-interviews and his post-interview was conducted on the same day as the pupil post-survey. Teacher interviews also took place immediately after eight of the eleven lessons, as shown by the numbered white bars in Figure 7.2.1. The teacher's perceptions of the intervention will be described in section 8.3, providing a comparison between his prior views, his views during the intervention and his views after it. Changes in the pupils' views of the role of scientists' models (section 7.3) and their mental models of the Sun-Earth-Moon system (section 7.5) were monitored by comparing their responses to the pre- and post-surveys and interviews with their responses in the post-post surveys.

The lessons of the intervention proceeded according to a four-phase sequential teaching structure. In general terms, this structure is:

* *The Focus on the Mental Model Phase*, during which ideas about both mental models and the way they are represented by models were elicited and shared with the class. The technique of critiquing models to show that all models have limitations was also introduced during this stage. In particular, the pupils' mental models were elicited and shared.

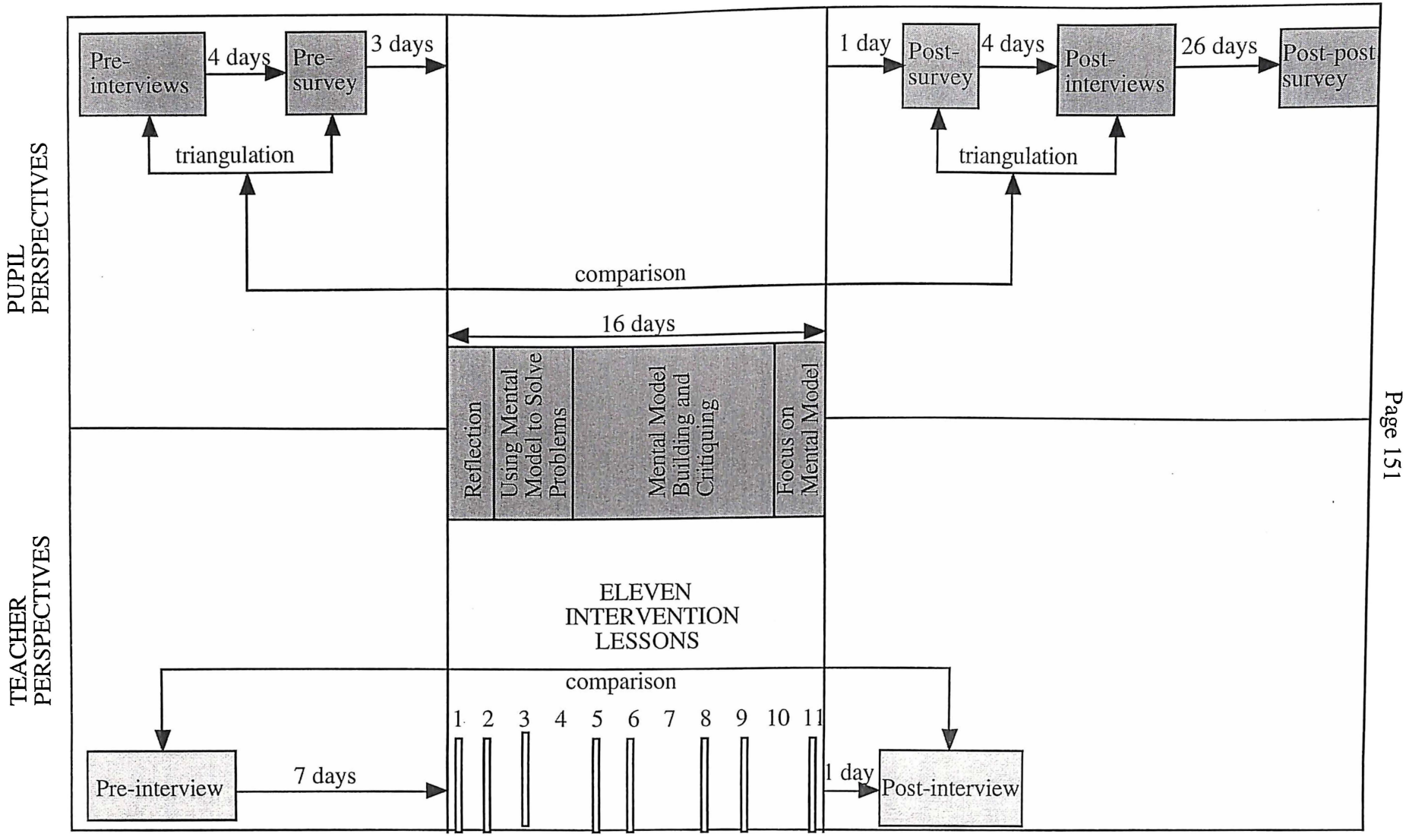


Figure 7.2.1: A Flow Diagram Showing the New Zealand Astronomy Intervention

* The *Mental Model-Building and Critiquing Phase*, during which the scientists' mental model was constructed by the pupils. The class repeatedly critiqued a model (the orrery), which represented the scientists' mental model, in its capacity to describe and explain concepts which are subordinate to, and are interdependent with, the mental model. Its purpose was to help pupils understand the intelligibility and plausibility of the scientists' mental model.
  Each lesson in this phase included a focus-challenge-review cycle of the concept under investigation in that lesson.
* The *Using the Mental Model to Solve Problems Phase*, during which groups utilised the scientists' mental model to solve some problems which were novel to the pupils. Its purpose was to help the pupils consolidate the scientists' mental model by investigating its fruitfulness.
* The *Reflection Phase*, during which groups reported and debated, with the whole class, their findings when solving the novel problems. Its purpose was to help the pupils further consolidate the scientists' mental model.

Table 7.2.1 is a brief account of how the general four-phase structure was used specifically for teaching and learning about the Sun-Earth-Moon system. It shows that the intervention proceeded as planned except that it was reduced from twelve to eleven lessons because of other school commitments. The teacher deviated considerably from the plan for lesson two by introducing a number of scales for the solar system model prior to introducing the one suggested. The lesson sequences were as in the four phases described above. That is, the teacher initially focused the pupils on scientists' models in general and on the mental model of the Sun-Earth-Moon system in particular. As indicated above, the *Focus on the Mental Model* phase was followed in lessons 3 to 7 by the *Mental Model-Building and Critiquing* phase, during which concepts subsidiary to, and dependent on, the mental model of the Sun-Earth-Moon system were explored. Each of these lessons consisted of an embedded focus-challenge-review cycle for each concept that was investigated. Also in this cycle, the orrery was repeatedly critiqued with respect to its capacity to explain the subordinate astronomy concepts such as the phases of the Moon.

During lessons eight and nine, the *Using the Mental Model to Solve Problems* phase, pupils in groups consolidated the scientific mental model of the Sun-Earth-Moon system by using it to solve problems that were new to them, such as the causes of tides on Earth and what they would expect to happen to the tides if Earth had two moons. Each of the problems was resolved by several groups. This practice ensured an attentive audience in the *Reflection* phase and provided the opportunity for debate in that different groups might approach the problems in different ways.

Lessons ten and eleven constituted the *Reflection* phase, which was designed to encourage interactive reporting about the problems so that the scientists' mental model of the Sun-Earth-Moon system would be further consolidated.

Table 7.2.1: The Astronomy Intervention in Practice

Lesson	Pupil-Teacher Activities
***Focus on the Mental Models* Phase**	
Lesson 1	Class discussion about models.
21.10.96	Co-operative critique of map (a model) of London Underground.
(11.10-12.30)	Awareness of Jones and Lynch's (1987) five mental models of Sun-Earth-Moon system, and subordinate concepts, which were present among the class.
	Each group built scale model of its allocated solar system object, such as Mars.
Lesson2	The class combined every group's scale model of a solar system object
22.10.96	to build a physical model which represented the scientific mental model
(11-12.30)	of the solar system. They then critiqued their solar system model.
***Mental Model-Building and Critiquing* Phase**	
Lesson3	Teacher introduced and operated the orrery as a representation of the
23.10.96	scientific mental model of the Sun-Earth-Moon system. Pupils
(11.10-12.30)	observed, operated and critiqued the orrery.
	The orrery was compared to class' mental models of Sun-Earth-Moon system.
	Class viewed and critiqued a video of a large orrery.
Lesson4	Teacher elicited the class' prior ideas about day and night, month and
24.10.96	year. He used the orrery to help them construct the scientific concepts.
(11.10-12.30	Pupils critiqued the orrery and Sun-Earth-Moon mental models with respect to its ability to represent day and night, month and years.
Lesson5	Teacher elicited pupils' ideas about seasons. He helped the class to
29.10.96	design and conduct an experimental test of their concepts.
(11.10-12.30)	Pupils critiqued the orrery with respect to its ability to represent seasons.
Lesson6	Teacher elicited pupils' prior ideas about eclipses. He used the orrery to
30.10.96	help them construct the scientific concepts. Pupils critiqued the orrery
(11.05-12.20)	with respect to its ability to represent solar and lunar eclipses
Lesson7	Teacher elicited pupils' prior views about phases of the Moon. He used
31.10.96	the orrery to help them construct the scientific concept. Pupils critiqued
(11.10-12.30)	the orrery with respect to its ability to represent phases of the Moon.
	The class agreed that only the scientific mental model of the Sun-Earth-Moon system was able to explain ALL of the above concepts.
***Using the Scientists' Mental Model to Solve Problems* Phase**	
Lessons8 & 9	There were seven problems new to the pupils. For example, days,
2.11.96	seasons and years on other planets (see Table 7.6.1 for a complete list).
(9-10)	Each problem was resolved in terms of the scientists' Sun-Earth-Moon
4.11.96	mental model .
(11.10-12.30)	
***Reflection* Phase**	
Lesson10	The appropriate groups reported from problem 4 that the Moon is the
5.11.96	main, but not the only, cause of tides.
(11.10-12.30)	Some groups reported from problem 5 that the Sun must also be a cause of high tides. The class concluded that both the Moon and the Sun cause our tides, the Moon being the main cause.
Lesson11	The appropriate groups used the orrery to report their findings about
6.11.96	days, seasons and years on other planets to the rest of the class.
(11.05-12.30)	Some groups reported why we always see the same face of the Moon from Earth and why the same is not true for Mercury as seen from the Sun.
	Some groups reported what it would be like on Earth if we had zero or two Moons, most of the discussion centring on the two Moons scenario.

7.3: WHAT ARE SCIENTISTS' MODELS? DEVELOPING PUPILS' IDEAS

7.3.1 Introduction

This section addresses research question one: *How effective was the intervention in developing pupils' ideas about the role of scientists' models*? It describes these Year 7-8 pupils' initial ideas about models, how scientists use models and the extent to which their views moved towards scientists' views during the intervention. To this end, it compares pupils' prior and post views about scientific models as determined by the pre- and post-interviews and by the pre-, post- and post-post surveys.

There were 33 pupils in the trial intervention class. However, one pupil was absent for the pre-survey and another was absent for the post-post survey. The analyses in chapter seven and chapter eight are of the 31 pupils who completed all three surveys.

Data is presented in the following sequence:

* the pupils' views of models (section 7.3.2);
* the pupils' views of how scientists use models (section 7.3.3).

7.3.2 The Pupils' Views of Models

The pupils' evolving views about models were elicited by an open-ended question (question D4). Part a of the question asked them to name a model used by scientists, the results of which are shown in Figure 7.3.1.

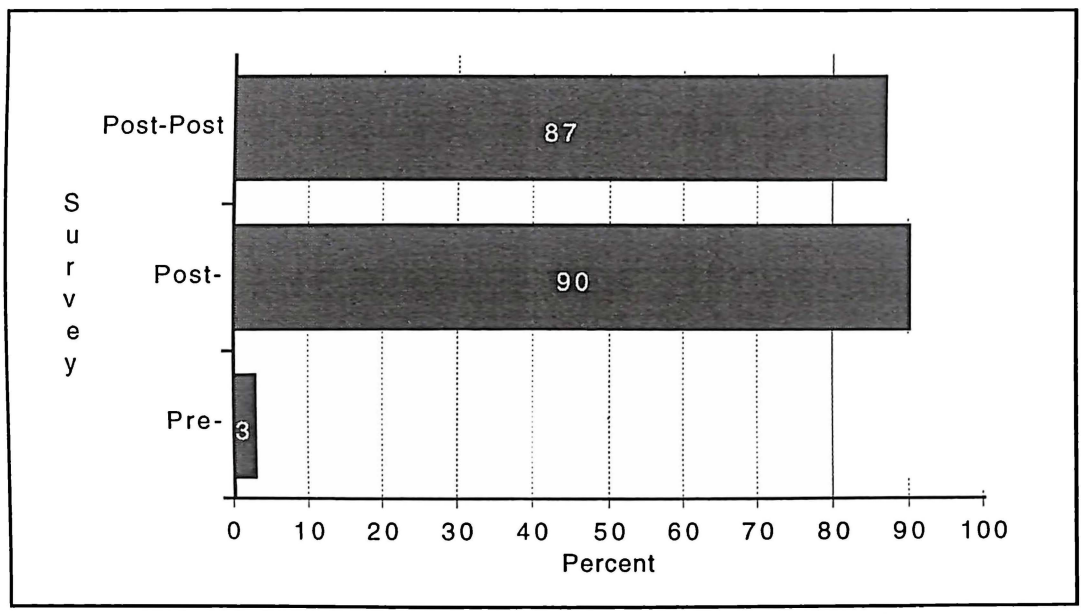


Figure 7.3.1: Percentages of Pupils Who Correctly Named a Scientific Model: Pre-, Post- and Post-post Surveys

Figure 7.3.1 shows that the pupils developed the ability to name a scientists' model as a result of the intervention. Both the non-parametric sign test and the parametric t-test indicate that the gains are statistically significant at the 0.001 level. Prior to the intervention, only 3% of the class named a model used by scientists, one mentioning

charts and another choosing a telescope (which is an instrument rather than a model).

Four of the six interviewed pupils named a scientific model, but two of them confused models with instruments in suggesting that *a satellite dish* [Hettie] and *a telescope* [Jack] are examples of models. The other two interview responses to this question suggested a model of the solar system. For example, Leonie saw scientists making *a model of the Sun and Moon and Earth in all different colours.*

After the intervention 90% of the surveyed pupils correctly named a scientists' model, 81% not surprisingly choosing the orrery, 7% referring more generally to a model of the solar system and 3% naming a computer program. However, 10% named the telescope (which is an instrument). Similarly, all six interviewed pupils simply stated *the orrery* in response to this question. These views continued into the post-post survey, the apparent decline in the number of correct responses from the post- to the post-post survey not being statistically significant on either the sign or t-test. In the post-post survey, 87% of the surveyed pupils correctly named a scientific model: 68% named the orrery and the other 19% variously named a mechanical working model of the solar system, a map, a computer, scale drawings and a globe. Again 13% incorrectly named a telescope.

Part b of question D4 asked the pupils what they thought models were for. Table 7.3.1 is a tabulation of their responses.

Table 7.3.1: Pupils' Statements of the Purposes of Models: Pre-, Post- and Post-post Surveys

Pupils' Responses	Pre-survey	Post-survey	Post-post survey
To show ideas using a scaled-down version of something	1	6	16
To test new theories	0	4	6
To find things out	1	0	2
To look at things (an instrument)	1	4	4
Totals	**3**	**14**	**28**

Table 7.3.1 shows that the pupils initially expressed very few ideas about models. However, their knowledge and confidence about them increased as the intervention progressed. Nevertheless, there were still three pupils who declined to answer this question by the time of the post-post survey.

The pupil in the pre-survey who had named a chart as a model said that its purpose was to give a smaller representation of real things. Support for this view that models are essentially scaled-down versions of reality increased to 19% of the class in the post-survey and further to 52% by the time of the post-post survey. For example, Leonie said that models were *to see things smaller so we can see what they look like*. Four pupils mentioned the orrery's teaching potential in this regard in being used to demonstrate

ideas, such as *to show what the solar system looks like.*

The second most popular view of models emerged as being their use to *show and test new theories* [Ann]. The proportion supporting this view increased from zero in the pre-survey to 13% in the post-survey and further to 19% in the post-post survey. Caleb, for example, said in the post-survey that models were *to calculate new theories*. Support for this view is surprisingly small considering that the pupils had repeatedly used a model (the orrery) during the intervention to test theories that were new to themselves.

The idea that models can be used to find out things had small but fluctuating support from these pupils. One pupil suggested this in the pre-survey, the idea attracted no support in the post-survey, but two pupils thought that by the time of the post-post survey. For example, Jennie referred to models being used to investigate unknown aspects, noting that scientists would use models to *see what changes, and if anything drastic happens they will know*. Again, from their own perspective, the pupils had, in fact, been finding out astronomy ideas by using a model (the orrery) during the intervention.

Pre-survey confusion between models and instruments was evident in that one pupil suggested that models could be used *to look at things*. Support for this view of models increased from 3% to 13% by the time of the post-survey and the post-post survey.

Table 7.3.1 demonstrates that these pupils had few initial ideas about models. However, by the end of the intervention a significant proportion of them had changed their views towards the scientists' view in understanding that models have a variety of uses, including testing new theories, finding out new ideas and demonstrating ideas by the use of scaled versions of reality. Nevertheless, the pupils primarily focused on the reducing aspect of models and many viewed this aspect as a *necessary* property of a model.

7.3.3 The Pupils' Views of How Scientists Use Models

The pupils' were asked (question D4, part c) how scientists use models. Table 7.3.2 shows their responses.

Table 7.3.2: Pupils' Statements About How Scientists Use Models: Pre-, Post- and Post-post Surveys

Pupils' Responses	Pre-Survey	Post-Survey	Post-post Survey
To demonstrate ideas	4	14	15
To solve theories	0	4	5
To predict theories	0	2	2
To challenge theories	0	2	3
To look at things (an instrument)	2	3	1
Too imprecise to be used	0	1	1
Totals	6	26	27

Tables 7.3.1 and 7.3.2 are very similar. This suggests that the pupils did not perceive the same distinction between the relevant questions that the researcher perceived.

This part of question D4 attracted more responses than either of the other two parts. Prior to the intervention, 19% of the surveyed pupils suggested how scientists use models, four of whom referred specifically to astronomy. After the intervention, 84% of the class responded to this question and 87% responded to it in the post-post survey. The most common response was that scientists use models to demonstrate their ideas. Four pupils made this suggestion in the pre-survey, an example being *it's a good way to demonstrate* [Ernie]. Support for this role of models increased to 45% of the class in the post-survey and 48% in the post-post survey. A typical example of a post-survey response was Leonie's *so they can show how the solar system works*, while a post-post survey response was *to show what they mean instead of tell* [Delia].

The second most popular response to this question related scientists' models to theories, support for which increased from zero in the pre-survey to 23% of the class in the post-survey to 32% in the post-post survey. Typical responses were *to help them solve theories and work out stuff* [Betty], *to predict the future* [Frank] and *to explain how things work and to challenge existing theories* [Mike].

One response in each of the post-survey and post-post survey was not clearly enough stated to be classified. Furthermore, two pupils in the pre-survey confused models with instruments, such as *to help people see the planets closely* [Pam]. The number of pupils with this misconception increased to three in the post-survey but reduced to one in the post-post survey.

Before the intervention, only two of the interviewed pupils made suggestions about how scientists use models. A correct response referred to models' scale property in commenting that *they scale down to the size of like Jupiter or the Sun* [Mary]. Mary also mentioned NASA's scale model of the Mars Rover. The other view was that modelling is done so that *they can learn more about things* [Frank], which ascribes an investigative role to scientists' models.

Before the intervention, the surveyed pupils had very limited views about how scientists use models and only 19% of the class responded to the question. In addition, they saw their use as only being to demonstrate ideas or they confused models with instruments. The intervention changed the pupils' views quite noticeably in that 84% of them responded in the post-survey and 87% responded in the post-post survey. Furthermore, the pupils' views of how scientists use models broadened to include their role in challenging and testing theories and in demonstrating ideas to people.

7.4 PROMOTING PUPILS' MENTAL MODELS DURING THE *FOCUS ON THE MENTAL MODEL* PHASE

7.4.1 Introduction

This section addresses research question three: *How effective are models in promoting mental model-building by Year 7-8 New Zealand pupils*? It describes the extent to which these Year 7-8 pupils engaged with the notion of models and model building in astronomy. The section begins with a consideration of the pupils' interaction with a pictorial model (a map of the London Underground) and continues with an analysis of their views about building a scale model of the solar system in their classroom.

Data is presented in the following sequence:

* the notion of models and critiquing them (section 7.4.2);
* the possibility of building a scale model of the solar system (section 7.4.3).

7.4.2 The Notion of Models and Critiquing Them

The teacher introduced the concept of models at the very start of lesson one, by asking the pupils what they thought a model was. This approach elicited pupil ideas that models were plans that could be changed and that were usually drawn to scale:

Netta: *It's like with an architect they have a plan or a drawing of the house.*
Pam: *It's a draft copy. Then you can change it until you like the drawing.*
Mary: *Oh, like people say they would work to scale.*

Rather than investigating whether scale is an essential property of models, the teacher supported Mary's view. So it is not surprising that the pupils later placed great emphasis on the miniaturisation aspect of models. Pupils then suggested that two other properties of models were demonstrating and explaining ideas:

Ann: *Show people how planets go around the Sun.*
Peter: *Once you find out how that works, you could say it would be a help to find out how something else works. And so it could, yeah, explain stuff.*

The pupils then examined a particular model, a map of the London Underground, a copy of which was available in each group folder. The map of the London Underground was chosen because it was seen by the researcher as a familiar icon. However, this proved not to be the case for many of these pupils. In retrospect, a similar map of the 'bus routes in the pupils' home city might have proved more effective. The teacher asked the pupils to state the advantages, the positive features in Hesse's terms, of the map. For example, Kit mentioned the different colours as an advantage of the map:

Kit: *It's got lots of colour as a key. So you can see different stations...*
P: *It also shows the different lines and it shows all the different stops, like all the stations that there are on the way.*

The pupils established a small number of advantages, which were the use of different colours for different rail routes, different colours for different stations and information about when each station was open, all of which refer to the information-giving role of

models. The map's positive features were limited, not referring, for example, to approximate relative positions. The pupils then re-formed into their groups to further discuss the London Underground map. Later, members from each group reported their findings about the disadvantages (the negative features in Hesse's terms) of the map. Again, they referred to colour, except that now it was seen as a disadvantage, as was the fact that they perceived too much information on the map:

Pam: *They make use of too many colours. Some of them are black, some of them dark purple. You really can't tell what colour they are.*
Fleur: *I can't read it all. It's all too close together.*
Leonie: *There are too many symbols.*
P: *And streets.*
Leonie: *And if you look at the symbols there are nineteen. There are nineteen symbols to follow and it's too much.*

By the end of lesson one the pupils had stated some of the main characteristics of a particular model (the map of the London Underground) and had critiqued it. However, the critique concentrated only on visual properties and did not include any neutral features such as the size of each station. The neutral features of a model are often the ones that stimulate further investigation. In addition, the critique concentrated only on the information-transmissive features of this model and the important feature of the map's usefulness even though it was not to scale was not mentioned. Thus the opportunity was lost to explore the idea that a model that is not a scaled-down miniature of reality can nevertheless be useful. However, the use of an example more familiar to the pupils might have been more effective. Nevertheless, it was a sound introduction to the idea that models have limitations and that their prime role is to explain things.

7.4.3 The Possibility of Building a Scale Model of the Solar System

The class' views about whether it was possible to build a visible scale model of the solar system in their classroom, the same scale to be used for both sizes and distances, were elicited via a two-level multiple-choice question (question D3). The results from the pre-, post- and post-post surveys for the question are shown in Figure 7.4.1. In reality, the huge difference between the sizes of the solar system models and their distances apart preclude such a visible model being built. The point of this question, and the associated task in lesson two, was to illustrate that a model can be useful without necessarily being a scaled-down miniature version of reality.

Figure 7.4.1 shows that the correct responses increased pre- to post-survey from 28% to 41%, a factor of 1.46. The non-parametric sign test indicates that the differences are statistically significant at the 0.01 level, but the parametric t-test indicates there is no statistical difference between the pre- and post-scores. That is, despite practical experiences to the contrary, described below, the results show that the majority of the pupils continued to hold the incorrect view that it is possible to build a visible scaled-down model of the solar system in their classroom. This incorrect view continued into the post-survey, the apparent decline in the number of correct responses from the post- to the

post-post survey not being statistically significant on either the sign or t-test.

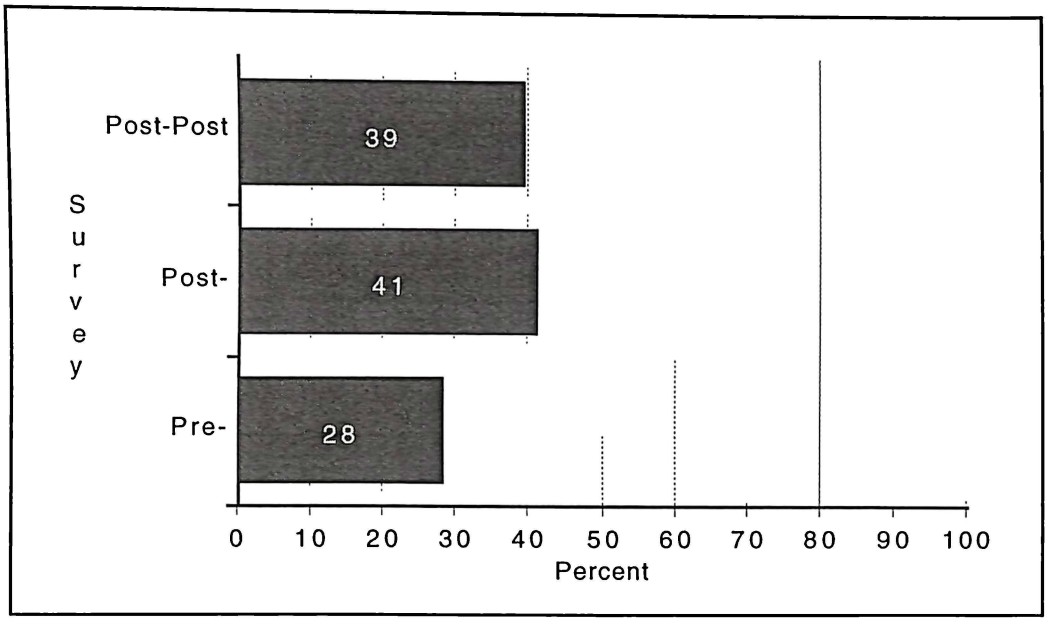


Figure 7.4.1: Percentages of Pupils Who Understood It Is NOT Possible to Build A Scale Model of the Solar System in Their Classroom: Pre-, Post- and Post-post Surveys

Before the intervention, five of the interviewed pupils wrongly considered that it was possible to build a visible scale model of the solar system in the classroom, although four of the five expressed some uncertainty in their responses. For example, *it depends how detailed you make it* [Frank] and it *depends on the scale you choose* [Jack]. One pupil did not respond to the question. After the intervention, despite their experiences to the contrary in that different scales had to be used for sizes and distances, four of the interviewed pupils remained certain that it was possible to make a scale model of the solar system that could fit into their classroom and that would be visible *because we've already done that* [Leonie]. One pupil was cautious in observing that we might have some difficulties seeing the smaller objects *such as the Moon and Pluto* [Hettie]. Only two pupils realised that we could not build a miniaturised model because, for example, *by the time you get it the right distance you won't be able to see the planets* [Frank]. That is, the intervention appeared to have caused only a modest growth from zero to two of the interviewed pupils sharing the scientists' view. This is despite the class having attempted and failed to build such a scale model. The idea of a model's prime property being that they are miniaturised versions of reality appears to be strongly held.

During lesson one, each of eleven groups (one for the Sun, one for the Moon and one each for the nine planets) built a scale model of its allocated solar system object. Each object was built to the scale in which Earth was represented by a sphere one centimetre in diameter. The information was provided in the group booklets and a variety of expanded polystyrene balls and cardboard was also provided. The teacher began by asking the Jupiter and Saturn groups what size their spheres would be:

P1: *Eleven centimetres.*
P2: *Nine point four centimetres.*

That is, the pupils appeared to have little difficulty in translating the scale for Earth to the scale size needed for 'their' solar system object. Each group used the micrometer to find a polystyrene ball that matched the scale size of their group's solar system object. There was no sphere large enough to model the Sun, so that group made their model from yellow card, to the same scale.

By the start of lesson two, the scale model of each solar system object had been hung from a string which stretched across the width of the room. Then the whole class critiqued the solar system model as it then existed, beginning with its advantages:

Betty: *It shows all the planets and they're in the order of the real planets.*
Peter: *You can see well, like, how things can seem... Like how Jupiter is to the Sun and how the Earth is to, like, Pluto or whatever.*

That is, the pupils identified the visible sequence of the planets and their relative sizes as advantages. They then critiqued it in terms of its disadvantages. Kit commented on the small size of some objects:

Kit: *It's, well, it's fairly accurate, but it's hard to see.*

Katie demonstrated that she had not fully understood the role of scale:

Katie: *In real life Pluto would not be that small and the Sun would not be that big.*

The pupils identified positive features of the model as being that it included all the main solar system objects, that they were in the correct sequence and that their relative sizes were correctly shown. However, they drew attention to the large disparity in the sizes of the Sun and Pluto, which made Pluto difficult to see. A key feature of critiquing a model appears to be that the pupils have to possess knowledge about the model in order to critique it. For example, the sequence of the planets as a positive feature could not have been identified without that prior knowledge by at least some of the pupils. The reverse also seems to be the case, in that pupils understood from the model the big difference in the sizes of the Sun and Pluto.

However, some pupils were not convinced that the wisest choice of scale had been made and they once again demonstrated their facility at arithmetically manipulating scale data:

P1: *If you started off with Earth, which is one centimetre, why haven't you just made Earth up to three centimetres so that you can see planets like Pluto?*
P2: *Then the Sun would be too big.*
P3: *The Sun would be huge.*
P1: *But then you'd be able to see all the planets.*

The teacher asked what would happen to the sizes of the model Sun and model Saturn if

model Earth's scale size was increased to three centimetres:

Peter: (*The Sun would be*) *three hundred and thirty centimetres.*
P: (*Saturn would be*) *twenty seven.*

The discussion further revealed that the pupils had little difficulty in manipulating scale in terms of the planets' sizes to make them more easily visible, even though this change would cause a huge Sun which would only just fit into the room. They understood that changing the size of one solar system model would affect the sizes of all the others proportionately. The teacher then asked the pupils to further critique their solar system model by asking if the real planets are all in a straight line out from the Sun:

Pam: *Like, different orbits that they've got, that go round the Sun further out. So it takes longer for them to go round. And so they're not always in a line.*

Here Pam has identified a negative feature of the solar system model in that the planets are not in reality in a straight line. As noted above, a key feature is that at least some of the pupils had to have some knowledge about the system to be able to critique it. That is, there appears to be an interactive relationship between knowledge and the skill of critiquing, each one supporting and building from the other.

The teacher then introduced the idea of scale distances for the solar system model. However, rather than using the scale provided in the intervention plan, the pupils suggested a different one:

P: *One hundred million kilometres to ten centimetres.*

Using that scale, the pupils were asked how many centimetres the Mercury model would have to be placed from the Sun:

P: *About five.*
Peter: *About six.*

Many pupils continued to show facility with these large numbers and scales. However, this scale for the planets' distances was different to the scale for the planets' sizes and it had the effect that their solar system model fitted into the classroom. It thus negated the major points of this exercise that it is **not** possible to build a visible model of the solar system if we use the same scale for both size and distance and yet that it could still be a useful model.

For about three quarters of an hour, the class continued to explore the effects of a variety of scales on the distances of the planets from the Sun. Then the teacher reverted to the original scale for both sizes and distances and asked Inez how far from the Sun Mercury would be:

Inez: *Forty five.*
T: *Forty five what?*
Inez: *Metres.*

That distance clearly surprised the pupils, so the teacher then asked Delia how far from the Sun Uranus would be, using this scale:

Delia: *Two point two kilometres.*

The pupils skilfully completed the calculations for each solar system object with the scale which was intended to have been used from the start. It indicated that Pluto, for example, would be 4.6 kilometres from the Sun. However, by this stage there was considerable confusion among the pupils. The teacher attempted to regain their acceptance of the idea that it is not possible to build a visible miniaturised scale model of the solar system in the classroom by asking what the model was good at showing:

Ann: *Size?*
T: *Yeah, or?*
Ann: *Or distance.*
T: *Or distance. But it's very poor at showing...*
Ps: *Both.*

However, some pupils remained confused. For example:

Chloe: *I'd got confused. I know that Mercury, and then you told me that it was such-and-such a size and some-one else told me it was a different size and then you said that Mercury was something else...*

A variety of distance and size scales had been used, causing confusion among many of the pupils. The result is that it was easier for them to remember that they had, in fact, built a visible scale model of the solar system in their classroom and to forget that the scales for sizes and distances had been different to each other. The point that this remained a useful model of the solar system without it necessarily being a scale version of it was not made. A further note about all of the above episodes is that only the positive and negative aspects of the solar system model were discussed. Neutral ones, such as the fact that the objects did not show the surface appearance of the solar system objects, were not articulated. It is easy to see how many of the pupils could have become confused about the possibility of building a visible scale model of the solar system.

7.4.4 Summary of Section 7.4

This class of Year 7-8 pupils enthusiastically engaged both with the notion of models and with the building of a particular astronomy model. Ideas from them included that models are used to illustrate ideas and to test theories but they did not address the difference between models and instruments. It appears that Year 7-8 pupils' ideas about scientific models are naive in that the prevailing view in this class was that they are of necessity scaled-down versions of reality which can be used to demonstrate and investigate that reality by predicting events and confirming or denying theories. To these pupils, the scale will of necessity be the same for all dimensions.

The intervention was only partially successful in changing pupils' views about the

impossibility of building a visible miniaturised model of the solar system in their classroom. The proportion of the pupils who understood that it would not be possible to do this increased from 28% to only 41%, despite the fact that the class had spent lesson two attempting and failing to build such a model. However, those pupils who did change their view as a result of the intervention also appeared to hold strongly to the new view. Unfortunately, the actual classroom interactions were probably a cause of the confusion. The researcher considers that the difficulties which followed would have been greatly reduced if the original plan had been adhered to.

7.5 PROMOTING PUPILS' MENTAL MODELS DURING THE *MENTAL MODEL BUILDING AND CRITIQUING* PHASE

7.5.1 Introduction

This section addresses research question three: *How effective are models in promoting mental model-building by Year 7-8 New Zealand pupils*? It describes the aspects and qualities of models that the pupils engaged in during their critique of that model. Furthermore, this section inquires into the teacher-promoted processes that were successful in helping these Year 7-8 pupils to construct their mental model of the Sun-Earth-Moon system. The section begins with a description of how the pupils described and critiqued the orrery. It then describes teacher-promoted classroom interactions during which the pupils constructed their mental model of the Sun-Earth-Moon system by using Hesse's system to repeatedly critique the orrery in its ability to illustrate and explain astronomy concepts which are subordinate to that mental model. Critiquing is seen as a key element in helping the pupils to build their mental model of the Sun-Earth-Moon system. It is a strategic departure from the more traditional approach of the teacher describing the orrery and then using it to illustrate astronomy ideas.

The orrery itself was explored and critiqued by the whole class in lesson three and by groups of pupils in lessons four to seven for concepts introduced in each particular lesson. For example, during lesson five, The Seasons, the teacher said "And then also turn to the red page, which asks you to, just in regard to the seasons, just in regard to the seasons, does the orrery model the seasons quite well? Does it show the different distances? Does it show the tilt? Is the model quite good at showing the seasons?"

Data is presented in the following sequence:

* identifying and critiquing the orrery (section 7.5.2);
* critiquing the orrery's ability to explain astronomy concepts (section 7.5.3).

7.5.2 Identifying and Critiquing the Orrery

As expected, before the intervention none of the interviewed pupils was able to describe an orrery or suggest any uses for it. In contrast after the intervention, all six were able to describe one. Two pupils described the orrery in static terms. For example, Hettie described it as having *the Earth, the Moon, the Sun and Mercury*, while Caleb added

that *it's a bit smaller than a desk.* The other four pupils all mentioned a dynamic aspect of the orrery, such as *it's got planets and the Sun in the middle, and you can turn it round and you can see them orbiting the Sun* [Jack].

As to purposes for the orrery, three post-interviewed pupils referred to its illustrative purposes. For example, an orrery is *so we can see kind of what the solar system looks like. What planets are smallest and biggest* [Leonie]. The other three pupils referred to the orrery being useful for investigations, such as predicting events and verifying theories. For example: the orrery is so people *can predict what's going to happen and prove that their theories are right... to get a better look at the planets' orbits and relative sizes and stuff* [Frank].

The pupils' understanding about the purposes of the orrery was elicited by asking them to decide which of several astronomy concepts the orrery was "very good" at explaining and which it was "poor" at explaining. Correct responses are shown in Table 7.5.1. The question was:

D5. In the following table, put a tick in the first column to show what an orrery is very good at demonstrating.
Put a tick in the second column to show what an orrery is poor at demonstrating.

Table 7.5.1: Acceptable Responses to Question D5

	Very Good	Poor
Tides		x
Phases of the Moon	x	
Eclipses	x	
Relative Sizes		x
Relative Times		x
The Seasons	x	

Figure 7.5.1 shows the results from the three surveys. It shows that the class as a whole increased its ability to critique the orrery from a mean pre-score of 0.5 (out of six) to a mean post-score of 3.9, a factor of 7.8. Both the non-parametric sign test and the parametric t-test indicate that these differences are statistically significant at the 0.001 level. The apparent decline in the mean score from the post- to the post-post survey was not statistically significant according to both the the non-parametric and the parametric tests, indicating that the pupils' skill in critiquing the orrery was conceptually strong.

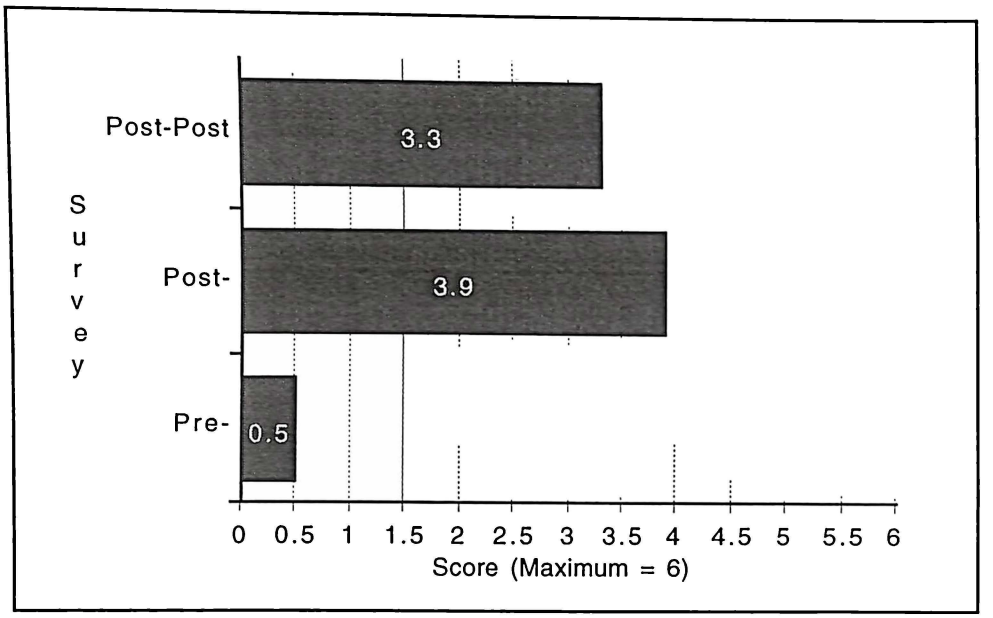


Figure 7.5.1: Mean Scores (Out of Six) of Pupils' Critique of the Orrery: Pre-, Post- and Post-post Surveys

The orrery was introduced in lesson three as a scientific model of the Sun-Earth-Moon system which most closely represented model (e) of the five mental models the pupils had considered in the pre-survey. The teacher said that the orrery would allow the pupils to understand and investigate an important part of the solar system model that they had constructed across the classroom. That is, the orrery *zoomed in*, to quote the teacher, on the Sun-Earth-Moon part of the solar system.

The practice of critiquing the orrery was also introduced in lesson three. The pupils were asked what the various parts of the orrery represented:

Ps: *The Sun.*
Ps: *The Moon.*
Ps: *Earth.*
Ps: *Mercury.*

The pupils correctly identified the component parts of the orrery, which was seen by them as being neither complicated nor threatening. The teacher then operated the orrery and asked the pupils to describe what month was represented by Earth's position, and why:

P1: *April.*
P2: *A quarter of the way through the year.*
P3: *'Cos we've done a quarter of a turn around the Sun.*

The teacher introduced the idea that the orrery, like all models, may not be an accurate representation of reality in that it has "advantages" (positive features) and "disadvantages" (negative features) that "distort" reality. Groups of pupils then observed and manipulated the orrery to answer some questions about the accuracy of its structure. For about 20 minutes they measured sizes and distances and wrote them on to the chalkboard. They then critiqued the orrery in terms of its positive points:

Ian: *The Sun and so on are all in it.*
Mary: *The way that the Earth doesn't go round in an exact circle.*
Mike: *How the Earth orbits the Sun.*
Peter: *The Earth spins on its axis and how the Moon orbits Earth.*
T: *OK. Now the orbit of the Moon. Is it elliptical around the Earth or circular?*
P: *It goes round the Earth.*
T: *Is it circular around the earth? Does the distance between the Earth and the Moon stay exactly the same?*
Ps: *No.*

The pupils had noted what they saw as the positive features of the orrery in that it included the Sun, Earth, Moon and Mercury, that it correctly represented Earth's elliptical orbit around the Sun, that Earth spins on its axis and that the Moon has an elliptical orbit around Earth. Again, the interaction between growth of knowledge and the ability to critique a model is evident. The pupils then discussed the negative features of the orrery:

Kit: *The size of the Earth to the Sun. On that it's about a quarter times smaller than the Sun.*
Ann: *The distances.*
T: *Tell me about the distances.*
Ann: *They're not accurate because they're not big enough.*
Hettie: *Sizes of the Earth and Mercury.*

The pupils enthusiastically contributed their ideas and questions during this activity. They noted a number of negative features about the orrery's ability to accurately model the Sun-Earth-Moon system, these being that the relative sizes of the Sun, Earth, Moon and Mercury are not accurate, that the relative distances between the objects are not accurate and the number of months in a year is shown inaccurately. The pupils then discussed neutral features of the orrery:

Mary: *Mercury doesn't spin on the axis.*
T: *OK. Is that right?*
P: *The white side always faces the Sun.*
T: *That is the observation, isn't it? That the white side is always facing the sun. Is Mercury spinning on its axis, though?*
Ps: *No.*
Mary: *I'm not sure. Is it accurate that Mercury's axis is not on a tilt? Do all planets have their axis' tilted?*
T: *OK. Good question. Can I put it in in here (the neutral column), with a question mark, because we're not sure?*
Geoff: *The colour of Mercury. We're not sure.*
T: *OK. Perhaps we'd better put that in here (the neutral column) as well. We're not sure.*
Ann: *Are the orbits right? The way they turn? Whether they turn correctly on the orrery.*
T: *OK. Whether the rotation of the planets is accurate? Or the rotation of the Earth is accurate? So put it in the don't know column.*

The neutral features identified by the class were whether Mercury spins, whether Mercury's axis is tilted and whether the colour of Mercury is shown accurately. Rather than giving the correct response, the teacher had pointed out that the items in this column

would be subject to further investigation. These interactions again underline the relationship between knowledge and the ability to critique a model.

Critiquing the orrery allowed the pupils to use Hesse's ideas of critiquing a model, the neutral column being indicated as a starting point for further exploration. That is, the pupils engaged with positive, negative and neutral features of the orrery. In addition as noted above, the pupils tended to concentrate on the scale property of the orrery in terms of relative sizes, relative distances and relative movements such as spin and orbit times.

The teacher recorded on the chalkboard the pupils' critiques of the orrery as they were articulated in the class discussion. These are shown in Table 7.5.2.

Table 7.5.2: The Pupils' Critique of the Orrery

Positive	**Negative**	**Neutral**
Things the Orrery Gets Right	**Things the Orrery Does Not Get Right**	**Things the Orrery Does Not Mention**
Sun, Earth, Moon, Mercury are present.	Relative sizes of Sun, Earth, Moon and Mercury.	Mercury has a vertical axis.
Earth orbits Sun.	Sun-Earth distance.	Colour of Mercury.
Earth spins on axis.	Earth-Moon distance.	Rotation of Moon.
Earth's axis is tilted.	Sun-Mercury distance.	Rotation of Mercury.
Earth's orbit is elliptical.	Comparative revolution and rotations of Earth.	
Moon orbits Earth.	Mercury does not spin (*).	
Moon's orbit is elliptical.	Moon does not spin (*).	
Mercury orbits Sun.	Relative orbit of Moon and of Earth.	

* denotes uncertainty by the pupils about whether Mercury and the Moon rotate.

The intervention was responsible for the fact that these pupils had come to the understanding that the orrery, as an example of a model, could illustrate some, but not all, the astronomy ideas related to the Sun-Earth-Moon system. The understanding that all scientists' models have limitations, while still being useful, was an important objective of the intervention.

The interaction between growth of knowledge and the ability to critique a model is again evident in that, for example, everyone in the class knew that Earth spins on its own axis. However, despite the orrery clearly showing that the axis of spin is through Earth's poles, later analysis (see Figure 7.7.3) reveals that the pupils' view is often different.

The pupils had been given the opportunity to describe the orrery in both static and dynamic terms and had been invited to critique it using Hesse's approach of positive, negative and neutral aspects of the orrery. Pupils' questions were not answered by the teacher, who pointed out that if there was not unanimity about any particular idea, then

that should be entered under the neutral column of the critique sheet for later investigation. For example, there was debate about whether the orrery demonstrates whether Mercury and the Moon rotate, quite apart from whether the orrery is correct or not in that regard. None of the pupils had directly mentioned the astronomy concepts of days, months, years, seasons, eclipses or phases of the Moon, although the relationship between the Moon's orbit of Earth and Earth's orbit of the Sun was questioned by Frank.

7.5.3 Critiquing the Orrery's Ability to Explain Astronomy Concepts

The *Mental Model Building and Critiquing* phase is the key phase in helping the pupils build their mental model of the Sun-Earth-Moon system. To that end, each of lessons 3-7 consisted of a focus-challenge-review cycle during which an astronomy concept subordinate to the scientists' mental model of the Sun-Earth-Moon system was investigated by the pupils. In each lesson the pupils were asked to state their prior ideas about an astronomy concept introduced by the teacher, so revealing the variety of ideas within the class. Each idea was then challenged by an activity which included operating the orrery (which represented the scientists' mental model) and debating the extent to which the orrery could be used to illustrate and explain that concept. At the conclusion of each lesson, the pupils reviewed their findings by completing a critique of the orrery (and thus the scientists' mental model of the Sun-Earth-Moon system) with respect to its capacity to effectively portray the astronomy concept they had investigated. The astronomy concepts are next considered in the sequence in which they were investigated.

The Orrery and Days

In lesson 4, the pupils investigated days, months and years on the orrery. The teacher began by asking the pupils what they thought a day is:

Jack: *The time when the Earth spins on its axis once.*

Having established the astronomy idea of a day, the pupils observed the orrery in action to see if it did, in fact, model day and night:

T: *Let's have a look. The time when the Earth spins on its axis once. Look. There's New Zealand. The Sun's shining on New Zealand. OK. New Zealand's back here. What can you tell me about that*?
Ps: *Twelve hours.*
T: *Twelve hours. And, Peter*?
Peter: *New Zealand is now dark.*

The pupils demonstrated a good understanding of the astronomy idea of day and night and realised that the orrery realistically portrayed them as being due to one rotation of Earth. That is, the scientists' mental model (portrayed by the orrery) of the Sun-Earth-Moon system was affirmed in its ability to explain days and nights. The pupils raised a question about the orrery's accuracy, wondering if it showed the correct number of days during one orbit of Earth around the Sun. They were asked to hang on to that question by placing it in the neutral critique column.

The Orrery and Years

The class then went on to consider the concept of the year, again using the orrery to model and investigate the concept after the pupils first enunciated their views of the astronomy meaning of a year:

Katie: *It's when the Earth goes once round the Sun.*

The teacher then took the opportunity to respond to the question from the previous section, thus critiquing the orrery in this respect, by asking the pupils to count the number of orrery days in one orrery year:

Ps: *... 1... 2... 3... 4... 5... 6... 7... 8... 9... 10... 11... 12... 13... 14... 15...*
T: *That's it. So is it realistic*?
Ps: *No.*
T: *Accurate*? *Or is it realistic and inaccurate*?
Ps: *Realistic and inaccurate.*

The pupils had been given the opportunity to define a year in astronomy terms, to illustrate a year on the orrery, to critique the orrery's ability to demonstrate years and to see that the scientists' mental model was affirmed in this respect. They clearly had a good understanding of the astronomy idea of a year being the time for Earth to orbit the Sun. Furthermore, they realised that the orrery illustrated the astronomical idea of a year *realistically*, but that it was *inaccurate* in its ability to model the actual relationship between days and years. These were terms introduced by the teacher to be the equivalent of Hesse's *positive and negative*. However, they are not directly equivalent and they do not include an equivalent term for neutral.

The Orrery and Months

The class then used the orrery to investigate the concept of months on Earth. First, the pupils' views of the astronomy meaning for months was stated:

Olive: *When the Moon goes round the Earth once.*
T: *Does that make sense*?
Ps: *Yep.*

The pupils defined a month in astronomy terms and were given the opportunity to illustrate it on the orrery. They appeared to have a good understanding of the concept of a month and they understood the scientists' mental model was affirmed in this respect. The pupils then critiqued the orrery's ability to demonstrate months by investigating whether the orrery gives a realistic and accurate representation of the Moon going around Earth:

T: *How many times should the Moon, roughly, go around the Earth in a year*?
Ps: *Twelve times.*
T: *Twelve times. OK. Let's have a look. Come back here, starting there. OK. Let's go.*
Ps: *... 1... 2... 3... 4... 5...*
P: *And a bit.*
P: *Yeah, there it is.*

The pupils realised a positive aspect that the orrery showed the astronomical basis of how we get months on Earth. They also noted a negative aspect about the orrery because of its inability to accurately reflect the numerical relationship between months and years. They had once again used the terms *realistic* and *accurate* as ways to critique the orrery, rather than Hesse's positive and negative. No neutral aspects had been elicited or referred to.

The orrery investigation of month suggested an implication to one pupil:

P1: *So if the Moon goes round the Earth every month, how come there's... Is there a full moon every month*?
P2: *Yes, there is.*
P1: *Oh, OK. That's alright then.*

That question, with the ready acceptance of another pupil's response, suggests that both pupils were developing a good conceptual understanding of the idea and cause of months and its implications for full moons. The scientists' mental model was further affirmed.

The Orrery and Seasons

Lesson five was conducted in a similar way to lesson four, in that the pupils stated their ideas about seasons and then devised and conducted an experiment to determine which of the competing ideas was most likely to be correct. The class changed its predominant view prior to the lesson that seasons are caused by Earth's changing distance from the Sun to one in which Earth's axis tilt is the main cause of the seasons, with Earth's changing distance from the Sun being responsible for about a third of the seasonal effect. This is different to textbook explanations, which say that the axis tilt is virtually the only cause of seasons. That is, the experiment further affirmed, in a modified form, the scientists' mental model. The class then discussed the orrery's ability to illustrate and explain seasons on Earth. The teacher again pointed out the limitations of any model by using *realistic* instead of Hesse's *positive* and by using *not accurate* instead of Hesse's *negative*. Again, the neutral features of the orrery were not mentioned.

The Orrery and Eclipses

Lesson six followed the same general pattern as the two previous lessons, in that the pupils stated their ideas about solar and lunar eclipses and then illustrated them on the orrery. They then critiqued the orrery by discussing its ability to explain eclipses. For example, a positive feature was:

P1: *In the way that you can see the shadow.*

A negative feature was:

P2: *... because it shows those other things, like too many eclipses.*

The pupils understood that a positive feature of the orrery was that it portrayed eclipses of both the Sun and the Moon. A negative feature was apparent in that the orrery had both lunar and solar eclipses every month, whereas in reality we only experience a few of each

type in a full year. The scientists' mental model was further affirmed in this respect. The teacher then referred back to the orrery to elicit the reasons for the disparity between reality and the orrery's portrayal of the frequency of eclipses:

Oliver: *The sizes aren't right.*
T: *Yep. The sizes and?*
P: *And distance.*

The pupils understood that the orrery, because of its not being to the same scale for sizes and distances, was not accurate (a negative aspect) with respect to explaining eclipses.

The Orrery and Phases of the Moon

Lesson seven was the last lesson in the *Building and Critiquing the Mental Model* phase. Using the same approach as in the previous three lessons, the pupils stated their various views about the causes of the phases of the Moon. Then they went to a darkened room where the orrery was used to model the phases. The class then returned to the classroom to critique the orrery in their groups, during which the teacher re-emphasised the orrery's representation of the visual pattern of the Moon's phases and elicited from them the point at which, according to the orrery, the pattern broke down:

P: *The new moon.*

The pattern on the orrery actually breaks down at the full moon, but this is a point only of terminology in that there had earlier been an unresolved discussion among the class as to which name made most sense to them. The reason for the orrery's inability to accurately fully model the phases of the Moon (a negative feature) were not discussed.

This activity further affirmed the scientists' mental model of the Sun-Earth-Moon system, in which the Moon orbits Earth to cause the phases of the Moon, rather than the phases being caused by Earth's shadow falling on the Moon. Despite the activities of observing the orrery as it illustrated the phases of the Moon and of critiquing the orrery in this respect, Jennie still held to the common view that the Moon's phases were caused by Earth's shadow:

Jennie: *The shadow. That's like the shadow is moving around.*

The teacher helped to resolve Jenny's misunderstanding by pointing out a logical inconsistency of her view and by introducing the term *optical illusion*. However, the same procedure had been followed earlier in the same lesson, during which all elicited ideas were subjected to scrutiny. This episode illustrated that alternative concepts are not easily changed towards scientists' ones.

7.5.4 Summary of Section 7.5

Table 7.5.3 tabulates the pupils' responses to the critique of the orrery during lessons four to seven.

Table 7.5.3: Pupils' Critique of the Orrery During Lessons Four to Seven

Positive	Negative	Neutral
Does Demonstrate Realistically	**Does Not Demonstrate Realistically**	
Earth's rotation causes days and nights.	Number of days in a year.	
Day-night terminator runs north-south, not east-west.	Number of days in a month.	
Moon's orbit of Earth causes months.	Number of months in a year.	
Earth's orbit of Sun causes years.	Frequency of solar eclipses.	
Seasons are caused mainly by tilt of Earth's axis.	Frequency of lunar eclipses.	
Nightless summers and dayless winters at the poles.	Never shows a new Moon.	
Solar eclipses occur when Moon comes between Sun and Earth.	Earth's changing distance from Sun affects seasons. **	
Lunar eclipses occur when Earth comes between Sun and Moon.		
Phases of Moon are caused by viewing the lighted Moon from different perspectives.		

** indicates that the pupils 'discovered' in their experiment in lesson five that the seasons on Earth are caused by both Earth's axis tilt and by Earth's changing distance from the Sun in a ratio of about 2:1. This finding is dissimilar to the one generally found in astronomy texts, which state that only the axis of tilt is of any significance in determining the seasons.

The intervention was successful in getting the pupils to repeatedly critique the orrery in terms of its ability to explain a number of astronomy concepts. This further affirmed the scientists' mental model of the Sun-Earth-Moon system. The pupils' ideas about the causes of days, months, years, seasons, eclipses and phases of the Moon had been elicited and then investigated on the orrery, while at the same time critiquing the orrery for how well it portrayed the scientists' mental model. However, the orrery's neutral features remained under-emphasised.

The pupils were enthusiastic about the critiquing process and did not tire of it. Also, they were focused about discussing and testing ideas and explanations with the orrery. As noted above, the orrery as a model was summed up by the teacher as being *realistic but not accurate*. That is, in Hesse's terms it had both positive and negative features. Even though the idea of neutral features had been introduced in lesson three the orrery's neutral aspects, such as its accuracy in portraying whether the same side of Mercury always faces the Sun, were not investigated in these lessons. During lessons 4-7 the overall critiquing

of the orrery as a model uncovered the features shown in Table 7.5.3.

The following teacher-promoted processes were successful in helping these pupils construct their mental model of the Sun-Earth-Moon system:

1. introducing the orrery as a model of scientists' mental model of the Sun-Earth-Moon system;
2. critiquing the orrery itself;
3. eliciting and sharing pupils views about each astronomy concept;
4. critiquing the extent to which the orrery illustrated and explained each astronomy concept;
5. relating each astronomy concept to the scientists' mental model of the Sun-Earth-Moon system.

In addition, there appears to be an interactive relationship between the practice of critiquing the orrery and pupils' understanding of astronomy concepts. Progress in each one appears to facilitate the other.

7.6 CONSOLIDATING PUPILS' MENTAL MODELS DURING THE *USING THE SCIENTISTS' MENTAL MODEL TO SOLVE PROBLEMS* AND THE *REFLECTION* PHASES

7.6.1 Introduction

This section investigates the extent to which groups of pupils applied their newly constructed scientists' mental model to solve problems that were new to them. It also describes how they interactively reported their findings to the rest of the class. Table 7.6.1 shows which groups were allocated to each of the novel problems.

Table 7.6.1: Allocation of Groups to the *Using the Mental Model to Solve Problems* Activities

Activity	Groups
1. Describe a day, year and seasons on Mercury.	Mercury, Mars, Uranus
2. Do the Moon and Mercury always show their same faces to Earth and the Sun, respectively?	Earth, Mars, Neptune
3. Describe the effect on the tides if Earth had zero or two moons.	Moon, Venus, Mercury
4. How are tide heights and Moon set times related? What does this tell us?	Mars, Saturn, Pluto, Moon
5. How are tide heights and Moon phases related? What does this tell us?	Uranus, Sun, Earth, Venus
6. Select a planet. Describe the days and years on it.	Jupiter, Saturn, Uranus, Sun
7. Select a planet. Describes its seasons.	Pluto, Neptune, Jupiter, Saturn

Data is presented in the following sequence:

* using the mental model to solve problems (section 7.6.2);

* reflecting on the solutions to the problems (section 7.6.3).

7.6.2 Using the Mental Model to Solve Problems

The purpose of this phase was to help the pupils consolidate the scientists' mental model of the Sun-Earth-Moon system that they had constructed in the previous phase by using it to solve problems that were new to them. That is, this phase consisted of small group tests of the fruitfulness of the scientists' mental model. Each of the seven activities was completed by three or four groups, as shown in Table 7.6.1.

Tides (activities four and five) was a new concept introduced in this phase.

The pupils were informed that they would have to interactively report each activity's findings to the rest of the class and defend their findings. That is, the other pupils and the teacher would be expected to ask questions. As an example, the Uranus group used the orrery to investigate ideas about Mercury and to critique the orrery in this regard. The pupils in the group interacted to resolve the problem, although Geoff seemed more interested in completing the task than in understanding it:

Jennie: *No tilt.*
Ian: *So is it right in that respect*?
Geoff: *Yep.*
Jack: *What's Mercury? Is it meant to have a tilt*?
Geoff: *No.*
Jack: *Is it not even slightly tilted*?
Geoff: *No. So the orrery is accurate for the tilt. But is it accurate for showing the same face facing the Sun all the time*?
Jenny: *No.*
Geoff: *OK. So just put something like that, so that we can report back to the class.*

This group merely described the relationship between Mercury's days and years, without considering the implications of the relationship:

Jennie: *Oh, what does that mean, in terms of Mercurian days*? *OK. One and a half days in one... One and a half days in one Mercurian year is equal to one year. Equals to one year. OK, finished.*

The pupils were a little unsure about the questions. Although they debated the issues among themselves, they tended to accept the first view that was enunciated. This reflected a desire to complete each task quickly rather than to engage in an investigation. There had, nevertheless, been interaction within the group rather than passive learning, because the pupils understood that they had to report back to possibly critical peers. The researcher and the teacher (see section 8.3) considered that the *Using the Mental Model to Solve Problems* phase was an important one in assisting the pupils to consolidate their acceptance of the scientists' mental model of the Sun-Earth-Moon system.

7.6.3 Reflecting on the Solutions to the Problems

The purpose of the *Reflection* phase was to further consolidate the pupils' construction

of the scientists' mental model of the Sun-Earth-Moon system by having them report back and defend their findings with respect to the problems they had solved from the viewpoint of that mental model. This phase was a whole class investigation of the fruitfulness of the scientists' mental model. Rather than passively receiving the reports, the class debated the ideas, with most pupils contributing to the discussion. For example, the pupils recognised that the planets' different orbital times meant that days and years on those planets would be different to those on Earth:

Mike: *Yep. A day on Venus is equivalent to eight months on Earth and although Jupiter spins a lot quicker on its axis it takes a long time for it to orbit the Sun. And a Jupiter year is as long as twelve Earth years. So if we lived on Jupiter then we'd be only one year old. The years are shorter if the planets are closer to the Sun, and longer if they're further away. And a year on Pluto is as long as two and a half centuries on Earth.*
Ps: *Wow.*

Later in the lesson a group reported its findings that seasons on another planet are due to the tilt of its axis:

Leonie: *OK. Question one, do other planets have seasons? And we put 'yes'. And what evidence do we have for our answer? Because of the tilt of this axis.*

Ann, in the same group, expanded on Leonie's response, adding that a planet's distance from the Sun would have a perturbing effect on its seasons:

Ann: *So just how we get seasons, they get same as us. But they wouldn't get the same degree of seasons as us, because we're closer to the Sun or further away from the Sun than other planets.*

There was widespread pupil recognition that seasons are caused by both the tilt of a planet's axis and by its changing distance from the Sun because its orbit is elliptical. This was made clear later in the lesson when seasons on Mercury were discussed:

Betty: *Mercury has no tilt. Does it have any seasons?*
Ann: *Probably.*
Betty: *Why?*
Ann: *Because it's orbit is elliptical.*

Later in the lesson further discussion occurred during which pupils indicated their understanding that while both axis tilt and distance from the Sun have an effect on seasons, the most important cause is the axis tilt:

Ernie: *If the orbit's elliptical, it might, it might make a change but the biggest change, really, is the tilt.*

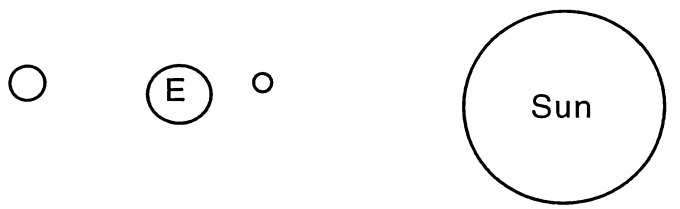
The effect of the groups doing their own problem-solving and reporting back was best exemplified during an interactive sequence during which one group reported its discussions on the effect of tides on Earth if Earth had two Moons. The report began with the assumption that the two moons were of the same size and distance from Earth, but on

opposite sides:

Olive explained the effect of these two moons on Earth's tides. Then Betty complicated the case by asking what would happen if one moon was bigger than the other. Olive drew that on the chalkboard and the class, in an interested and informed manner, discussed the new effect on the tides, which they agreed would continue to occur twice each day but which would now have a greater range. Later, Peter asked a question relating to the effect on the tides if the two moons were at 90^{o} to each other. Again, the class debated the effect of this, concluding that there would then be four high tides each day:

Peter: *Oliver had a very awesome hypothesis of how you could do it. I think, since there are two moons that this moon's, like, pulling the tide this way and this way. I think it could sort of... there could be a high tide here and a high tide there and also a high tide there and a high tide there. And so it's sort of pulling the water, like, more there. And so, like, the low tides are sort of there. So, like, there might be more high tides but some of them, like these areas over here are lower.*

More than half the class had become involved in the question about the different Moon situations, discussing the tidal effects of two moons at different distances from Earth and at different relationships to each other and with moons of different sizes. Betty then added a further complication, using the orrery to demonstrate her concept that the Sun also had an effect on tides:



Betty: *It might only be centimetres different. It depends on that scale further away. If it was only, like, a little bit further away then it would be higher tides here and a little bit lower tide here. But if it was a lot further away, then it could be about the same high tides. Again, if it was smaller and that far away then... I don't know.*

The pupils, in a class discussion at the reporting back phase, demonstrated a clear understanding of their findings from the problem-solving activities, including the role of the Moon and Sun in causing tides. While the discussion became quite noisy at times, it was because of pupils' involvement in a genuine discussion. They estimated the effect on the tides of two moons of the same size and at the same distance from Earth, both at 180^{o} and at 90^{o} to each other. They had considered if the two moons were of different sizes, if the two moons were at different distances and if the Sun was also involved.

7.6.4 Summary of Section 7.6

The pupils in each group used the scientists' mental model to co-operatively solve problems that were novel to them. While there was a tendency at times for the group to accept the first response offered to a question, in general the pupils were fully involved, undertook the tasks in the way intended and debated both the various ideas that arose and the methods of reporting back to the rest of the class. In practice, the Sun, Mercury, Venus, Earth, Jupiter, Neptune and Pluto groups all resolved two novel problems and the Mars, Saturn and Uranus groups each resolved three novel problems.

Most of the pupils developed further understanding during the *Using the Mental Model to Solve Problems* phase, which appeared to be important in helping the pupils to consolidate their construction of the scientists' mental model of the Sun-Earth-Moon system because of its fruitfulness in solving new problems.

During the *Reflection* phase the pupils used their newly constructed scientists' mental model of the Sun-Earth-Moon system to interactively report back their findings from the problem-solving activities. They were confident in using both the orrery and the Sun-Earth-Moon mental model. They appeared to develop a considerable depth of understanding during the *Reflection* phase, which appeared to be a key feature in helping the pupils to further consolidate their acceptance of the scientists' mental model of the Sun-Earth-Moon system. The *Reflection* phase, in this interactive form, appeared to be as significant as the *Using the Mental Model to Solve Problems* phase.

7.7 THE EXTENT TO WHICH THE PUPILS BUILT THE SCIENTISTS' MENTAL MODEL OF THE SUN-EARTH-MOON SYSTEM

7.7.1 Introduction

This section considers research question two: *Are pupils able to construct the scientists' mental model of the Sun-Earth-Moon system*? It discusses the extent to which the pupils constructed a mental model of the Sun-Earth-Moon system that is compatible with that of scientists. It compares data from the pre-, post- and post-post surveys and the pre- and post-interviews to reveal any changes to their prior mental models. This section also considers a more detailed examination of the pupils' understanding of the inter-relationships between the component parts of the Sun-Earth-Moon mental model.

Data is presented in the following sequence:

* pupils' mental models of the Sun-Earth-Moon system (section 7.7.2);
* pupils' ideas about the inter-relationships between Sun, Earth and Moon (section 7.7.3).

7.7.2 Pupils' Mental Models of the Sun-Earth-Moon System

The Sun-Earth-Moon mental models of the whole class were investigated via a one-level, five-item, multiple-choice question (question D1) which asked the pupils to indicate which one of five Sun-Earth-Moon systems made most sense to them (see Figure 2.5.3). The model closest to the scientists' model was model E, in which the Moon orbits Earth which itself orbits the Sun. The distribution of the pupils' responses is shown in Table 7.7.1.

Table 7.7.1: Distribution of Pupils' Mental Models of the Sun-Earth-Moon System: Pre-, Post- and Post-post Surveys

	Pre-survey	Post-survey	Post-post survey
Model A	2	1	0
Model B	0	1	3
Model C	1	0	0
Model D	7	1	0
Model E	15	28	28
No Response	6	0	0
Totals	25	31	31

Six pupils failed to respond to this question during the pre-survey, but they all responded during the post-survey and the post-post survey. Support for mental model A, which had a stationery Earth at the centre of the system with the Sun and Moon alternately moving nearer and further away to cause day and night, declined from 6% in the pre-survey to 3% in the post-survey to zero in the post-post survey. Mental models B and C were also Earth-centred models. While support for mental model C declined from 3% in the pre-survey to zero subsequently, support for mental model B increased from zero in the pre-survey to 9% by the time of the post-post survey. Support for mental model D, which represented both Earth and the Moon orbiting the Sun, had the support of 23% in the pre-survey. This reduced to 3% in the post-survey and was extinguished by the time of the post-post survey.

On the other hand, support for mental model E, the one closest to the scientists' mental model, is illustrated in Figure 7.7.1.

Figure 7.7.1 shows that the class as a whole changed its mental model of the Sun-Earth-Moon system towards the scientists' view, from pre-survey support of 48% to post-survey support of 90%, a factor of 1.9. Both the non-parametric sign test and the parametric t-test indicate that the differences are statistically significant at the 0.001 level. Before the intervention, most pupils in this class were not in a position to use the scientists' mental model to discuss and explain effects caused by the Sun-Earth-Moon system, such as days, months, seasons and years. However, after the intervention, 90% of them had constructed the ability to use the mental model to understand and explain those concepts. Nevertheless, a tenth of the class, despite the intervention, failed to

construct for themselves the scientists' mental model of the Sun-Earth-Moon system.

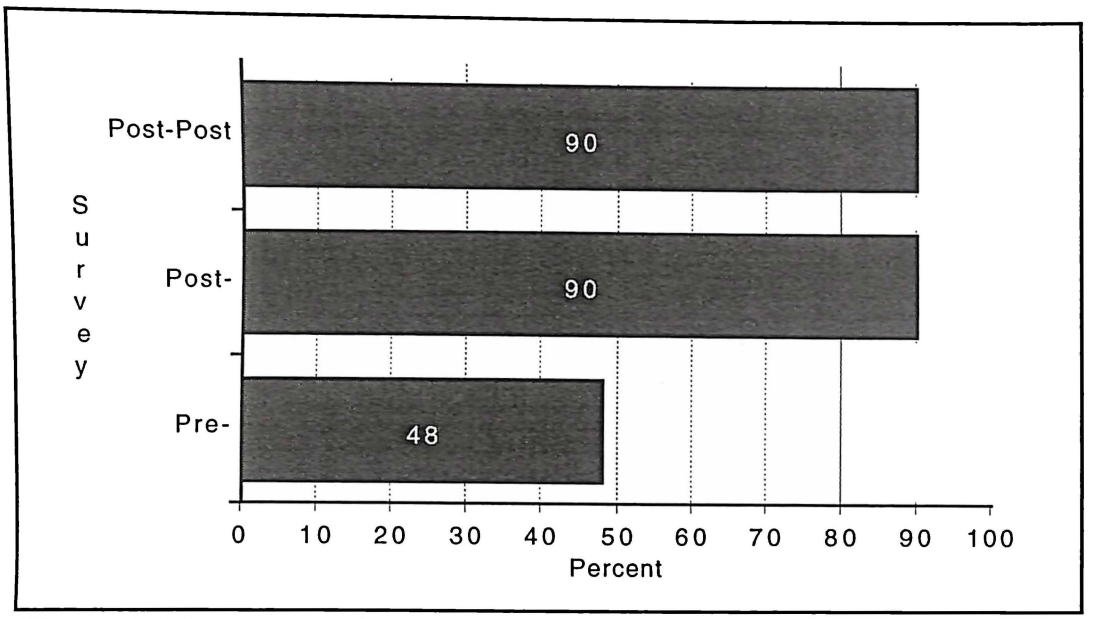


Figure 7.7.1: Percent Support for the Scientists' Mental Model of the Sun-Earth-Moon System: Pre-, Post- and Post-post Surveys

Support for mental model E remained constant from the post-survey to the post-post survey, indicating that the pupils' mental model of the Sun-Earth-Moon system was conceptually strong. That is, for 90% of these pupils, their mental models of the Sun-Earth-Moon system appear to securely agree with those of scientists as a result of the intervention.

7.7.3 Pupils' Ideas About the Inter-Relationships Between Sun, Earth and Moon

It could reasonably be argued that selection of one mental model from among five mental models is not necessarily a clear indication of any person's viewpoint, in that the selection could be a learned but not understood response. Thus a more detailed probe of these pupils' mental models of the Sun-Earth-Moon system was investigated via interviews and by four-item multiple choice questions which asked for the pupils' more detailed ideas about the structure of the Sun-Earth-Moon system. For example, a four-item multiple choice question (C8b) asked the pupils to select their reason for what causes a day. A response similar to that of scientists is that *days depend on the time for Earth to spin once on its axis.* The percentages who responded correctly in the pre-, post- and post-post surveys to this question are shown in Figure 7.7.2.

Figure 7.7.2 shows that the class as a whole changed its view of what causes a day on Earth towards the scientists' view, from pre-survey support of 25% to post-survey support of 91%, a factor of 3.6. The non-parametric sign test indicates that the differences are statistically significant at the 0.001 level and the parametric t-test indicates the differences are statistically significant at better than the 0.001 level. Before the intervention, the majority of the pupils in this class who responded to the question was of

the view that a day is due to Earth orbiting the Sun. However, after the intervention, 91% of this class agreed with the scientists' view that days on Earth are caused by Earth's rotation on its axis. Support for the scientists' view remained constant, with no statistical difference from the post-survey to the post-post survey on either the sign or the t-test, indicating that the pupils' view of the cause of days was conceptually strong.

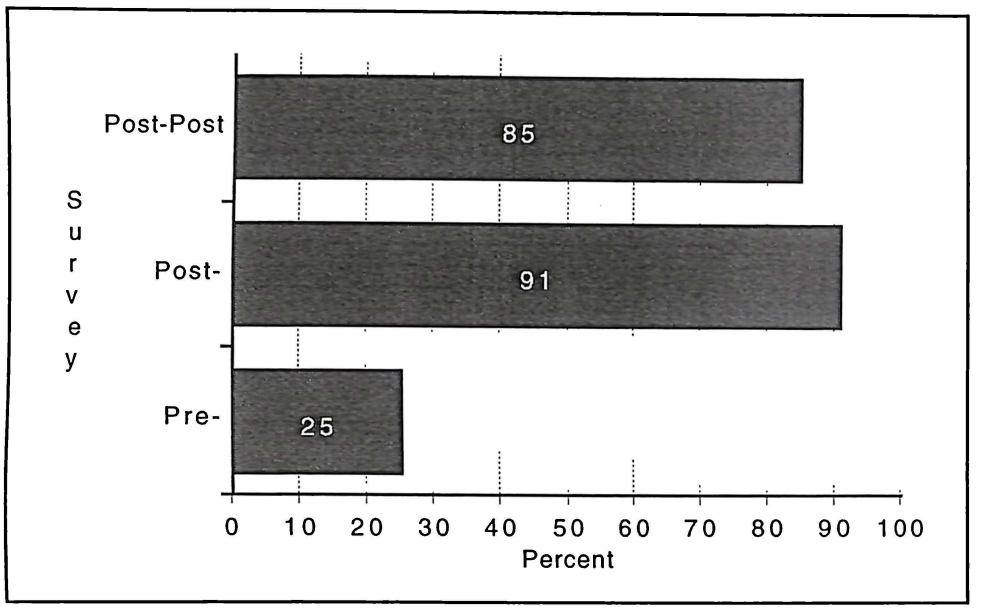


Figure 7.7.2: Percent Support for the Scientists' View of the Causes of Day and Night: Pre-, Post- and Post-post Surveys

However, question C8b did not uncover the extent of the pupils' concepts in this regard. A second four-item multiple choice question (C11b) also asked the pupils to indicate their reason for why day and night do not occur at the same time all over Earth. A response similar to that of scientists is that this is *because Earth spins on an axis through its north and south poles.* The percentages who responded correctly in the pre-, post- and post-post surveys to this question are shown in Figure 7.7.3.

Figure 7.7.3 shows that the class as a whole changed its view of why days and nights do not occur at the same time all over Earth, from 16% pre-survey support for the scientists' view to post-survey support of 47%, a factor of 2.9. The non-parametric sign test indicates that the differences are statistically significant at the 0.05 level and the parametric t-test indicates the differences are statistically significant at the 0.02 level. Before the intervention, the majority of the pupils in this class responded that the Sun orbits between the north and south hemispheres to cause day and night. Even after the intervention, only 47% of the pupils agreed with the scientists' view. The majority view was that the axis of rotation is through Earth's equator. The apparent decline in support for the scientists' view between the post-survey and the post-post survey was not statistically significant on either the sign or the t-test. It is clear that the pupils' view of the cause of days and nights was not well developed by this intervention.

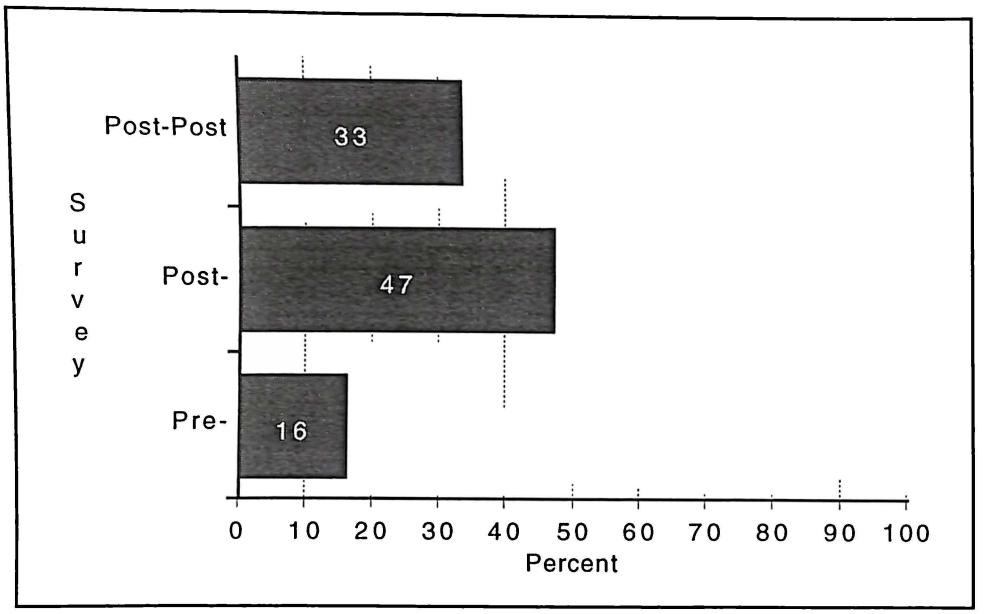


Figure 7.7.3: Percent Support for the Scientists' View of the Axis of Earth's Rotation: Pre-, Post- and Post-post Survey

A four-item multiple choice question (C9b) asked the pupils to indicate their reason for what causes a year. A response similar to that of scientists is that *years depend on the time for Earth to go around the Sun.* The percentages who responded correctly in the pre-, post- and post-post surveys to this question are shown in Figure 7.7.4.

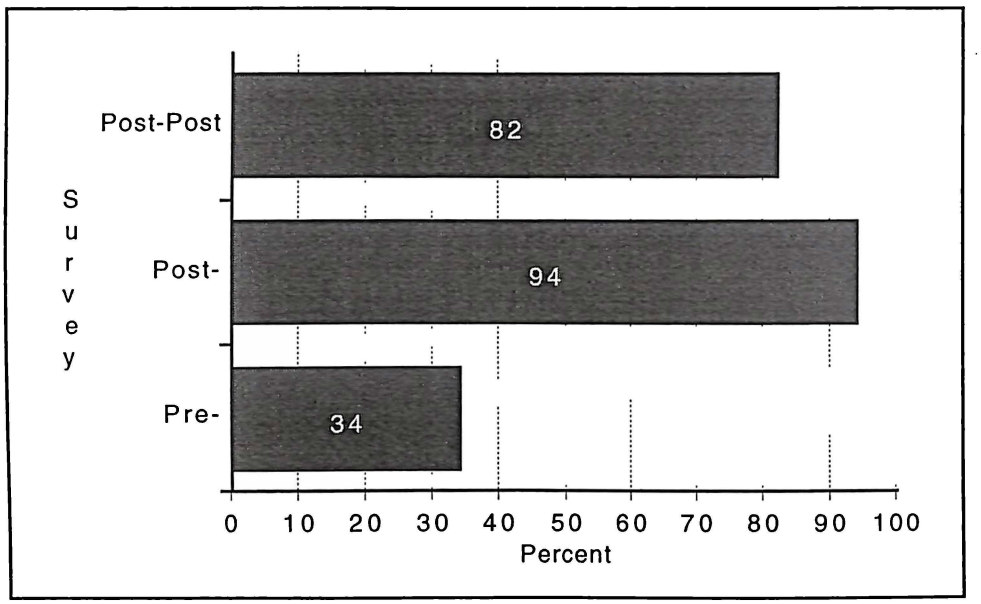


Figure 7.7.4: Percent Support for the Scientists' View of the Causes of Years: Pre-, Post- and Post-post Survey

Figure 7.7.4 shows that the class as a whole changed its view of what causes a year on Earth towards the scientists' view, from pre-survey support of 34% to post-survey support of 94%, a factor of 2.8. The non-parametric sign test indicates that the differences are statistically significant at the 0.001 level and the parametric t-test indicates the

differences are statistically significant at better than the 0.001 level. Before the intervention, the majority of the pupils in this class failed to respond to this question. However, after the intervention, 94% of them agreed with the scientists' view that years on Earth are caused by its orbit around the Sun. The apparent decline in support for the scientists' view from the post-survey to the post-post survey was not statistically significant on either the sign or the t-test, indicating that the pupils' view of the cause of years is conceptually strong.

Prior to the intervention five of the interviewed pupils understood that *the Earth goes around the Sun* [Caleb], while one pupil held very strongly to the view that *the Sun and the Moon just stay still and the Earth moves* [Leonie] around them. Two pupils offered reasons for their views. For example, *the Sun is in the middle of the solar system so it can't go round more than one planet at once* [Jack] and because *that's why night and day happen* [Caleb].

After the intervention, all six interviewed pupils shared the scientists' view that *the Earth goes around the Sun*, two pupils adding that it was because *the Sun has a gravitational pull* [Frank]. Leonie related the statement to the definition of a year in that *that's when a year goes by* and added that Earth's axis is tilted. Jack offered the logical reason that the Sun can't orbit the Earth because *it can't just orbit one planet. So all the other planets orbit it as well.*

As to how long these movements take, before the intervention three of the interviewed pupils thought that it takes *a year* for Earth to orbit the Sun, but three of them thought that it takes 24 hours. For Leonie, it was the time for Earth to orbit *both* the Sun and the Moon. After the intervention five of the six pupils responded that it takes *a year* [Leonie] or *365 days* [Caleb] for Earth to orbit the Sun. One pupil mentioned *that's how they made year, from the time it takes to orbit the Sun* [Frank].

A four-item multiple choice question (C10b) asked the pupils to indicate their reason for what causes a month. A response similar to that of scientists is that *months depend on the time for the Moon to go around Earth*. The percentages who responded correctly in the pre-, post- and post-post surveys are shown in Figure 7.7.5.

Figure 7.7.5 shows that the class as a whole changed its view of what causes a month on Earth towards the scientists' view, from pre-survey support of 19% to post-survey support of 75%, a factor of 3.9. The non-parametric sign test indicates that the differences are statistically significant at the 0.001 level and the parametric t-test indicates the differences are statistically significant at better than the 0.001 level. Before the intervention, the majority of the pupils in this class failed to respond to this question. However, after the intervention, 75% of them agreed with the scientists' view that months

on Earth are caused by Moon's orbit around Earth. Support for the scientists' view remained constant from the post-survey to the post-post survey, the apparent difference in the scores not being statistically significant on either the sign or the t-test, indicating that the pupils' view of the cause of months was conceptually strong.

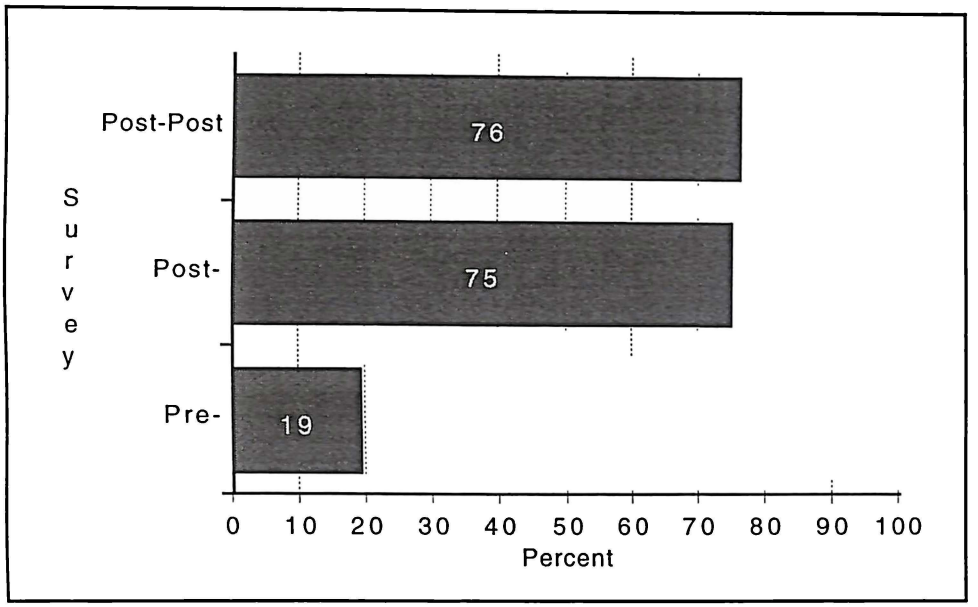


Figure 7.7.5: Percent Support for the Scientists' View of the Causes of Months: Pre-, Post- and Post-post Survey

When they were asked, prior to the intervention, if the Moon orbits Earth or vice-versa, only 19% of the surveyed pupils responded correctly that the Moon orbits Earth. On the other hand, four interviewed pupils correctly responded that *the Moon goes round the Earth* [Mary], while one pupil's view was that *the Earth goes round the Moon* [Hettie] and Leonie reaffirmed her view that the Earth moves between a stationary Sun and Moon. One pupil knew from his observations that the Moon orbits Earth because the Moon *seems to be always there and (yet) it's not... staying still* [Caleb]. While he shared the scientists' view that the Moon goes round Earth, one pupil revealed a commonly held view (see section 2.5) in his explanation that it was because of *the gravitational pull of the Earth. There's no gravity or anything on the Moon* [Frank].

After the intervention, 75% of the surveyed pupils responded correctly that the Moon orbits Earth while a quarter of the class remained convinced that the Earth orbits the Moon. However, all six interviewed pupils responded after the intervention that *the Moon goes around Earth.* The three boys said they thought that it's because of *the pull of the Earth or something... pull of gravity* [Jack], and Frank added that *the Moon's been caught in the gravitational pull of the Earth so it's in orbit*. One pupil supported her view by noting that it looks as if the Moon is orbiting Earth because *the Moon, as it goes round, it changes all the time. You see different parts of it* [Mary].

Before the intervention, five interviewed pupils thought that it took either *a day* [Caleb] or *24 hours* [Frank and Jack] for the Moon to orbit Earth, while the other pupil *wouldn't have a clue* [Mary] how long it took. Two pupils gave similar reasons for their views in that there are *twelve hours for the day and twelve for the night* [Jack], an indication that they associated the Moon solely with night-time.

After the intervention, only one interviewed pupil continued to respond that the Moon takes *24 hours* [Hettie] to orbit Earth while the other five pupils said that it takes about one month. Two pupils referred to the phrase 'lunar months' when explaining why they thought it took a month, one pupil noting that *you see all the phases of the Moon for one month* [Jack] and another referred to the connection between astronomy and the time period of one month in that *months were basically made from how long the Moon goes round the Earth* [Frank].

7.7.4 Summary of Section 7.7

The process of the pupils building a mental model of the Sun-Earth-Moon system, outlined in sections 7.2 and 7.3, had the effect that 90% of these pupils did construct their mental models to be similar to that of scientists. Nevertheless, 10% of them continued to support a geocentric mental model of the system. However, the geocentric mental models A and C were extinguished by the time of the post-post survey and the other geocentric mental model, B, had almost been extinguished by that time.

It was suggested that simply asking pupils to select one of five mental models of the Sun-Earth-Moon system is not sufficient to gain a full understanding of their mental models. For further clarification, the pupils were asked about their views of concepts which are subsidiary to the mental model. Table 7.7.2 summarises the changes in those concepts.

Table 7.7.2: Percentages of Pupils Who Agree With Scientists' Astronomy Views: Pre-, Post- and Post-post Surveys

Scientists' View	% Agreement From Pupils		
	Pre	Post	Post-post
Moon Orbits Earth which Orbits Sun	48	90	90
A day is one spin of Earth on its axis	25	91	85
Earth spins on an axis through its poles	16	47	33
A year is one orbit of Earth around the Sun	34	94	82
A month is on orbit of Moon around Earth	19	75	76

Table 7.7.2 demonstrates that most pupils became aware of the astronomical causes of days, months and years, those causes being stable and consonant with their expressed overall mental model of the Sun-Earth-Moon system. However, their concept about the cause of months was not as well developed as their concepts of days and years.

While the idea that Earth spins on its axis was understood by most pupils, less than half

of them thought that spin was through Earth's poles and only a third of them understood that four weeks after the intervention. The majority view was that the axis of rotation is through Earth's equator. This may be due to the fact that most texts refer to it being night time in England or Europe when it is day time in New Zealand. The pupils are aware that Europe and New Zealand are in opposite hemispheres separated by the equator.

A close analysis, then, of the pupils' mental model of the Sun-Earth-Moon system reveals that the process of the pupils building a mental model of the Sun-Earth-Moon system had the effect, measured by their responses in the post-survey, that:

1. 90% of them constructed the scientists' mental model of the Sun-Earth-Moon system. The proportion who share this concept held steady between the post-survey and the post-post survey;
2. 91% of them share the scientists' understanding that days and nights are caused by Earth spinning on its axis. The proportion who share this concept held steady between the post-survey and the post-post survey;
3. 94% of them share the scientists' understanding that years are the result of Earth orbiting the Sun. The proportion who share this concept reduced to 82% between the post-survey and the post-post survey;
4. 75% of them share the scientists' understanding that months are the result of the Moon orbiting Earth. The proportion who share this concept held steady between the post-survey and the post-post survey;
5. Only 47% of them share the scientists' understanding that Earth's axis of rotation is through its poles. Most of the pupils continued to believe that Earth rotates on an axis through its equator. The proportion who share the scientists' concept further reduced to 33% between the post-survey and the post-post survey.

7.8 SUMMARY AND CONCLUSIONS

7.8.1 Introduction

Section 7.8 summarises the discussion of the preceding sections of this chapter in terms of responses to research questions one, two and three (section 7.8.2). It then states the conclusions drawn from the findings in this chapter (section 7.8.3) and makes some suggestions for amendments to any further astronomy interventions (section 7.8.4).

7.8.2 Summary

This section provides a summary of the results described and analysed in chapter seven. It responds, in turn, to the three research questions reported at the beginning of this chapter.

This research considered astronomy mental model building of one class in one school, so generalisability cannot be assumed. However, the researcher wanted to gain an in-depth understanding of children's ideas about models rather than a wider survey and was unable to do that with a larger population. The investigation revealed the following results:

1 How effective was the intervention in developing pupils' ideas about scientists' models?

* Section 7.3.2 showed that before the intervention, only one pupil (3% of the class) was able to name a model used by scientists. After the intervention, 90% of the pupils named a scientists' model, although 25 of that 28 named only the orrery. These figures remained constant into the post-post survey, suggesting a clear understanding that the orrery is an example of a scientists' model.
That is, the intervention was effective in developing the pupils' knowledge of at least one scientists' model.
* Section 7.3.2 showed that these pupils did not, in general, begin the intervention with many intuitive ideas about models. However, by the end of the intervention a significant proportion of them had changed their views towards the scientists' view in understanding that models are used widely by scientists. Nevertheless, most pupils focused on the scale property of models and they appeared to view this aspect as a *necessary* property of a model.
* Section 7.3.3 showed that before the intervention, the surveyed pupils had very limited views about how scientists use models. They saw their use as being only to demonstrate ideas or, wrongly, they confused models with instruments. The intervention changed the pupils' views quite noticeably in that the pupils' views of how scientists use models broadened to include their role in challenging and testing theories in addition to demonstrating ideas to people.

2 Are pupils able to construct the scientists' mental model of the Sun-Earth-Moon system?

* Section 7.5.3 showed that the orrery was effective in helping the pupils to build the scientists' mental model of the Sun-Earth-Moon system in that they equated the orrery with the scientists' mental model and they repeatedly critiqued the orrery with respect to its ability to model and explain astronomy concepts that were introduced during the intervention.
* Section 7.6.2 showed that the pupils co-operatively applied their newly constructed mental model of the Sun-Earth-Moon system to resolve at least two problems that were novel to them.
* Section 7.6.3 showed that the pupils had applied their newly constructed scientists' mental model of the Sun-Earth-Moon system to interactively report back their findings from the problem-solving activities. The pupils were confident in using both the orrery and the Sun-Earth-Moon mental model to report their findings to the rest of the class.
* Section 7.7.2 showed that the process of the pupils building a mental model of the Sun-Earth-Moon system had the effect that 90% of these pupils did construct their mental models to be similar to that of scientists. That is, the intervention was effective in helping the pupils develop the scientists' heliocentric mental model of the Sun-Earth-Moon system. Nevertheless, 10% of them continued to support a geocentric mental model of the system despite the activities directed specifically to that end, thus affirming the robustness of pupils' mental models.

* Section 7.7.3 showed that a closer analysis of the pupils' mental model of the Sun-Earth-Moon system reveals that the process of the pupils building a mental model of the Sun-Earth-Moon system had the effect, measured by their responses in the post-survey, that:
  1. 91% of them share the scientists' understanding that days and nights are caused by Earth spinning on its axis. The proportion who share this concept held steady between the post-survey and the post-post survey.
  2. Only 47% of them share the scientists' understanding that Earth's axis of rotation is through its poles. Most of the pupils continued to believe that Earth rotates on an axis through its equator. The proportion who share the scientists' concept further reduced to 33% between the post-survey and the post-post survey.
  3. 94% of them share the scientists' understanding that years are the result of Earth orbiting the Sun. The proportion who share this concept reduced to 82% between the post-survey and the post-post survey.
  4. 75% of them share the scientists' understanding that months are the result of the Moon orbiting Earth. The proportion who share this concept held steady between the post-survey and the post-post survey.
* Sections 7.5, 7.6 and 7.7 showed that the following teacher-promoted processes were successful in helping these pupils construct their mental model of the Sun-Earth-Moon system:
  1. introducing the orrery as a model of scientists' mental model of the Sun-Earth-Moon system;
  2. critiquing the orrery itself;
  3. eliciting and sharing pupils' views about each astronomy concept;
  4. critiquing the extent to which the orrery illustrated and explained each astronomy concept;
  5. relating each astronomy concept to the scientists' mental model of the Sun-Earth-Moon system.

3 How effective are models in promoting mental model building by New Zealand pupils?

* Section 7.4.2 showed that the pupils had little difficulty in engaging with the notion of models when the teacher introduced these ideas in the form of a map of the London Underground. They understood that models are a representation of reality and that they have positive and negative aspects to them (to use Hesse's terms). They did not engage with the neutral aspects of the model. The qualities of the map that the pupils engaged with mainly referred to information-transmissive features such as the number and choice of colours.
* Section 7.4.3 showed that the pupils were able to engage with the notion of building and critiquing an astronomy model when the teacher introduced the idea. Nevertheless, before the intervention only 28% of the pupils responded that it was not possible to build a visible scale model of the solar system in their classroom if the model used the same scale for both sizes and distances.

After the intervention the proportion of pupils who understood that this was not possible had increased to only 41%. This proportion remained constant into the post-post survey.

The intervention, then, was not very effective in helping change the pupils' prior idea that models are *essentially* scaled-down miniature versions of reality.

* Section 7.5.2 showed that the pupils utilised Hesse's ideas of critiquing a model (in this case the orrery), the neutral column being indicated as a starting point for further exploration. The positive features that the pupils engaged with included the representation of the Sun, Earth, Moon and Mercury and observations of the rotations and revolutions of those bodies. The negative features that the pupils engaged with related to the inaccuracy of scale in the orrery's representation of the relative sizes, distances and movements of the four bodies.
* Section 7.5.3 showed that the intervention was responsible for the fact that the proportion of pupils who correctly critiqued the orrery's ability to represent six astronomy concepts increased from a mean score of 0.5 to a mean score of 3.9. These pupils had come to the understanding that the orrery, as an example of a model, could illustrate some, but not all, the astronomy concepts related to the Sun-Earth-Moon system. The understanding that all scientists' models have limitations, while still being useful, was an important objective of the intervention.

7.8.3 Conclusions

* The *Focus on the Mental Models* phase was effective in helping the pupils to articulate their mental model of the Sun-Earth-Moon system and to understand the contrary views present within the class. Furthermore, it introduced the idea that the differences would be resolved by investigation rather than by appeals to authority.
* The *Mental Model Building and Critiquing* phase was effective in helping the pupils construct their mental model of the Sun-Earth-Moon system by continually critiquing a model's (the orrery) capacity to describe and explain observed events such as phases of the Moon.

  There appeared to be a symbiotic interactive relationship between critiquing the orrery and understanding the observed events.
* The *Using the Mental Model To Solve Problems* phase was effective in consolidating the pupils' mental model of the Sun-Earth-Moon system. Each group of pupils was able to use the scientists' mental model to solve astronomy problems that were new to them.
* The *Reflection* phase was effective in further consolidating the pupils' mental model of the Sun-Earth-Moon system by them using the scientists' mental model to interactively report back their findings to the rest of the class.
* That models are of necessity exact scale replicas of reality appears to remain a powerful idea among the pupils even though they had been unable to build a single-scale model of the solar system, the orrery itself had been found to be not

to scale, and the repeated critiques of the orrery's inability to accurately explain astronomy concepts were always because of its lack of scale. While models may be miniatures of reality, it is not a necessary condition.

* The following approaches appear to have been important in helping these Year 7-8 pupils construct their mental models of the Sun-Earth-Moon system:
  (a) eliciting and sharing, without comment at that stage, the pupils' variety of mental models of the Sun-Earth-Moon system.
  (b) establishing the idea that models are not perfect scaled copies of reality.
  (c) introducing the orrery as a possible representation of the scientists' mental model of part of the solar system.
  (d) critiquing models in terms of their ability to reflect the reality they represented. As the intervention progressed, the pupils continued to be enthusiastic about critiquing the orrery.
  (e) being consistent in *investigating* related astronomy concepts such as solar eclipses by *exploring* the ability of the orrery to describe and explain each concept.
  (f) giving the pupils the opportunity to construct the scientists' mental model by repeatedly critiquing a model of the mental model. This appeared to facilitate a strong inter-relationship between the model and the subordinate concepts of the mental model, whereby increasing facility with either seems to support progress in understanding the other. It enhances the *intelligibility* and *plausibility* of the mental model.
  (g) giving the pupils the opportunity to use the scientists' mental model to solve problems that are new to them. This appeared to consolidate the mental model in their minds by enhancing its *fruitfulness*.
  (h) giving the pupils the opportunity to interactively report their findings to, and debate with, the rest of the class. The pupils had to defend their mental model and use it to explain ideas to other members of the class. This process further consolidated the mental model by enhancing its fruitfulness in explaining ideas to others.
  (i) the intervention provided a supportive environment in which pupils increasingly felt able and willing to share and debate their ideas without fear of ridicule.

7.8.4 Suggestions for Amendments

The following suggestions for amendment to the intervention arise from the analysis of the intervention in practice.

* A more relevant example of a model is required, rather than a map of the London Underground, with which most pupils were unfamiliar. For example, a similar map of the bus routes in the intervention city could have been used.
* A wider range of examples and non-examples of models should have been used. Other examples of scientists' models are models of atomic structure, double-helix models and computer models of electric circuits.

Examples of non-models are instruments such as telescopes.

* Using phrases more accessible to the pupils to explain Hesse's system of critiquing models is advised. The teacher's use of *realistic but not accurate* appeared to be effective with the pupils. However, they were not the phrases recommended to the teacher. In addition, it was a bi-modal representation which omitted the neutral aspect of critiquing. The neutral aspects are often the focus for further investigations.
* A definition of a mental model that was more accessible to the pupils is needed.
* Building (or failing to build) a miniaturised yet visible scale model of the solar system was not a valuable exercise. It needs to be accomplished without the confusion initiated by the teacher introducing intermediate steps of a variety of scales for sizes and distances. The same scale used for the planets' sizes should immediately afterwards be used for the planetary distances. Then the pupils would be more likely to realise that scientists' models do not, of necessity, have to be miniaturised versions of reality.
* It is not sufficient just to put pupils in groups and expect them to debate ideas. This is a skill which develops only through direction and practice. Otherwise, as sometimes occurred in the *Using the Mental Model to Solve Problems* phase, pupils tended to accept the first opinion that was uttered.

Chapter eight will consider the outcomes of the intervention in terms of the extent to which these pupils learned astronomy knowledge and constructed the astronomy concepts which are subordinate to the Sun-Earth-Moon mental model. That is, chapter eight will respond to research questions four and five.

CHAPTER EIGHT: THE TRIAL INTERVENTION OUTCOMES 2: THE CHILDREN'S LEARNING OF ASTRONOMY CONTENT AND THE TEACHER'S RESPONSE TO THE INTERVENTION

8.1 INTRODUCTION

The primary aim of the research was to investigate Year 7-8 pupils' processes of constructing their mental models of the Sun-Earth-Moon system, as discussed in chapter seven. Nevertheless, it was considered essential to ensure that this did not occur at the expense of traditional learning of astronomy content knowledge. For Year 7-8 pupils in New Zealand these latter are to be found in the level four learning objectives of the *Making Sense of Planet Earth and Beyond* contextual strand of *Science in the New Zealand Curriculum*. The appropriate curriculum statement is:

3	(b) investigate and use models which explain the changing spatial relationships of the Earth, its moon and the Sun... e.g. phases of the Moon, eclipses, tides, seasons

(Ministry of Education, 1993b, p.114)

Astronomy teaching difficulties were discussed in section 2.4 and pupils' construction of the mental model of the Sun-Earth-Moon system was described in chapter seven. Section 8.2 considers the pupils' astronomy learning with respect to the solar system, tides, the Moon and eclipses. It will contribute material relevant to research question four:

4 What are the astronomy conceptual learning and teaching difficulties experienced, respectively, by New Zealand pupils and teachers?

Section 8.3 considers the intervention teacher's developing views of the extent to which the processes and objectives of the astronomy intervention were met. It will contribute material relevant to research question five:

5 How effective was the intervention in promoting the astronomy knowledge and concepts in *Science in the New Zealand Curriculum*?

Chapter eight concludes with section 8.4, a chapter summary and a statement of the conclusions drawn from sections 8.2 and 8.3.

As was noted on page 148, analyses in chapter eight are of the 31 pupils who completed all three surveys.

8.2 ASTRONOMY KNOWLEDGE: SPECIFIC LEARNING OUTCOMES DUE TO THE INTERVENTION

8.2.1 Introduction

This section considers the pupils' astronomy knowledge additional to that considered in chapter seven. It addresses the extent to which the pupils in the intervention class increased their astronomy knowledge as a result of the intervention. It compares their responses to the appropriate questions in the pre-, post- and post-post surveys and in the pre- and post-interviews. Data is presented in the following sequence:

* pupils' knowledge about the solar system (section 8.2.2);
* pupils' understanding about the causes of tides (section 8.2.3);
* pupils' understanding about the Moon (section 8.2.4);
* pupils' understanding about eclipses (section 8.2.5).

8.2.2 Pupils' Knowledge About the Solar System

Section 8.2.2 considers the pupils' knowledge about the sequence of the planets out from the Sun, the relative sizes of the planets and descriptions of the planets.

Pupils' Knowledge of the Sequence of Planets from the Sun

The pupils' knowledge about the sequence of the planets out from the Sun was investigated by two one-level multiple choice questions. Question A1 asked the pupils to select the planet that is nearest to the Sun and question A2 asked them to select the planet which is the next one beyond Earth. Table 8.2.1 shows the percentages of the class who correctly selected Mercury and Mars respectively in the pre-, post- and post-post surveys.

Table 8.2.1: Percentages of Pupils Who Knew the Sequence of Planets Out from the Sun: Pre-, Post- and Post-post Surveys

Question Number	Item	Pre-survey (%)	Post-survey (%)	Post-post Survey (%)
A 1	Planet Nearest Sun	66	94	94
A 2	Next Planet after Earth	47	91	85

Table 8.2.1 indicates that the pupils began the intervention with a good knowledge of the sequence of planets from the Sun and they increased that knowledge from the pre- to the post-survey. Both the parametric and the non-parametric tests for question A1 were significant at least at the 0.02 level and both the parametric and the non-parametric tests for question A2 were significant at the 0.001 level. The mean scores for questions A1 and A2 remained constant during the four weeks between the post-survey and the post-post survey. That is, the intervention was successful in increasing the pupils' knowledge about the sequence of the planets from the Sun

Before the intervention, all the interviewed pupils except Leonie (who thought it was *either*

Mars or Pluto) knew that the planet nearest to the Sun is Mercury and four of them knew Mars was the next planet out after Earth - the other two selected Venus. After the intervention, all six pupils correctly cited Mercury as being the planet nearest to the Sun, and five of them then knew that Mars was the next planet out after Earth. Leonie continued to think that Venus held that position.

Pupils' Knowledge of the Relative Sizes of the Planets

The pupils' knowledge about the relative sizes of the planets was investigated by two one-level multiple choice questions. Question A5 asked the pupils to select the smallest planet and question A6 asked them to select the largest planet. Table 8.2.2 shows the percentages of the class who correctly selected Pluto and Jupiter respectively in the pre-, post- and post-post surveys.

Table 8.2.2: Percentages of Pupils Who Knew Which Were the Smallest and Largest Planets: Pre-, Post- and Post-post Surveys

Question Number	Item	Pre-survey (%)	Post-survey (%)	Post-post Survey (%)
A 5	Smallest Planet	72	100	100
A 6	Largest Planet	66	81	91

Table 8.2.2 shows that the pupils began the intervention with a good knowledge of the relative sizes of the solar system objects and they increased that knowledge from the pre- to the post-survey. Both the parametric and the non-parametric tests for question A5 were significant at least at the 0.01 level and both the parametric and the non-parametric tests for question A6 were significant at least at the 0.02 level. The mean scores for questions A5 and A6 remained constant during the four weeks between the post-survey and the post-post survey. That is, the intervention was successful in increasing the pupils' knowledge about the relative sizes of the planets.

None of the interviewed pupils, before the intervention, was able to place nine solar system objects in order from the smallest to the largest, although five of them were substantially correct in that they made less than three errors. The most common confusion was between the relative sizes of Earth, Venus and Mars. Hettie was the only one who had very little idea at all, to the extent of choosing the Sun and Moon as being larger than the solar system. Leonie thought that the Moon and the Sun are the same size *because they look that way*. Five of these pupils knew that Pluto is the smallest planet and that Jupiter is the largest planet.

Even after the intervention, only Frank was able to list the astronomical objects in the order perceived by scientists. Hettie continued to think the Sun was bigger than the solar system, which makes one wonder what she had in mind when she earlier described the solar system

as *a group of planets orbiting the Sun.* Again, there was confusion between the relative sizes of Earth, Mars and Venus. All six interviewed pupils knew that Pluto is the smallest planet and that Jupiter is the largest one.

Pupils' Knowledge of Descriptions of the Planets

The pupils' knowledge about the appearance of planets was investigated by two one-level multiple choice questions. Question A3 asked the pupils to select the planet which is large, has a big red spot and many satellites. Question A4 asked them to select the planet which is red, has dust storms and has ice caps at its poles. Table 8.2.3 shows the percentages of the class who correctly selected Jupiter and Mars respectively in the pre-, post- and post-post surveys.

Table 8.2.3: Percentages of Pupils Who Knew the Surface Features of Jupiter and Mars: Pre-, Post- and Post-post Surveys

Question Number	Item	Pre-Survey (%)	Post-survey (%)	Post-post Survey (%)
A 3	Description of Jupiter	53	75	76
A 4	Description of Mars	44	56	58

Table 8.2.3 shows that the pupils began the intervention with a good knowledge of the surface features of planets and that they increased that knowledge from the pre- to the post-survey. Both the parametric and the non-parametric tests for question A3 were significant at the 0.001 level and both the parametric and the non-parametric tests for question A4 were significant at least at the 0.02 level. The mean scores for questions A3 and A4 remained constant during the four weeks between the post-survey and the post-post survey. That is, the intervention was successful in increasing the pupils' knowledge about the surface features of planets.

Four of the interviewed pupils, before the intervention, were able to name Jupiter as the planet which is large, has a big red spot and many satellites, although Mary showed uncertainty in her response. Frank thought that Saturn best fitted that description and Hettie simply responded *I don't know.* After the intervention, all six interviewed pupils unhesitatingly answered that *Jupiter* best fits that description.

8.2.3 Pupils' Understanding About the Causes of Tides

The pupils' knowledge about tides was investigated by two one-level multiple choice questions. Question B2 asked the pupils to select the main cause of tides on Earth and question B3 asked them to indicate the extent of the Sun's effects on the tides. Table 8.2.4

shows the percentages of the class who correctly responded in the pre-, post- and post-post surveys that the Moon is the main cause of tides but that the Sun also has a noticeable effect on tides .

Table 8.2.4: Percentages of Pupils Who Understood the Causes of Tides: Pre-, Post- and Post-post Surveys

Question Number	Item	Pre-survey (%)	Post-survey (%)	Post-post Survey (%)
B2	Moon is main cause of tides	53	100	100
B3	Sun affects tides	9	63	58

Table 8.2.4 shows that about half the class began the intervention with an understanding that the Moon is the main cause of tides on Earth and that knowledge increased from the pre- to the post-survey. Both the parametric and non-parametric tests for question B2 were significant at the 0.001 level.

Table 8.2.4 also shows that few of these pupils began the intervention with an understanding that the Sun also affects tides but their understanding increased from the pre- to the post-survey. Both the parametric and non-parametric tests for question B3 were significant at the 0.001 level. The mean score for questions B2 and B3 remained constant during the four weeks between the post-survey and the post-post survey. That is, the intervention was successful in increasing the pupils' knowledge that both the Moon and the Sun affect tides.

Before the intervention, four of the interviewed pupils related tides to the Moon and none of them thought the Sun had any effect on tides. This was often in a general way, as shown by Caleb's response that it's *just the Moon*, and Mary's reply that *it's something to do with the Moon and where it is*. Jack was more explicit in saying that tides are related to *the Moon's gravitational pull*, although he was not sure how. Leonie was confused in her view that the tides are *something to do with time.*

After the intervention, all six interviewed pupils thought the Moon was a cause of tides but only Hettie and Frank thought that was the only cause. The other four thought the Sun also had an effect and two pupils added that Earth also contributed to the tides. For example, *the Moon and the Sun... and the Earth's got an effect on the tides as well* [Jack], a view shared by scientists. Two pupils referred to tides being caused by gravitational pull, such as *the Sun has a bit of a pull, but the Moon does most of the pulling* [Caleb].

8.2.4 Pupils' Understanding About the Moon

Section 8.2.4 considers the pupils' understanding about the day and night visibility of the

Moon and their understanding about the Moon's phases.

Pupils' Understanding About Day and Night Visibility of the Moon

The pupils' knowledge about the times when the Moon is visible was investigated by a two-level multiple choice question. Question C3a asked the pupils to say whether we could sometimes see the Moon during the day and question C3b asked them to indicate why this was so. Table 8.2.5 shows the percentages of the class who, in the pre-, post- and post-post surveys, correctly selected that we can sometimes see the Moon during the day and that the Moon is present in the day sky as often as it is present in the night sky.

Table 8.2.5: Percentages of Pupils Who Understood that the Moon is Present in the Day-time Sky as Often as in the Night-time Sky: Pre-, Post- and Post-post Surveys

Question Number	Item	Pre-survey (%)	Post-survey (%)	Post-post Survey (%)
C3a	See Moon in Day-time	97	100	100
C3b	The Reason	22	38	30

Table 8.2.5 shows that almost all the class began the intervention with the knowledge that the Moon is sometimes present in the day-time sky and they maintained that understanding throughout and after the intervention. However, few of the class initially understood that the Moon is present in the day-time sky as often as it is present in the night-time sky, and there was little growth in that understanding by the time of the post-survey. Neither of the parametric and the non-parametric tests for questions C3a and C3b were significant. In addition, the mean scores for questions C3a and C3b remained constant during the four weeks between the post-survey and the post-post survey. That is, the intervention has not been successful in increasing the pupils' understanding that the Moon is present in the day-time sky as often as it is present at night.

Before the intervention, four of the interviewed pupils associated the Moon almost solely with the night sky. However, of those four, Frank said he'd *sometimes* seen it during the day and Leonie noted that the Moon can sometimes be seen at dawn or dusk *when the Sun's going down or when the Sun's just coming up and you can just slightly see the Moon.* Hettie said that the Moon can sometimes be seen during the day as a result of daylight saving putting the times wrong, but *not most days 'cos it comes up at the normal time* [Hettie]. Contrary to that view, one pupil thought that the Moon can be seen in the day-time *about five days a week* [Caleb] and Mary said *I think you could see it almost every day* [Mary].

After the intervention, all six interviewed pupils thought that it was possible to see the Moon during the day time, but *only sometimes* [Hettie] and she again offered the explanation that

the Moon can be seen in the day time sky *when it's daylight saving. Because when we put our clocks back... because the Moon still comes out at the same time... But it's actually an hour from what we think it's about five but it's actually four o' clock*. The other five now thought that the Moon could be seen in the day sky *as much as you can in the night-time* [Mary] but *sometimes there's a new Moon, which means it's when you can't see it* [Caleb] and *it depends how late it sets at night* [Leonie].

Pupils' Understanding about the Moon's Phases

The pupils' understanding about the phases of the Moon was investigated by a two-level multiple choice question. Part a asked the pupils to describe the phases of the Moon and Part b asked them to indicate what causes the phases of the Moon. Table 8.2.6 shows the percentages of the class who selected both the scientists' description of the Moon's phases and their cause in the pre-, post- and post-post surveys.

Table 8.2.6: Percentages of Pupils Who Understood the Causes of the Phases of the Moon: Pre-, Post- and Post-post Surveys

Question Number	Item	Pre-survey (%)	Post-survey (%)	Post-post Survey (%)
C4	Phases of Moon	0	16	15

Table 8.2.6 shows that none of the pupils began the intervention with the scientists' understanding about the causes of the phases of the Moon and they increased their understanding only to a limited extent between the pre- and the post-survey. The parametric test for question C4 was significant at the 0.01 level, whereas the non-parametric test was not significant. The mean scores for question C4 remained constant during the four weeks between the post-survey and the post-post survey. That is, the intervention had limited success in increasing the pupils' understanding about the causes of the phases of the Moon.

Close examination of the pupils' responses to question C4 indicated that 39% of them initially thought that the phases were caused by the Sun lighting different parts of the Moon at different times. After the intervention 58% thought that and 16% shared the scientists' view. Thirteen percent thought that the phases were due to Earth's shadow falling on the Moon and 6% thought they were caused by planets casting a shadow on the Moon. These proportions remained unchanged from the post-survey to the post-post survey.

Before the intervention only three of the interviewed pupils recognised the term *the phases of the Moon.* Those three were variously able to describe them in their own words, such as *how you get a half moon and a quarter moon... new moon* [Jack], although two thought they were caused by a shadow in that phases are *how much of it is blocked out, how much*

of it is showing [Caleb]. After the intervention, all six recognised the term and could describe phases in terms of the Moon appearing to change shape.

Both before and after the intervention all six of the interviewed pupils had heard of a full moon. Leonie describe one in terms of *it's just a sphere, round circle* and Jack's description was *when you can see the whole Moon.*

Crescent moons were understood before the intervention by three interviewed pupils. They saw them as being much smaller than a full moon, such as it *looks like a banana* [Jack]. Mary continued with the shadow idea by saying that a crescent moon was when *the Earth's shadow hits on the Moon and covers most of it*. After the intervention, three pupils remained confused about crescent moons, with one pupil thinking they were *about half* [Caleb] and two suggesting that we'd be able to see *about a quarter* [Mary]. Two others were more accurate in describing their appearance as being *just like a thin banana* [Leonie].

Before the intervention, four of the interviewed pupils realised that a new moon is when we see only a very small part of the Moon. They are *just a tiny tip of a finger nail* [Caleb] or *like a really thin banana* [Jack] or *just a tiny piece of the Moon* [Hettie]. One pupil was close to the scientists' description in that she described it as *a time when you can't see a Moon* [Mary]. After the intervention, five of the pupils described new moons in various ways, apparently having difficulty in expressing their views. Examples are the apparently contradictory statements that *you can't see it but it's there* [Mary], *we can't see it. You can see, like, a circle with a shape of it* [Leonie] and *you can't see hardly any part of the Moon. It's completely blank* [Frank].

Before the intervention only one pupil expressed any idea at all of the term 'gibbous moon', saying that it is *probably smaller than a full Moon* [Leonie]. After the intervention, three pupils variously replied that we would see *three quarters* of the Moon [Hettie], with Leonie adding that *it's just got a little banana shape* (missing). Three pupils had their ideas of crescent and gibbous moons reversed, one describing it as when *three quarters of it's black, and a quarter of it's light* [Frank].

Prior to the intervention there was little understanding among the interviewed pupils about the causes of the Moon's phases. Two of them simply had no idea about how they are caused and two more related the phases to Earth's shadow, a concept widely held by pupils and teachers. This was revealed in section 2.5 and repeated here by Mary that the Moon's phases are *when the Earth's shadow falls on the Moon.* The other two pupils understood that the phases are related to sunlight reflected from them. For example, the Moon's phases are

caused depending on *how much sunlight reflects on the Moon* [Caleb].

After the intervention, one pupil continued to have no idea about the cause of the Moon's phases and two others continued with their idea that they are caused by Earth's shadow falling on the Moon. For example, they are due to *the Sun's light on it when the Moon and the Earth and the Sun are lined up* [Leonie]. The other three pupils revealed aspects of the scientists' view in that they realised that phases are due to the Sun's light being reflected from the Moon to Earth. However, a full description appears to be very complicated for this age group to put into words, as shown by Mary's attempt to explain the phases. She said that *you can see half the Moon but from... half of it's shadow... 'cos it's not in the right... facing the Sun. But it's also facing the Sun. Different parts of the world see all different sides of it. Different times you see different sides of the Moon. If it's directly in front of you you can see a full moon. When it's behind you, you see a new moon*. It is possible that pupils could understand this concept yet be unable to describe it accurately.

That is, the intervention was partially successful in increasing the interviewed pupils' understanding of the shapes of the phases of the Moon and that they are a sort of optical illusion in that the Moon's shape does not really change. The intervention also increased the pupils' understanding of full moons, new moons and gibbous moons. However, they remained unsure about crescent moons.

8.2.5 Pupils' Understanding About Eclipses

The pupils' knowledge about solar and lunar eclipses was investigated by two two-level multiple choice questions. Part a of question C5 asked the pupils to say what a solar eclipse is and part b asked them to indicate what causes one. Similarly, question C6 asked the pupils to say what a lunar eclipse is and to indicate what causes one. Table 8.2.7 shows the percentages of the class who correctly responded in the pre-, post- and post-post surveys that solar eclipses are caused when the Sun, Moon and Earth line up with the Moon between the Sun and Earth and that lunar eclipses are caused when the Sun, Moon and Earth line up with Earth between the Sun and Moon.

Table 8.2.7: Percentages of Pupils Who Understood the Causes of Solar and Lunar Eclipses: Pre-, Post- and Post-post Surveys

Question Number	Item	Pre-survey (%)	Post-survey (%)	Post-post Survey (%)
C5	Solar Eclipse	53	72	70
C6	Lunar Eclipse	19	68	56

Table 8.2.7 shows that the class began the intervention with a good understanding of solar eclipses but with a more limited understanding of lunar eclipses. Their understanding of both

phenomena increased between the pre- and the post-survey. Both the non-parametric and the parametric tests indicate that the increases in scores for questions C5 and C6 were significant at the 0.001 level. The mean scores for questions C5 and C6 remained constant during the four weeks between the post-survey and the post-post survey. That is, the intervention was successful in increasing the pupils' knowledge about solar and lunar eclipses.

The interviewed pupils, in general, did not understand solar eclipses before the intervention. Three of them were unable to offer either a description or an explanation and the other three thought it was when something passes in front of the Sun as viewed from Earth. Frank thought they were *when a planet gets in the way of the Sun shining on the Earth*, a concept not previously encountered by the researcher. On the other hand, two pupils responded that a solar eclipse is *when the Moon passes in front of the Sun* [Mary].

After the intervention, only one of the interviewed pupils was unable to describe a solar eclipse. The other five variously agreed that a solar eclipse is when *it goes darker because the Moon goes between the Earth and the Moon* [Hettie] or that the Moon *blocks out the Sun. It covers it so you can't actually see the Sun* [Mary] or *the Moon gets in the path of the Sun's rays shining on the Earth so it casts a shadow on certain parts of the Earth* [Frank].

Four of the interviewed pupils were unable, before the intervention, to offer any views at all about lunar eclipses, but the other two suggested the scientists' view that lunar eclipses occur *when the Earth's shadow shadows the Moon* [Mary]. In contrast, after the intervention five of the pupils responded in a way similar to scientists that lunar eclipses are caused when the Earth moves between the Sun and the Moon *so that Earth puts its shadow over the Moon* [Caleb] so that *you can't see any of the Moon* [Mary]. Only one pupil remained confused about their cause, stating that it was when *the Moon goes between the Earth and the Sun* [Leonie] which is, of course, the cause of a solar rather than a lunar eclipse.

8.2.6 Summary of Section 8.2

Many of these pupils began the intervention with knowledge of the structure of the solar system in that they knew the sequence of the planets in order from the Sun and the relative sizes of the planets. The intervention contributed to a significant advance on that knowledge to the extent that all of them knew which was the smallest planet and about 90% of them knew which was the largest planet and the correct sequence of the planets from the Sun.

Initially, half these pupils understood that the Moon affects Earth's tides but only about one-tenth understood that the Sun affects them. The intervention had the effect that all the pupils came to understand the role of the Moon in affecting Earth's tides. However, the fact that the

Sun contributes to our tides remained not widely acknowledged by these pupils.

Concepts about the Moon remain difficult for these pupils despite the intervention, a conclusion supported by the findings reported in chapter seven. While the pupils understood that the Moon is sometimes present in the day-time sky, the majority of them remained convinced after the intervention that the Moon is predominantly a night-time phenomenon despite having observed it during the day and despite having engaged in a lengthy discussion on that topic in lesson seven of the intervention. They also remained unable to understand the causes of the Moon's phases, the proportion that agreed with the scientists' view after the intervention increasing to only one-sixth.

While the pupils increased their knowledge about solar eclipses, lunar eclipses continued to cause difficulties for these pupils. After the intervention, despite modelling eclipses on the orrery and with a computer program and discussing diagrams that illustrate the causes of eclipses, about seven tenths agreed with the scientists' interpretation of solar eclipses but only three-fifths agreed with the scientists' interpretation of lunar eclipses. While the intervention had a positive effect with respect to the pupils' knowledge of eclipses, the results once again underline that these Year 7-8 pupils have a particular difficulty with understanding concepts related to the Moon.

As a whole, the pupils appear to have learned astronomy facts and concepts suggested in the appropriate level four achievement objective of the *Making Sense of Planet Earth and Beyond* contextual strand of *Science in the New Zealand Curriculum*. They performed well in the one-level multiple choice questions, but less well in the two-level multiple choice questions. Either Parts B and C are measuring different aspects or perhaps one-level multiple choice questions do not readily measure knowledge because of the 25% chance of guessing the correct response.

8.3 THE TRIAL TEACHER'S PERCEPTIONS OF THE INTERVENTION

8.3.1 Introduction

This section describes and analyses the trial teacher's views of the astronomy intervention before, during and after the intervention. The section constitutes a triangulation to ascertain the extent to which the teacher validated the mental model building approach to learning astronomy. The trial teacher fully collaborated with the researcher, including an audio-taped interview seven days before the intervention, interviews immediately after eight of the lessons and a further interview one day after the last lesson. However, it became clear that the teacher did not initially understand the mental model building approach to teaching astronomy, appeared to see the offered support as a series of very well developed, complete, lesson plans and thus was not thoroughly prepared prior to teaching the unit. The interview format is

shown in Appendix F (page 325).

Data is presented in the following sequence:

* the trial intervention teacher's views before the intervention (section 8.3.2);
* the trial intervention teacher's views during the intervention (section 8.3.3);
* the trial intervention teacher's views after the intervention (section 8.3.4).

Section 8.3.5 is a summary of the conclusions drawn from the teacher interviews. It answers the question "What did we learn about the teacher's response to the astronomy intervention?".

8.3.2 The Trial Intervention Teacher's Views Before the Intervention

This section describes the teacher's responses seven days before the first lesson of the astronomy intervention. The interview occurred several days after he had received and read a copy of the proposed intervention. A question about the extent to which the teacher understood the radical features of the intervention at this early stage was signalled by his response:

> *As far as I'm understanding the way you've written it, I think I understand the way it's going.*

The teacher thought that this approach would help teachers overcome their difficulties about teaching astronomy, commenting that:

> *... it allows the teachers to work their way through it with the kids. And the teacher doesn't have to be the expert. In the long run, the kids are generating their own knowledge.*

That is, his view was that their lack of subject knowledge was the most important reason for teachers' difficulties in teaching astronomy and that the intervention provided the subject knowledge for the teacher and the pupils to learn together in a co-operative enterprise.

In addition, the teacher considered that the proposed approach made sense to him with respect to his understanding of how pupils at this age learn. He expressed enthusiasm for the astronomy intervention based on his knowledge and experience of how Year 7-8 pupils learn and he saw *no difficulty* that the proposed teaching approach would help pupils attain the level four astronomy content requirements in *Making Sense of Planet Earth and Beyond.* He showed enthusiasm for the intervention and was positive about its probable effect on helping the children in his class to further develop the investigative skills described in *Science in the New Zealand Curriculum.* However, he commented that

> *They do lots of hands-on stuff. And we know that kids take in a lot more than*

when they just listen.

His comment that *kids take in a lot more* suggested that the teacher may well have interpreted the proposed intervention only as a more efficient way of transmitting the astronomy information to the pupils. The reference to *hands-on stuff* suggests that he interpreted the investigative skills merely as a way of providing concrete materials rather than them being thinking skills in their own right. This interpretation of his responses is supported by his later references to models only in their illustrative role rather than as helping pupils to represent and reinterpret their emerging mental abstractions of reality.

Nevertheless, with respect to the interactive and questioning nature of the intervention, the teacher was convinced that most of his class would be comfortable about sharing their prior astronomy knowledge and ideas, even if they were not fully sure about them. Furthermore, with reference to having those views challenged, he was sure that they would react positively to what he referred to as *constructive criticism.* Overall, referring to the proposed approach, he *couldn't see how it could fail* to be successful in helping the pupils move their astronomy concepts towards the scientists' ones. However, he cautioned that some of the language and concepts were quite complex, particularly for two pupils in his class for whom English was their second language and for one pupil with learning difficulties. It is of interest to note that he saw a clear relationship between language and concepts.

However, the teacher expressed concerns about classroom management aspects of breaking the class into the eleven groups proposed for this intervention. He was concerned about the possible increased noise level and the possibility of one pupil dominating in the small groups. He had spoken to his class about it and had set ground rules to minimise what he saw as *management possibilities.* Nevertheless, his reservations about the large number of groups was tempered by the fact that the researcher would be in the classroom when the astronomy was taught. In addition, the teacher referred to research findings that support having small groups in the class, *particularly for girls.*

Overall, the teacher was enthusiastic about the astronomy intervention he was about to teach. He thought it matched the learning approaches suitable for Year 7-8 pupils, that it would help his pupils to attain the learning and investigative skills objectives of the level four astronomy strand of *Science in the New Zealand Curriculum* and that it would be effective in helping the pupils develop their ideas towards the scientifically accepted ones. In addition, he felt that his pupils would both welcome and benefit from the interactive approach in which ideas would be shared, debated and investigated by the whole class and the teacher.

However, it appears that the teacher, in fact, re-interpreted the intervention away from the pupils building, assessing and re-constructing their mental models to one in which the key

issues were the extent to which he was given a good teaching resource for the traditionally difficult area of astronomy education. That is, he tended to focus on the fact that the proposed intervention provided clearly stated specific learning outcomes and investigative skills objectives, that all the relevant information and resources were provided for both the teacher and the pupils and that clear instructions were provided for the teacher to manage the intervention. That is, although prior to teaching the intervention the teacher had noted its many positive aspects, including the pupils debating their prior ideas, he had not perceived its radically different features.

8.3.3 The Trial Intervention Teacher's Views During the Intervention

It had been intended to interview the intervention teacher after each astronomy lesson with respect to his developing views about the intervention. However, this was not possible after lessons 4, 7 and 10 because of the teacher's other commitments such as playground duty and staff meetings. Thus eight post-lesson interviews were conducted. The interview format is shown in Appendix F (page 325).

Following the *Focus on the Mental Model* phase, management concerns remained a factor for the teacher in that he referred to his perception that he was a little disorganised, that the lack of co-operation in one group would be resolved by moving pupils to different groups, that the recent school theatre production made it difficult to refocus the pupils on to learning and that the pupils did not share their prior ideas as well as anticipated because of the lack of time. Nevertheless, despite the suggested approach being novel to the teacher, he saw the large number of small groups in a positive light and was generally satisfied with the way this phase progressed.

He observed that the pupils did, in practice, share their prior ideas within the groups but that they were reluctant to do so within the whole class. Furthermore, most of the pupils were accepting of the approach in that they participated when their ideas were challenged and because they were involved in their own learning. The teacher's view was that this phase had been effective in its purpose of getting the pupils focused on the astronomy concepts, although it is noticeable that he made no comment about the pupils' prior mental models.

The teacher's understanding of, and enthusiasm for, the approach increased markedly during the *Mental Model Building and Critiquing* phase. He noted that the pupils demonstrated increasing interest in the mental model by asking an increasing number of their own questions as the intervention progressed and by willingly approaching the teacher for clarification of points they had not understood. These positive aspects were seen by the teacher as being due to the fact that the pupils were actively involved in their own learning and due to the variety of hands-on learning opportunities provided for the pupils, particularly their use of the orrery.

As the intervention progressed, the teacher thought that the pupils more readily shared and challenged prior ideas both within their groups and with the whole class. He thought that they genuinely listened to others' ideas, even if they were different to their own, and they increasingly judged the ideas on the basis of their ability to explain observations. He was surprised to discover that concepts about lunar eclipses were very difficult for these pupils.

The teacher reported positively about the pupils' increasing skill in their repeated critiquing of the orrery as a representation of their mental model of the Sun-Earth-Moon system. He also commented that he would not change anything in this sequence for when he taught astronomy in the future, thus indicating a high level of support for the approach. This phase was, in summary, seen by the teacher as a very effective part of the astronomy intervention.

The teacher thought that the main problems for the pupils in the *Using the Mental Model to Solve Problems* phase were in interpreting the data that was provided in the appendices and in thinking back to the astronomy mental model that had been constructed in the previous phase. The latter is, of course, the intent of this phase of the intervention, so it appears that the teacher had not fully understood the reason for its inclusion. He nevertheless reported that the pupils remained focused on the task in hand and that they generally co-operatively solved the problems. He considered that this was because of the variety of activities, because of the interactive nature of the discourses and because the pupils felt ownership of their learning. He thought that this phase was very effective in consolidating the mental model.

However, the teacher did comment that the group interactions did not always proceed as interactively as planned. For example, he reported that sometimes a group, rather than investigating the topic, simply wrote down the first response by someone in that group. He also noted, to his surprise, that the ideas about tides were particularly challenging to the pupils.

The teacher's view of the effectiveness of the *Reflection* phase of the intervention is summed up by his remark that *I don't have any problems with that... I think it's a really good way to teach astronomy*. He thought that the pupils used the orrery well to explain their ideas, that they had applied the mental model to resolve the novel problems, that they did challenge and debate each other's reports and that this phase further helped them to consolidate their mental model of the Sun-Earth-Moon system.

It was clear that there had been a development in the teacher's insights into the mental model building process as a result of the astronomy intervention. At the beginning of the intervention his comments tended to relate to managerial and content aspects. By the end of it, he was articulating the interactive nature of learning, pupils being responsible for their own learning and to the radical and central feature of the intervention - pupils building, testing and

consolidating the scientists' mental model of the Sun-Earth-Moon system.

8.3.4 The Trial Intervention Teacher's Views After the Intervention

This section will consider the teacher's views after he had taught the astronomy intervention. His views will be reported and analysed in terms of the support provided by the intervention for the teacher, the intervention's effect on the pupils and management of the intervention.

The Support Provided by the Intervention for the Trial Teacher

The teacher reported satisfaction with teaching astronomy using a mental model building approach. He said that he felt good about it and that he would teach it again.

He valued the fact that the support document very clearly stated both the learning and investigative skills objectives for each lesson and that it provided all the necessary astronomy information, thus removing the usual barrier of his first of all having to become an expert before he could teach it. The unit supported him, he reported, in developing both his knowledge and his investigative skills expertise along with the pupils. This comment further indicates that the teacher thinks that their lack of astronomy knowledge is a barrier to many teachers and a rationale for them not to teach it. It also underlines that his main consideration was with the astronomy content rather than the pupils building the mental model, although he had become aware that investigative skills are utilised in astronomy as well as with other subject areas.

He was of the view that the support provided for him met the curriculum requirements for astronomy at level four in terms of the recommended content for *Making Sense of Planet Earth and Beyond*. He quoted evidence in the pupils' books that those requirements had been met by the intervention. He also responded positively and enthusiastically that this approach met the curriculum requirements in terms of the recommended science investigative skills.

The teacher was enthusiastic about the resources provided for him to teach the astronomy, responding:

> *Brilliant, yeah, generally brilliant. I mean, there's certainly plenty of it and I really like the columns. The columns, particularly. They might find things easier to read in charts rather than, say, looking at a huge page of writing on Pluto.*

He particularly mentioned the fact that the tables of data (*the charts*) were more useful to the pupils than having to find the same information in prose form. He was also enthusiastic about *the columns* on the red pages provided for the repeated critiquing of the orrery. By this response, the teacher demonstrated his awareness of the central importance of the pupils

critiquing the orrery as a representation of the mental model they were constructing.

The teacher was a little ambivalent about the time aspect in that he first of all thought that more time was necessary to teach in a mental model building way compared to more traditional approaches due to having to elucidate and challenge pupils' ideas. He wondered if there was a way in which he could reduce the time needed, but then he realised its importance for the pupils and changed his mind to the extent that he thought there had been insufficient time and *we were a wee bit short*. This exchange suggests that the teacher was still coming to terms in his own mind between the learning needs of his pupils and the pragmatic restraints of such things as time. For instance, his school had a rule that all teaching units were to be completed in three weeks.

When asked about the practicability of the approach, the teacher misunderstood the question and commented that the mental model building approach was *very practical* and the supplied intervention plans were easy to follow. In contrast to his views before the intervention, he now saw the small groups as being an advantage. Furthermore, he had become very enthusiastic about the role of mental models and models in astronomy education, particularly the orrery, of which he would have liked greater numbers, and he discussed how he could improve the one supplied to him. He had developed his view of the efficacy of the orrery from their use being illustrative to having the view that they would help the pupils *conceptualise their mental model.*

The Intervention's Effect on the Pupils

In terms of the pupils' reaction to the approach in the astronomy intervention, the teacher reported:

> *In general terms, I think they reacted very well. There's been a lot of continuing interest in things that are going on. I've had several kids come up to me with information that they've discovered and, as you know, I think that's a testament to how many of them are reacting and responding to what's been going on. Next time, next year, I'll do it earlier on in the year. Like early in the second term, because I believe winter's a better time to be looking at the stars and I'll have the whole unit based on astronomy. So the whole unit classroom will be running on an astronomical basis rather than trying to run it side by side with other things I taught as well.*

That is, he thought that the pupils had reacted very well to the intervention. However, he displayed his information-processing emphasis by referring specifically to those pupils who found information in books. He repeated that he would be teaching astronomy again in the following year but that he would change the time of its implementation to make it the focus of an approach that integrated it with other curriculum areas.

The teacher reported that the intervention was successful in getting the pupils to state, share and debate their prior knowledge and ideas about astronomy:

> *That's one thing it was particularly good at because they had an opportunity to write them down.*

That is, he thought that the pupils sharing their ideas was a very strong aspect of the intervention. In particular, he added that a strong and educative feature was that the pupils had to justify their prior views rather than just recording them. They were not allowed to just write them down without giving reasons for their views.

In respect of the pupils' prior views actually being challenged during the intervention, he was of the view that there were the odd exceptions who resisted it but that *most of them were fine* about it. His response was more subdued than it had been to the same question in the pre-interview when he said that they *would welcome* their views being challenged. He was very sure that the intervention did, as required, challenge the pupils' prior ideas and he felt that most of them were *happy to go along with the approach.*

In his view, the pupils did, in fact, critically evaluate astronomy ideas during the intervention. He specifically named Ann, Betty and Oliver for whom the intervention had been particularly effective in this respect. He saw those pupils as being exemplars of a wider cross-section of the class, but not of the whole class.

The teacher reported that the intervention had provided appropriate support for the pupils to make sense, in the scientists' way, of the requirements for level four astronomy:

> *As best any model was able to, I guess, this one did it very well. So, yeah, I'm quite happy with that. It's the set-up, the learning environment, for the kids to do that. Whether they choose not to get in and take those views on board or not is up to them.*

That is, he felt that the intervention had, in fact, supported the pupils towards their making sense of the scientists' views about astronomy. It had provided the framework but the actual learning was up to each individual child. He again pointed out that it was not effective for all the pupils, although he attributed any lack of success to the attitudes the pupils themselves brought to class. He cited Ian as an example of a pupil who usually *resisted learning.*

The teacher thought the intervention had, in fact, been successful in helping the pupils construct the scientists' concepts and mental model:

> *I think very clearly that they have come to a different understanding about*

moons, tides, phases of the Moon. We'll get there eventually.

He was enthusiastic that the pupils' astronomy ideas had been challenged and that both their astronomy concepts and their mental model of the Sun-Earth-Moon system had developed further towards the scientists' view. His comment that *We'll get there eventually* indicates that he thought that not everyone in the class had fully come to share the scientists' astronomy views, but that a good basis had been made for further development. His response concentrated more on the concepts than on the mental model, suggesting that he had not fully understood its central role in this intervention. That is, he himself had only partially moved his thinking from a predominantly fact-orientated approach to astronomy education towards the mental model building and testing approach that was the basis of this intervention.

Science in the New Zealand Curriculum stresses that pupils should develop investigative skills in addition to concepts and information. In this context the teacher talked about the pupils' willingness to use computers to find astronomy information and their reluctance to use books. That is, his understanding of investigative skills appeared to be limited mainly to information gathering, particularly from books. His view had thus not substantially changed since his pre-interview. He did not mention other skills such as mental model building, despite that being a focus of the intervention he had just taught.

To the teacher, a major difficulty was that many of the pupils found the reading level of the available books too difficult and thus they sometimes copied out parts of it without understanding it. His emphasis on this as the most important investigative skill, and his pragmatic approach to classroom problems, lead him to propose, for the following year that he would select books that were more easily read by his class.

The teacher's view was that the language concerned with eclipses was of particular difficulty to his pupils and added that sometimes it is the specialised astronomical language itself, rather than the underlying concepts, that causes pupil difficulties. For example, Herbie appeared to understand the concepts of tides but used his own terminology to describe them:

> *Herbie is not particularly language-orientated. He was talking about king and queen tides and things like that. So that's the particular language that he used.* ***My*** *(*teacher's emphasis*) under-standing of what Herbie was saying is that king tides are what we call spring tides and queen tides would be neap tides. It's just a different way of saying things.*

That is, language was not seen by the teacher as a wide-ranging problem but it did pose difficulties for specific concepts and for particular pupils. He also thought that the pupils had particular difficulties with the large numbers for sizes and distances in astronomy and they did not see the point of learning them. He thought that their view was that *I don't need to*

know this. I need to know that it's really huge, huge, huge distances out there. Pupils even had difficulty, in the teacher's view, in conceptualising the scale distances used to help illustrate solar system distances in that *It's just so difficult for them to bring that into real terms*. As he pointed out, even the scale distance of Pluto was difficult for many pupils.

The Management of the Intervention

In the pre-interview, the teacher had been equivocal about the large number of small groups to be used in the astronomy intervention. After the intervention, he became much more supportive of them from a management perspective. However, he understood there were both positive and negative aspects to whatever group arrangement was made and that his choice of which pupils were in the groups was important. He stated that positive aspects of having a large number of small groups were that the teacher could interact with everyone in the group and that there was less chance of pupils in the group being off-task. However, he found it was sometimes difficult to interact with all the groups in every lesson. Overall, though, he thought it was appropriate for the pupils to work in groups to learn astronomy:

> *I think it is, particularly for girls. Research tells us that girls work better in groups and that they share their ideas.*

With reference to the astronomy knowledge required of teachers, his view was that it was not a problem because all the information was provided for each of the investigations in the lesson plans within the intervention unit. In addition, he had several computer programs which provided additional information and the researcher had also provided a selection of astronomy books.

The teacher was emphatic that the approach to teaching astronomy *made sense* to him in terms of what he knew about how pupils learn. He related any shortcomings to his own lack of expertise rather than to the programme for the intervention and he was of the view that he had noticeably developed his skills as a result of his participation in the intervention. For example, he suggested that he would be in a better position in future to anticipate pupils' questions and responses. He thought the intervention was effective in getting the pupils to open mindedly critically evaluate each other's ideas, adding the point that it managed this without becoming threatening to the pupils. In fact, he saw the approach as being *caring*.

8.3.5 Summary of the Trial Teacher's Views

The teacher was enthusiastic about the teaching approach and saw a great deal of potential in the astronomy intervention. While initially expressing concerns about possible management aspects related to the number of groups required, his view was that the approach would meet all curriculum requirements for astronomy and would both enthuse the pupils and further develop their astronomy ideas towards those held by the science community.

After teaching the astronomy, the teacher's view was that there were many features of the intervention which resulted in positive outcomes for the teacher and the pupils. For example, he thought that the pupils' astronomy concepts had been elicited, made public within groups and the class as a whole and then challenged to see which of the competing ideas made most sense to the pupils. Then the fruitfulness of the scientists' ideas had been investigated, followed by a reflection phase in which the pupils reported and defended their new ideas within vigorous debate about any competing ideas. In addition, he noted that the intervention challenged the pupils' ideas in a way which was both supportive and non-threatening.

He felt comfortable with the approach, affirming that he did not need to be an astronomy expert before implementing it. He added that this was because the intervention lessons provided the background knowledge he needed and also encouraged pupil learning in a rather caring and supportive way. He further found that the pupils in his class had examined their own and the teacher's ideas and that the intervention had assisted in furthering the diverse aims of *Science in the New Zealand Curriculum.* The teacher also found that the pupils had developed the skill of critiquing the orrery as a representation of the mental model of the Sun-Earth-Moon system and that management difficulties had not been increased by using the approach. The large number of small groups was also not a problem.

However, the teacher was surprised to learn that there was a minority of pupils who resisted the approach, who continued to be uncomfortable about having their astronomy views challenged and who did not readily adopt the language used by astronomers, continuing to prefer their own descriptive phrases. In addition, he became aware that the approach needs more time than more traditional approaches, that more models, particularly orreries, are desirable for pupils to thoroughly explore ideas and that the pupils continued to have difficulties with the large numbers.

8.4 SUMMARY AND CONCLUSIONS

This section is a summary of the results described and analysed in chapter eight. It responds to the research questions posed at the start of the chapter. In addition, it summarises the trial intervention teacher's views of the efficacy of the approach adopted in this intervention. The following statements are in addition to those concepts discussed in chapter seven.

Research Question 5 **How effective was the intervention in promoting the astronomy knowledge and concepts in *Science in the New Zealand Curriculum*?**

This study shows that the astronomy intervention resulted in pupils often making substantial (and usually enduring) gains in understanding in the following areas:

* The sequence of the planets. For example, the proportions who knew that Mercury is the planet nearest to the Sun and that Mars is the next planet out from the Sun after Earth rose, respectively, from 66% and 47% to 94% and 91% (section 8.2.2).
* The size of the planets. For example, the proportions who knew that Pluto is the smallest planet and Jupiter is the largest planet rose, respectively, from 72% and 66% to 100% and 81% (section 8.2.2).
* Descriptions of the planets. For example, the proportions who recognised the surface features of Jupiter and Mars rose, respectively, from 53% and 44% to 75% and 56% (section 8.2.2).
* The cause of the tides. The proportions who knew that the Moon is the main cause of tides and that the Sun also affects tides rose, respectively, from 53% and 9% to 100% and 63% (section 8.2.3).
* Eclipses. The proportions who knew how solar and lunar eclipses occur increased, respectively, from 53% and 19% to 72% and 68% (section 8.2.5).

In addition, the trial intervention teacher noted the following effective aspects of the astronomy intervention:

* *Focus on the Mental Model* phase. Most pupils were keen to share and debate their prior ideas. This phase was effective and necessary to alert pupils to the role of models and in focusing them on to the Sun-Earth-Moon mental model and associated concepts (section 8.3.3).
* *Mental Model Building and Critiquing* phase. The pupils demonstrated interest in the mental model, the pupils were actively involved in their own learning, the orrery was a valuable model of the mental model and critiquing the orrery was valuable in helping the pupils construct their mental model. This phase was effective and necessary for the pupils to construct the scientists' mental model (section 8.3.3).
* *Using the Mental Model to Solve Problems* phase. The groups co-operatively used the scientists' mental model to solve the problems. This phase was effective and necessary for the pupils to consolidate the mental model (section 8.3.3).
* *Reflection* phase. The pupils' solutions to the problems were reported and debated. This phase was effective and necessary for the pupils to consolidate the mental model (section 8.3.3).
* Support provided for the teacher. The intervention programme was very supportive in that it provided the rationale, the appropriate content for level four of *Making Sense of Planet Earth and Beyond*, the appropriate investigative skills for *Science in the New Zealand Curriculum*, the astronomy information required and all the necessary resources (section 8.3.4).
* The effect on the pupils. Most pupils were enthusiastic about the intervention, they shared, debated and challenged each others' prior ideas and most of them constructed a mental model of the Sun-Earth-Moon system that was similar to that of scientists

(section 8.3.4).

* Management of the intervention. The teacher became supportive of using a large number of small groups, the approach made sense to him in the way that pupils learn concepts, he developed his own teaching skills as a result of participating in the intervention and the management was non-threatening to, and inclusive of, the pupils (section 8.3.4).

Research Question 4 **What are the astronomy conceptual learning and teaching difficulties experienced, respectively, by New Zealand pupils and teachers?**

This section will summarise the New Zealand pupil learning difficulties that were revealed by the intervention. In addition it will summarise the trial intervention teacher's views about the difficulties of teaching astronomy. Overseas teachers' and other New Zealand teachers' views about the difficulties of teaching astronomy have already been described, respectively, in section 2.4 and section 6.2

This study shows that the intervention was less successful in ameliorating a number of conceptual learning difficulties. The following concepts remain difficult for year 7-8 pupils:

* Understanding why we observe the Moon during the day. The proportions who understood why the Moon is present in the day-time sky as often as in the night-time sky increased from 22% to only 38% (section 8.2.4).
  Most pupils remained convinced that the Moon is solely a night-time phenomenon. This is despite having observed the Moon during the day and despite having engaged in a lengthy discussion on that topic.
* Cause of the phases of the Moon. The proportions who understood how the Moon's phases are caused increased from 0% to only 16% (section 8.2.4).
  Many pupils remained unable to understand the causes of the Moon's phases despite having spent a lesson investigating them.
* The teacher's views of investigative skills were more narrow than those expressed in *Science in the New Zealand Curriculum* and he felt that the pupils often had difficulty in expressing their astronomy concepts (section 8.3.4).
* The teacher was of the view that the intervention required more teaching time than more traditional approaches. (section 8.3.4).
* *Using the Mental Model to Solve Problems* phase. Some pupils had difficulty in interpreting the supplied tables of data (section 8.3.3).

Chapter eight adds to the conclusions from chapter seven that the usual knowledge outcomes were achieved as a result of this intervention. In addition, the pupils also accessed the whole process of mental model building. To this end, all four phases of the intervention were

effective and necessary in helping the pupils develop astronomy concepts and build the scientists' mental model of the Sun-Earth-Moon system. During the intervention the pupils became increasingly confident about sharing and comparing their ideas and in investigating the variety of ideas to find out which one was more likely to be correct.

Some important challenges in implementing a mental model building approach appear to be related to the teacher. It appears that the teacher initially failed to recognise the central role of the pupils constructing their mental model of the Sun-Earth-Moon system and he initially reinterpreted the intervention as a novel way to facilitate his own predominantly transmissive approach to teaching astronomy. The intervention, in fact, was also a form of professional development for the teacher in that he gradually came to see the value of the approach and did, in fact, re-build his own mental model of teaching.

Chapter nine will bring together the key findings from chapters six to eight in terms of the research questions.

CHAPTER NINE: SUMMARY, CONCLUSIONS AND DISCUSSION

9.1 INTRODUCTION

Astronomy has recently regained increased emphasis in science curricula throughout the world, including New Zealand. However, it is seen as difficult for both learners and teachers and astronomy education often emphasises content rather than processes. Models are usually used to illustrate content rather than to explore pupils' ideas and help them construct mental models.

This study investigated how Year 7-8 pupils can be helped to construct the scientists' mental model of the Sun-Earth-Moon system by the process of repeatedly critiquing a model of that mental model. Insights learned from a pilot study were used in a modified trial intervention one year later.

Interviews and surveys showed that the pupils began both the pilot and trial interventions with a range both of mental models and astronomy concepts. Furthermore, their concepts were often mutually unrelated or held in isolation from their mental models.

Findings from the trial intervention indicated that most of these pupils increased their understanding of how scientists use models, constructed the scientists' mental model of the Sun-Earth-Moon system by the process of repeatedly critiquing a model of the mental model, continued to have difficulties with some astronomy concepts and learned the astronomy content which the New Zealand curriculum suggests for their age group.

Chapter nine summarises the findings from the five research questions in section 9.2, including the effectiveness of the novel teaching approach, and draws conclusions from the study in section 9.3. Section 9.4 discusses the implications arising from the study and section 9.5 discusses its limitations. Section 9.6 contains some suggestions for further research and the chapter ends with some concluding remarks in section 9.7.

9.2 SUMMARY OF THE FINDINGS

9.2.1 Introduction

Section 5.2 articulated five research questions. This section describes the outcomes in terms of each of the research questions. The discussion is presented in the following sequence:

* pupils' developing ideas about scientists' models (section 9.2.2);
* pupils developing the scientists' mental model of the Sun-Earth-Moon system (section 9.2.3);
* pupils using models to build their mental models (section 9.2.4);
* pupils' astronomy learning and teaching difficulties (section 9.2.5);
* pupils' astronomy curriculum knowledge (section 9.2.6);

9.2.2 Pupils' Developing Ideas About Scientists' Models

Research question one was:

How effective was the astronomy intervention in developing pupils' ideas about the role of scientists' models?

It is concluded that the intervention was generally effective in developing these pupils' ideas about scientists' models. This conclusion is based on the findings that:

* the proportion of pupils who were able to name a model used by scientists increased from 3% before the intervention to 90% after it (although 81% of them named the orrery) and that proportion remained constant for more than four weeks after the intervention.
* the proportion of pupils who understood at least one of the roles of models in science (for example to show a concrete representation of their mental model) increased from 10% before the intervention to 45% after the intervention and unexpectedly increased further to 90% more than four weeks after the intervention.
* the proportion of pupils who understood that scientists use models to represent and investigate their ideas increased from 19% before the intervention to 84% after it and remained constant more than four weeks after the intervention.
* however, most pupils continued to think, incorrectly, that an accurate scale is an essential feature of a model.

The pupils came to understand that scientists, particularly astronomers, use models to represent and investigate their ideas. This is in contrast to Smit and Finegold's (1995) finding that secondary student teachers in Namibia and South Africa thought that the main use of models was as scale representations of reality so teachers could explain science ideas more clearly. In addition, these Year 7-8 pupils came to understand that models can be used to investigate ideas by critiquing the positive, negative and neutral aspects of the model's ability to predict and explain those ideas. However, they did not focus sufficiently on the implications of the neutral aspects and many continued to think that a necessary and essential feature of a model is that it is a scaled representation of reality.

9.2.3 Pupils Developing the Scientists' Mental Model of the Sun-Earth-Moon System

Research question two was:

Are pupils able to construct the scientists' mental model of the Sun-Earth-Moon system?

It is concluded that almost all these pupils were able to construct for themselves the scientists' mental model of the Sun-Earth-Moon system. In addition, most pupils shared those scientists' concepts which are subordinate to, and dependent on, the mental model of the Sun-Earth-Moon system.The evidence for these conclusions is presented in the

following sequence:

* the Sun-Earth-Moon mental model;
* the concept of day and night;
* the concept of months.
* the concept of years;

The Sun-Earth-Moon Mental Model

The proportion of pupils who shared the scientists' mental model of a rotating Earth orbiting around the Sun while the Moon orbits Earth increased from 48% before the intervention to 90% after it, and that proportion remained constant for more than four weeks after the intervention.

This finding compares favourably with that of both Lynch (1996) and of Sharp (1996). Lynch found that only 72% of grade 6 children in Tasmania were able to construct the scientists' mental model of the Sun-Earth-Moon system and Sharp found that only 55% of Year 6 pupils in England were able to do this. The present study demonstrates the powerful effects of the orrery and the process of critiquing it and contrasts with Baxter's (1989) view that the teaching of the Sun-Earth-Moon mental model should not begin until early adolescence. The finding is also not in agreement with Nussbaum and Sharoni-Dagan's (1983) report that an intervention can only be expected to be fruitful for about half of the pupils in a class. However, neither Baxter nor Nussbaum and Sharoni-Dagan attempted to intervene in the pupils' learning in the way described in this thesis.

The Concept of Day and Night

The proportion of pupils who shared the scientists' concept that days and nights are caused by Earth rotating on its axis increased from 25% before the intervention to 91% after it, and that proportion remained constant for more than four weeks after the intervention.

This finding compares with that of both Sadler (1999) and Sharp, Bowker, Mooney, Grace and Jeans (1999). Sadler found that only 66% of grade 8-12 pupils in the USA understood the cause of night and day and Sharp, Bowker, Mooney, Grace and Jeans (1999) found that the proportion of Year 6 pupils in England who came to understand it increased from 36% to only 77.4% after being taught. However, the present study's finding is in agreement with Baxter's (1989) work which concluded that the concept of night and day was more easily understood than most astronomy concepts. However, both he and Adams, Doig and Rosier (1991) reported that very common explanations for the cause of night and day were that the Sun orbits Earth. That is, the intervention reported in this study appeared to have been successful in addressing this common pupil misconception.

The Concept of Months

The proportion of pupils who shared the scientists' concept that months are the result of the Moon orbiting once around Earth increased from 19% before the intervention to 75%

after it, and that proportion remained constant for more than four weeks after the intervention.

This view is in contrast to Sadler's (1998) finding that most pupils in the United States have not understood this idea by Grade 8. Skam (1994) discovered a similar viewpoint in his study among English primary student teachers. The finding in this study is particularly notable because these Year 7-8 pupils initially held very strongly to the view that the Moon was associated only with night times and thus rose every evening and set every morning. Sharp (1996) had also found that very few Year 6 pupils in England associated the Moon with the day-time sky, a misconception shared with primary and secondary student teachers in England (Parker and Heywood, 1998). The intervention was clearly successful in addressing this part of the Sun-Earth-Moon mental model.

The Concept of Years

The proportion of pupils who shared the scientists' concept that years are the result of Earth orbiting once around the Sun increased from 34% before the intervention to 94% after it, and that proportion remained constant for more than four weeks after the intervention.

This is in contrast to the work by Durant, Evans and Thomas (1989) who reported that about 40% of adults in the USA and UK thought that the Sun orbits Earth. The contrary finding in this study indicates that the astronomy intervention was successful in addressing this concept which is subordinate to the Sun-Earth-Moon mental model. This finding provides further support for the efficacy of the mental model building process.

9.2.4 Pupils Using Models to Build their Mental Models

Research question three was:

> **How effective are models in promoting mental model building by New Zealand pupils?**

It is concluded that models are effective in promoting mental model building by these New Zealand pupils. In fact, there appeared to be a symbiotic relationship between their emerging skill at mental model building and the sophistication of the mental models they actually held. That is, the more they understood the power of mental models and the process of generating them, the more rapidly and fruitfully did their actual understandings develop. This conclusion is based on the findings that the pupils:

* successfully engaged with and critiqued a map of the London Underground.
* successfully built, engaged with and critiqued a model of the solar system.
* successfully engaged with the process of critiquing the orrery as a model of the Sun-Earth-Moon system.

A pedagogy grounded in constructivism was used in this study to give Year 7-8 pupils the opportunity to generate, make explicit and critique astronomy mental models. It was

found that a large majority of these pupils was able to construct the scientists' mental model of the Sun-Earth-Moon system.

During this study a novel teaching approach was devised and trialled. The final form of this approach, which had its genesis in earlier constructivist teaching models and the procedures of astronomers themselves, was intended to facilitate mental model building in astronomy. Its possible wider application is discussed in section 9.6. The effective use of models to promote mental model building was noted in each of the four phases of the teaching approach, viz:

* *Focus on the Mental Model* phase;
* *Mental Model Building and Critiquing* phase;
* *Using the Mental Model to Solve Problems* phase;
* *Reflection* phase.

Focus on the Mental Model Phase

Chapter seven showed that these Year 7-8 pupils successfully engaged with the notion of models when the teacher introduced them in the form of a map of the London Underground (section 7.4.2) or a model of the solar system (section 7.4.3) and particularly when the model was the orrery as a representation of the Sun-Earth-Moon system (section 7.5.2). In each case the pupils utilised, with increasing skill, Hesse's (1966) method of critiquing a model, although the neutral aspects of the map of the London Underground were not addressed. They understood that models are a way of representing ideas and that they are not perfect in that they have positive and negative features.

Pupils were encouraged to articulate their own mental model of the Sun-Earth-Moon system and to become aware that there were contrary views present among their class-mates. As well, this phase introduced the idea that different viewpoints would be resolved by investigation rather than by appeals to authority.

During the *Focus on the Mental Model* phase the pupils' mental models were made explicit, as was their view of the role of models in science. In the latter case, it was clear that their view of models was initially similar to that revealed by Osborne and Gilbert (1980b) and by Smit and Finegold (1995) that an essential property of models is that they are scaled replicas of the reality they represent. However, they were introduced to the idea of critiquing models and discovered that a model of the solar system was useful in many respects without being a scale model. The pupils realised that there was a variety of views present in the class and they raised questions about their pre-existing ideas about models and their mental models.

Mental Model Building and Critiquing Phase

Section 7.5.3 showed that these Year 7-8 pupils repeatedly critiqued a model (the orrery) of the Sun-Earth-Moon mental model in terms of the mental model's and orrery's ability

to describe, explain and test observed events and concepts. For example, section 7.4.2 showed that the pupils identified positive features of the orrery as its representation of the rotations and revolutions of the Sun, Earth, Moon and Mercury. They identified some of its negative features as the inaccuracy of scale in the orrery's representation of the relative sizes, distances and movements of the four bodies. The neutral features of the orrery often indicated a starting point for further exploration. An example was the equal rotation and revolution periods of the Moon.

During this phase there was an apparent symbiotic interactive relationship between critiquing the orrery and understanding the concepts, thus enhancing the intelligibility and plausibility of the mental model. The repeated critiquing of the orrery was seen by the researcher and the teacher (section 8.3.3) as being both necessary and very effective in helping the pupils construct for themselves the scientists' mental model of the Sun-Earth-Moon system. For their part, the pupils enthusiastically reacted with interest to the model of the Sun-Earth-Moon system (the orrery) and did not tire of critiquing it and the mental model it represented.

Using the Mental Model to Solve Problems Phase

Section 7.6.2 showed that groups of pupils co-operatively applied their newly constructed mental model of the Sun-Earth-Moon system to resolve at least two problems that were novel to them. The pupils had little difficulty with this phase and were engrossed with the tasks in hand. This phase consolidated the scientists' mental model and the process enhanced the fruitfulness of the mental model.

While there were instances in which some pupils merely followed the lead of one person in the group, most groups appeared to find the problems interesting, relevant and an effective way to learn. They were motivated, focused and on task. It was a key phase in illustrating the fruitfulness of the mental model and thus in consolidating the scientists' mental model of the Sun-Earth-Moon system.

Reflection Phase

Section 7.6.3 showed that the pupils applied their newly consolidated mental model of the Sun-Earth-Moon system to interactively report back to the rest of the class their findings from the problem-solving activities. The pupils were confident about reporting back and used both the orrery and the scientific mental model to explain their findings and to respond to questions. This phase was clearly another key step in the process of the pupils further consolidating the scientists' mental model as their own, a conclusion also reached by Taylor and Coll (1997) after their research into Fijian student teachers' use of models in constructing concepts about solubility. A similar view was shared by the intervention teacher (section 8.3.3), who considered that the *Reflection* phase was both effective and necessary for the pupils.

This phase was an extension of the *Using the Mental Model to Solve Problems* phase in

that groups of pupils jointly reported to the rest of the class their approach to the problems and their findings. The rest of the class questioned their views and findings and articulated their own interpretations of both. Thus each group was obliged to defend and reconsider its position on a variety of issues during this phase.

A central feature of the two phases of *Mental Model Building and Critiquing* and *Using the Mental Model to Solve Problems* was that the pupils were actively encouraged to generate and test their views within a co-operative environment in which they were challenged to test assumptions and to solve novel problems. This was on the assumption that a group is likely to generate more ideas than an individual and the process of explaining one's ideas is often mutually helpful to all members of the group. Building and critiquing models is essentially a process of generating and testing and allowing learners the freedom and independence to judge for themselves the validity or otherwise of their ideas. A group is more likely than an individual to generate a greater number of ways of testing those differing ideas. A further point is that debate, which is itself an important form of testing ideas, is more freely encouraged within a group.

The study showed that every one of the four phases of the teaching approach provided fruitful opportunities for pupils to use models to promote mental model building. The *Focus on the Mental Model* phase alerted the pupils to scientists' models and mental models, the *Mental Model Building and Critiquing* phase made the scientists' mental model intelligible and plausible to the pupils and the *Using the Mental Model to Solve Problems* phase both consolidated the scientists' mental model for the pupils and showed them that it was fruitful. Finally, the *Reflection* phase further consolidated the scientists' mental model.

This is in marked contrast to the findings of Driver, Leach, Scott and Millar (1966) that model-based reasoning was rare in pupils under 16 years of age. They regarded model-based reasoning as when pupils use models to explain theoretical systems and they noted a clear distinction between that process and simply visually describing a model. The Year 7-8 pupils reported in the current study did describe the model (the orrery). However, they also used it to explain concepts related to the theoretical Sun-Earth-Moon system. Furthermore, they critiqued the orrery and constructed for themselves the theoretical Sun-Earth-Moon mental model.

9.2.5 Pupils' Astronomy Learning and Teaching Difficulties

This section discusses both the astronomy ideas with which these pupils had difficulty and the difficulties of teaching astronomy. That is, this section is a response to research question four:

> **What are the astronomy conceptual learning and teaching difficulties experienced, respectively, by New Zealand pupils and teachers?**

Pupils' Astronomy Conceptual Learning Difficulties

It is concluded that there are several astronomy concepts which proved very difficult for many of these pupils to construct. The concepts are those related to the pupils' understanding about Earth's axis of rotation and the Moon. Some of these concept difficulties are similar to those reported for overseas pupils, but some have not been reported elsewhere. The evidence for the conclusions is presented in the following sequence:

* Earth's axis of rotation;
* causes of seasons;
* Moon's day-time visibility;
* phases of the Moon;
* lunar eclipses.

Earth's Axis of Rotation

The proportion of pupils who understood correctly that Earth rotates on an axis through its poles increased from 16% before the intervention to 47% after it and then reduced to 33% more than four weeks after the intervention. This compares with the proportion of pupils who thought that Earth rotates about an equatorial axis, which increased from 10% in the pre-survey, to 13% in the post-survey and then to 29% by the time of the post-post survey.

A view that Earth's axis of rotation is through its equator has implications for understanding such things as the international date line and time zones. Furthermore, pupils with that understanding will consider that when it is day time in New Zealand, for example, it will also be day time everywhere south of the equator and it will be night time everywhere north of the equator. This misconception may stem from their understanding that the seasons are opposite in the different hemispheres. They may be transferring their understanding of seasons to their concept of days. It may also arise from the common practice of teachers, when discussing day and night, to use examples from opposite hemispheres, such as it being day time in New Zealand when it is night time in London. Teachers might be better advised to compare New Zealand day and night times with those in other places in the southern hemisphere, such as in South America and South Africa.

Causes of Seasons

The proportion of pupils who constructed the scientists' understanding that Earth's seasons are caused by the tilt of its (polar) axis increased from 6% before the intervention to 22% after it, and that proportion remained constant for four weeks after the intervention.

These findings are in agreement with previously reported research that a majority of learners have the misconception that seasons are caused by Earth's changing distance from the Sun (Baxter, 1989; Baxter, 1991; Ojala, 1992; Atwood and Atwood, 1996; Sharp, 1996; Schoon and Boone, 1998). This study, though, uncovered an intermediate

outcome that Earth's tilt causes the difference in distances from the Sun, which in turn causes the seasons. That intermediate outcome was also reported for Grade 8-12 pupils in the United States (Sadler (1998), for primary student teachers in Finland (Ojala, 1997) and for primary and secondary student teachers in England (Parker and Heywood, 1998).

Moon's Day-time Visibility

Only 30% of these pupils understood after the intervention that the Moon is visible during the day. This misunderstanding was also found among Year 6 pupils in England (Sharp, 1966).

Phases of the Moon

Only 16% of the pupils constructed the scientists' concept that the phases of the Moon are due to people on Earth seeing differing fractions of the illuminated half of the Moon as the Moon orbits Earth.

The findings from this study about the Moon's phases are supported by Adams, Doig and Rosier's (1991) report that very few Year 5 children in Australia could explain why the Moon shines, by Milkent's (1977) investigation which reported that only 15% of his sample in the USA were able to explain the phases of the Moon and by Sharp, Bowker, Mooney, Grave and Jean's (1999) finding that only 32% of Year 6 pupils in England understood the phases of the Moon after being taught them. In agreement with those findings, Sadler (1998) concluded that understanding the causes of the phases of the Moon is much too difficult for most pupils even by Grade 12. In fact, Zeilik, Schau and Mattern (1998) found that 66% of Year 1 university students in the United States were unable to understand them.

The most common and enduring view in this study was that the phases are caused by Earth's shadow falling on the Moon's surface. This incorrect view is common among nine to sixteen years old pupils in England (Baxter, 1989), among Australian primary school student teachers (Skam, 1994), among American primary student teachers (Schoon and Boone, 1998), among English primary and secondary student teachers (Parker and Heywood, 1998) and among Year 6 children in England (Sharp, 1996).

Lunar Eclipses

Sixty percent of the pupils constructed the scientists' concept that lunar eclipses are caused by the Moon moving into Earth's shadow when Earth passes directly between the Sun and the Moon.

There is very little research into ascertaining and modifying learners' concepts about eclipses, although Mohapatra (1991) found that Indian pupils aged thirteen to sixteen mostly had non-scientific ideas about them. Clearly, there is a need for further research in this area.

New Zealand Teachers' Perceptions of the Difficulties of Teaching Astronomy

Section 2.4 discussed overseas teachers' views about teaching astronomy and section 6.2 revealed twelve New Zealand teacher perceptions about the difficulties. It is concluded that New Zealand and overseas teachers share many perceptions of the difficulties of teaching astronomy. The evidence for the conclusions is presented in the following sequence:

* personal lack of content knowledge;
* astronomy can only be taught in the traditional transmissive style;
* the difficulty of using investigative skills when teaching astronomy;
* pupils and models;
* other difficulties.

Personal Lack of Content Knowledge

Seventy five percent of the New Zealand teachers considered that the biggest problem when teaching astronomy was their personal lack of content knowledge. This is similar to the overseas findings that very few schools have teachers who are confident about teaching astronomy (Harris, 1982; Carre and Carter, 1993; Tebbutt, 1993; Swinbank, 1997).

Astronomy Can Only be Taught in the Traditional Transmissive Style

A majority of New Zealand teachers were unhappy in that their perception was, essentially, that astronomy can only be taught in a transmissive way. This is similar to findings that overseas teachers see transmissive teaching as being undesirable but necessary (Swinbank, 1997).

The Difficulty of Using Investigative Skills When Teaching Astronomy

Thirty three percent of the New Zealand teachers saw that a challenge to teaching astronomy was that there is very little practical work. This is similar to overseas findings (Osborne, 1991; Tebbutt, 1993; Swinbank, 1997).

Fifty eight percent of the New Zealand teachers thought that investigative skills would pose difficulties for their pupils during astronomy lessons. Furthermore, 75% of them thought that observing astronomy events was not worth the effort because astronomy events occur mainly at night, because astronomical events take place very slowly, because such observations are difficult to organise and because of the unreliability of the weather. These views are reflected in overseas research which revealed that challenges to astronomy education are that observations are mostly at night (Maddison, 1982; Tebbutt, 1993; Jarman and McAleese, 1996), that astronomy events take place slowly (Tebbutt, 1993; Swinbank, 1997) and that the unpredictability of the weather is a problem for organising astronomy observations (Ratliff, 1995).

Pupils and Models

When they were asked to name resources they would like to have to teach astronomy, three interviewed New Zealand teachers specifically mentioned models. This is related to the finding that 75% of them thought that the large sizes and distances in astronomy would prove difficult for their pupils, a finding which is in agreement with the views of overseas teachers (Tebbutt, 1993; Smith, 1988). The teachers' request for models is illustrated in that 67% of them thought that their pupils would understand how models are used in astronomy.

Other Difficulties

Thirty three percent of the New Zealand teachers thought that a challenge to teaching astronomy is a lack of resources. However, most of them did not see the lack of resources as an actual problem because their most preferred astronomy resource was books. This reflected their tendency towards transmissive approaches. Research revealed that the lack of resources was a particular concern to overseas teachers (Osborne, 1991) and that the available resources were often not compatible with the curriculum (Swinbank, 1997).

A further difficulty perceived by 42% of the New Zealand teachers, but not reported overseas, was that the specialist language used in astronomy would cause problems to their pupils.

The intervention teacher initially shared many of the above concerns. However, as described in section 8.3, his concerns had been addressed by the approach described in this study and he became increasingly enthusiastic about both the approach and its outcomes.

9.2.6 Pupils' Astronomy Curriculum Knowledge

This section discusses the extent to which aims in addition to those discussed in section 9.2.3 were attained. That is, this section is a response to research question five:

> **How effective was the intervention in promoting the astronomy knowledge and concepts in *Science in the New Zealand Curriculum?***

In addition to those concepts reported in section 9.2.3, that is, concepts directly related to the mental model of the Sun-Earth-Moon system, it is concluded that the intervention was successful in promoting the following astronomy knowledge and concepts suggested for level four of the *Making Sense of Planet Earth and Beyond* contextual strand of *Science in the New Zealand Curriculum*. The evidence for the conclusions is presented in the following sequence:

* relative sizes of planets;
* sequence of planets;

* Moon and tides;
* Sun and tides;
* solar eclipses.

Relative Sizes of Planets

The proportion of pupils who knew the relative sizes of the planets increased from about 70% before the intervention to 100% after the intervention and that proportion remained constant for more than four weeks after the intervention.

This is in contrast to Lynch's (1996) finding that 69% of Year 6 pupils in Tasmania had difficulty with the relative sizes, as did 58% of Year 1 students at a university in the USA (Zeilik, Schau and Mattern (1998). Sadler (1998), in fact, was of the view, contrary to the findings in this study of Year 7-8 pupils, that understanding relative sizes and scales is beyond the reach of high school pupils.

Sequence of Planets

The proportion of pupils who knew the order of the planets out from the Sun increased from about 57% before the intervention to 94% after the intervention and that proportion remained constant for more than four weeks after the intervention.

Moon and Tides

The proportion of pupils who knew that the Moon is the main cause of tides increased from 53% before the intervention to 100% after the intervention and that proportion remained constant for more than four weeks after the intervention.

There has been surprisingly little research into learners' concepts about the causes of tides Galili (1995) and Skam (1994) found it was a common view among English primary student teachers that the Moon is the sole cause of tides.

Sun and Tides

The proportion of pupils who knew that the Sun also affects tides increased from 9% before the intervention to 63% after the intervention and that proportion remained constant for more than four weeks after the intervention.

That result underlines the relative effectiveness of the intervention when compared to the 22% of English primary student teachers who understood that (Skam, 1994).

Solar Eclipses

The proportion of pupils who understood that solar eclipses are caused when the Moon moves in a direct line between the Sun and Earth increased from 53% before the intervention to 72% after the intervention and that proportion remained constant for more than four weeks after the intervention.

Section 8.2.5 showed that the pupils have a better understanding of solar eclipses than of

lunar eclipses, even though the same three bodies (Earth, Sun and Moon) are involved. The above figures related to solar eclipses are similar to those of Year 1 university students in the United States (Zeilik, Schau and Mattern, 1998). The most popular misconception, held by about 11% of the pupils in this study, is that solar eclipses are caused by Earth moving between the Sun and the Moon. In summary, the intervention achieved generally high student understanding in these five concepts required by *Making Sense of Planet Earth and Beyond.*

9.3 CONCLUSIONS

The findings from this investigation suggest a number of conclusions. These are considered in the following sequence:

* pupils and the role of models;
* pupils interacting with models;
* pupils and mental model building;
* astronomy concepts constructed by the pupils;
* pupils' astronomy conceptual difficulties.

The astronomy intervention was successful in developing Year 7-8 pupils' understanding about the role of models in science, although many of them continued to view models as being, preferably, scaled versions of the reality they represent. However, many pupils came to understand that models can be useful without being scaled representations of reality and most of them understood that scientists use them for learning, for problemetising previous ideas and for restructuring those previous ideas.

Year 7-8 pupils are capable of, and did not tire of, repeatedly critiquing the model of the mental model of the Sun-Earth-Moon system with respect to its capacity to illustrate, explain and test related concepts. In fact, critiquing the model (the orrery) was seen as a key factor in assisting these pupils towards modifying their initial mental model of the Sun-Earth-Moon system towards that of scientists. Furthermore, it is concluded that there is a symbiotic relationship between critiquing the model of the Sun-Earth-Moon system and developing knowledge and concepts represented by that model, such that increasing facility in one assists understanding of the other.

Contrary to the suggestions of Driver, Leach, Millar and Scott (1996), described in section 9.2.4, mental model building (at least in astronomy education) is an effective and appropriate cognitive activity for Year 7-8 pupils in that these pupils did construct the scientists' mental model of the Sun-Earth-Moon system.

There was a number of astronomy concepts associated with the scientists' mental model that were successfully constructed by most of these Year 7-8 pupils. These concepts, required by *Making Sense of Planet Earth and Beyond*, were:

* days and nights are the result of Earth's rotation on its axis;

* years are the result of Earth's orbit around the Sun;
* months are the result of the Moon's orbit around Earth;
* knowledge of the sequence of the planets from the Sun;
* knowledge of the relative sizes of the planets;
* both the Moon and the Sun affect Earth's tides;
* solar eclipses are the result of the Moon passing directly between the Sun and Earth;
* seasons are mainly due to Earth's axis being tilted.

Nevertheless, despite the astronomy intervention many pupils were not successful in constructing the following concepts:

* that the Moon is present in the day-time sky as often as during the night-time sky;
* that the phases of the Moon are a result of people on Earth viewing different proportions of the half of the Moon that is illuminated by the Sun;
* that lunar eclipses are the result of Earth passing directly between the Sun and Moon;
* that Earth's axis of rotation is through its poles rather than through its equator;
* knowledge of planetary surface features.

9.4 IMPLICATIONS ARISING FROM THIS STUDY

9.4.1 Introduction

This section discusses the implications of this research. The discussion is presented in the following sequence:

* implications for mental model building in astronomy (section 9.4.2);
* implications for astronomy and science curriculum (section 9.4.3);
* implications for teachers of astronomy (section 9.4.4);
* implications for pupils when learning astronomy (section 9.4.5).

9.4.2 Implications for Mental Model Building in Astronomy

This study supports a view that pupils as young as twelve years old are able, given the right conditions, to build, affirm and defend their mental model of the Sun-Earth-Moon system. In fact, such a process is necessary because there is no direct experiential evidence from Earth that can affirm or deny geocentrism and heliocentrism (Albanese, Neves and Vicentini, 1997). Building the mental model is a developmental process in which learners come to understand the scientific viewpoint and then repeatedly critique its ability to explain and predict related subordinate concepts. While those two conditions are essential, they are not sufficient. The learners then need to affirm what has become 'their' mental model by using it to resolve related problems that are new to them and then by defending their problem-solving to their peers in an interactive debate. That is, mental model building appears to be facilitated by the process of:

* articulation of the mental models in the classroom;
* making the scientists' mental model intelligible to the learners;

* the learners repeatedly critiquing the mental model to enhance its plausibility;
* using the mental model to solve related problems, thus enhancing its fruitfulness;
* defending the mental model, thus further enhancing its fruitfulness.

The implications are that other mental models in astronomy (e.g. the Milky Way galaxy) may be constructed by pupils in the same way, rather than by them merely receiving a series of mental models of increasing complexity that make sense to other people rather than to themselves. An additional benefit of such an approach should be that learners come to understand the role of models and mental models in science.

9.4.3 Implications for Astronomy and Science Curriculum

The findings, observations and reflections from this study suggest that the teaching package provided learners with an enjoyable and accessible way to learn astronomy. It further suggested that many learners are capable problem solvers. It provided learners with opportunities to generate and test their ideas collaboratively. However, it also demonstrated that some concepts may be conceptually difficult for the level suggested by *Science in the New Zealand Curriculum* and they should be delayed until later in the pupils' education. For example, the New Zealand science curriculum suggests that seasons be taught to pupils at level two, yet this study suggests that a full understanding of seasons is beyond the reach of level four pupils.

The study also indicates that pupils and teachers often use some words interchangeably, a finding also supported by Parker and Heywood's (1998) investigation of English primary and secondary student teachers' use of the words rotate and revolve. Either curriculum documents need to provide correct definitions of such terms or they might be better replaced by more distinct words, such as using spin and orbit, respectively, to replace the similarly sounding rotate and revolve.

This study's approach to developing a teaching unit, based on the pupils constructing for themselves the scientists' mental model of the Sun-Earth-Moon system, has implications for other areas of the science curriculum in which pupils are unable to physically observe a complicated system, such as atoms and electrical circuits. A similar approach is possible, for example, for electrical circuits in which a model which reflects the scientists' mental model could be introduced to the pupils, who then investigate the model's implications with respect to subordinate concepts such as current, energy and voltage, then solve problems that are novel to them and then defend their new insights.

A further implication for the curriculum arises from the fact that constructivist-grounded approaches to teaching are seen as being more demanding of teachers' time than are more traditional approaches (section 2.4; Allchin, 1997). This may not be seen as a problem if learning after such approaches is longer-lasting than after traditional approaches. This study indicates that the mental model and the concepts built by these pupils remained constant for more than four weeks after the end of the intervention. In any case, this intervention occupied no more time than the usual time allocated to a science topic in the

school in which the study was carried out. Thus the criticism may be unfounded.

As discussed in chapter two, most of the reported research reflects education practices of concentrating on the products of astronomy education rather than on its processes. This practice is likely to continue until assessment procedures better reflect the emphases of the new curricula. Thus assessment procedures need to be developed that more closely reflect a conceptual and mental model building approach. For example, pupils could be asked to predict the shape of the Moon if it is seen to rise 6 hours after the Sun sets.

9.4.4 Implications for Teachers of Astronomy

Primary school teachers often have feelings of inadequacy with respect to teaching science in general and astronomy in particular (section 2.4) and yet they play a key role in the success or otherwise of curriculum innovations (Mellado, 1998; Harlen, 1997). Few primary teachers have studied science beyond the age of 16 years (Summers, Kruger and Mant, 1998) and thus have little knowledge about the subject (Kokkotas and Vlachos, 1998). This transforms into a lack of science pedagogic knowledge (Bishop and Denley, 1997) which may lead them to suggest inappropriate explanations to their pupils. Thus teachers themselves need to become cognisant with the products and processes of astronomy. It is imperative that astronomy concepts are made accessible to teachers in a readily available form.

Related to the processes of science, teachers themselves need to be exposed to constructivist-grounded learning approaches during their pre-service and in-service teacher education (Trumper (1997). This will require time, because teachers are unlikely to readily change their well-established mental models about teaching approaches (Ebenezer and Gaskell, 1995). However, this study's findings indicate that Year 7-8 pupils can construct mental models of complex systems of inter-related concepts. Being aware of this will assist teachers to understand pupils' views and to provide learning experiences which facilitate the mental model building process rather than assuming that the subject matter is too complex for their pupils and thus has to be presented in a didactic manner. For example, chapter two showed that teachers are aware of the difficulties children have with the large numbers associated with astronomy sizes and distances yet continue to teach using a didactic approach. It may, in fact, be counter-productive to ask their pupils to memorise them.

Teachers may also underestimate the difficulties of changing pupils' prior ideas about astronomy. Learning many facts, even though they are often fascinating to the pupils, does not, in general, change the pupils' prior concepts and their mental model. For example, teachers need to be aware that their pupils find particular difficulty with lunar concepts. Most pupils come to classes with the idea that the Moon orbits Earth once each day and is visible only at night. Those misconceptions need to be addressed because they are a major barrier to pupils' understanding of other lunar concepts such as the phases of the Moon, tides and eclipses.

For teachers with little or no experience of astronomy, resource problems, in addition to questions about how to structure the course, often appear to be insurmountable (section 2.4). The teaching intervention developed for this study provides a means for developing astronomy education in a way far removed from the transmissive approaches so often used. It is accessible to both teachers and learners with limited astronomy background yet does not constrain them from their own interpretations and additions.

9.4.5 Implications for Pupils When Learning Astronomy

This study found that the use of a mechanical model (the orrery) to represent the mental model was particularly effective in helping the pupils to construct the scientists' mental model of the Sun-Earth-Moon system. However, orreries are expensive and are unlikely to be readily available to most teachers. Nevertheless, simpler ones can easily be constructed, after which the process of critiquing them would be much the same as described in this study. In addition, it is the process of critiquing the model that is important, rather than the accuracy of the physical representation of the mental model. That process can be applied to any model of the mental model, such as photographs, diagrams, dioramas and computer programs.

This study indicated that there should be more emphasis on Year 7-8 pupils building, affirming and defending the 'big' ideas in science rather than the more usual procedure whereby subordinate concepts are separately introduced. This recommendation applies equally to pupils older that Year 7-8 pupils. However, it has not been demonstrated whether the approach is likely to be fruitful for younger pupils. It is suggested that they be exposed to a rich experiential approach in astronomy education during which they are able to observe and describe events and ideas that can later be built upon when they are constructing mental models. For example, if younger pupils observed and described patterns associated with the Moon, such as its phases and that it sets about 50 minutes later each succeeding day, they would later be in a better position to construct within their mental model that the Moon takes one month to orbit Earth.

Throughout the pilot and trial astronomy interventions, it became clear to both the intervention teacher and to the researcher that the workbooks allowed pupils to work at their own pace and freed the teacher to move around the classroom to provide help and to answer questions. Pupils found the teaching-learning package to be supportive and the workbook to be straightforward to use. They responded positively to all aspects, including the orrery and the repeated critiques of both it and the mental model it represented. In addition, they appeared to find the co-operative problem-solving and reporting-back phases to be interesting, challenging and informative, particularly when they realised there were conflicting views that needed to be resolved and when they were confronted with problems that were new to them. They completed all their work on schedule and filed it appropriately and neatly.

The pupils responded positively to the learning-teaching approach adopted in this astronomy intervention. They showed a clear affinity with the idea that they could

attempt, as a group, to resolve problems in their own way within an overall supportive milieu that provided guidance when needed. The pupils did not feel threatened by the approach and became comfortable with the idea that they could change their minds. The group situation appeared to provide both a greater number of possible solutions to problems, and at an enhanced level of complexity, than each individual pupil would have provided, a view supported by Sprod and Jones (1996). Both the teacher and researcher observed that there were few off-task incidents during the intervention and that such off-task incidents decreased in frequency as the intervention proceeded. This was particularly the case during the *Using the Mental Model to Solve Problems* and *Reflection* phases.

An implication is that the approach should be more widely adopted in schools. It is based on sound learning theory and on an approach to constructing mental models that the study has shown in this instance to be both effective, appropriate and motivational. However, an implication for pupils is that this approach asks that they be more responsible for their own learning, rather than accepting a passive role. This may not always be to their liking, as evidenced by the following quote from White and Gunstone (1989, p.585):

> *"We see all of this now," one said. "You are trying to get us to think and learn for ourselves."*
> *"Yes, yes," replied the teacher, heartened by this long-delayed breakthrough. "That's it exactly."*
> *"Well," said another student, "we don't want to do that."*

9.5 LIMITATIONS OF THE STUDY

This study did not have the resources to investigate the effect of the intervention on a fully representative sample of pupils in New Zealand. That is, the study was conducted in a school which was not necessarily representative of the ethnic or socio-economic mix of New Zealand as a whole. The pupils at the school were from a higher than average socio-economic status catchment area and the findings need to be read with that in mind.

The small sample precluded the research from differentiating between the learning processes and outcomes for different ethnic groups. Lesson observations, however, revealed no ethnic differences during the classroom interactions with respect to participation and enthusiasm.

In addition, the research was conducted with a small sample of only one class. While such a study has strengths in that it concerned itself in depth with the pupils in that class, it is not necessarily generalisable to other classes within New Zealand or beyond. Also, the researcher was unaware of the degree of pupil exposure during the study to information and ideas about astronomy from sources other than the intervention, such as older siblings, books and television programmes.

No attempt was made in this study to differentiate between the learning processes and outcomes on a gender basis. This was due to the small sample and the resulting limitations of statistical analysis. However, observations during the lessons suggested that girls' initial reluctance to study astronomy not only dissipated but was replaced by increasing enthusiasm to discuss and debate conceptual matters. Nevertheless, such observations are, at best, indicative and suggestive of further research.

This study was conducted into how Year 7-8 pupils build mental models of the Sun-Earth-Moon system. A simple transfer to other age groups of children, or to the construction of mental models of other phenomena, cannot be assumed without further research. It is interesting to note, however, that the most specific reference to understanding mental models found in New Zealand science curricula occurs in *Physics in the New Zealand Curriculum* at Levels 6, 7 and 8 (Ministry of Education, 1994). In response to the above two items, the researcher has outlined the investigation in sufficient detail to enable readers to judge the extent to which the findings may be generalised.

A further limitation of the study is that, while the process of constructing a mental model is seen as dynamic and developmental, it may also be subject to other influences such as social, motivational and affective. That is, the study may have been overly rational, focusing only on pupils' cognition.

9.6 SUGGESTIONS FOR FURTHER RESEARCH

There is very little classroom-based research into how pupils construct mental models, particularly in the context of astronomy education. Six possibilities for further research are listed:

* How pupils of different age groups construct mental models of the Sun-Earth-Moon system.
* How pupils of different cultures construct mental models of the Sun-Earth-Moon system.
* The extent to which models other than the orrery can further assist pupils in constructing mental models.
* How pupils of any age group construct mental models other than the Sun-Earth-Moon system (for example, mental models of conservation and ecology, electric circuits, atoms and the age of the Earth) possibly using the four-stage teaching approach trialled in the present study.
* Learning astronomy beyond the scope of this study. That is, can pupils be facilitated in constructing mental models of such processes as the evolution of stars, the Milky Way galaxy and cosmology, all of which are considered at various levels in *Science in the New Zealand Curriculum*?
* How teachers modify both their own concepts about astronomy and their ideas about teaching and learning it. This raises the following research questions:

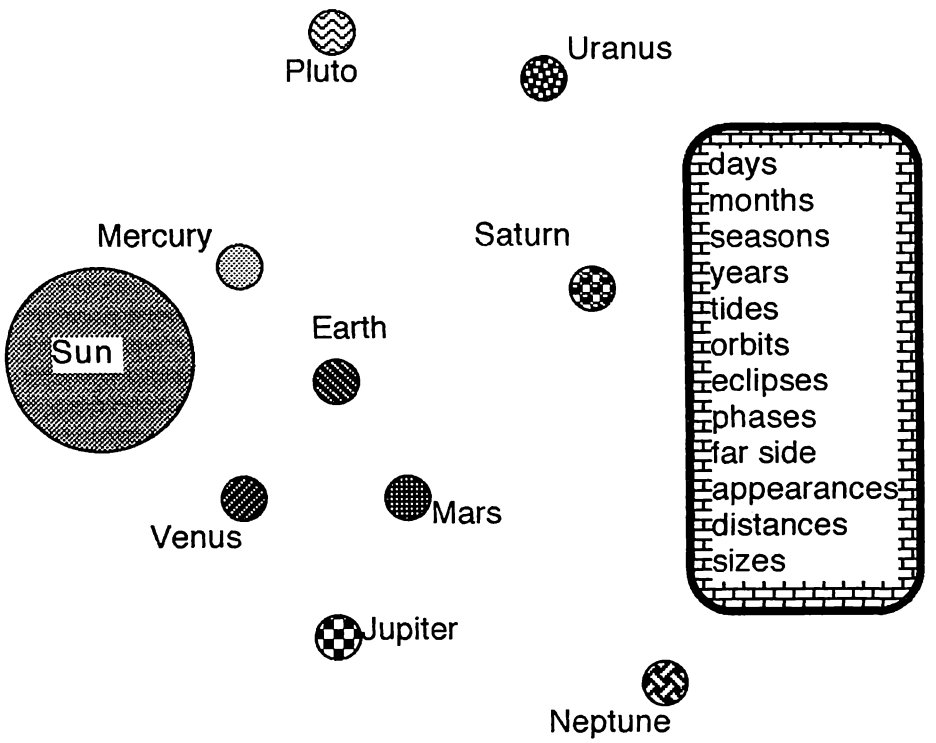
a. what is the most effective way to enhance teachers' awareness of the problems associated with teaching and learning about astronomy?
b. what is the most effective way to empower teachers to make changes to their classroom practice that would facilitate pupils' astronomy learning?

9.7 CONCLUDING REMARKS

The purpose of this study was to investigate how pupils develop their mental models of the Sun-Earth-Moon system. The study has described what happens when a constructivist pedagogy is used to give a classroom of Year 7-8 pupils the opportunity to repeatedly critique and revise their own mental models. The fact that so many of the pupils' final mental models of the Sun-Earth-Moon system approximated to that of the scientists suggests that this pedagogy can be effective. It may also help pupils construct mental models of other phenomena while learning the traditional content at the same time. That is, this pedagogy might be generalisable to help pupils construct mental models of, for example, the Milky Way, the periodic table of the elements and electric circuits.

APPENDIX A: THE ASTRONOMY TRIAL INTERVENTION

MIND-MODELLING THE SOLAR SYSTEM



An Introduction for Years Seven and Eight

Ian Taylor
School of Education
University of Waikato
Hamilton
New Zealand

ASTRONOMY INTERVENTION: INTRODUCTION

Introduction To The Teacher

This teaching unit is designed to offer suggestions for the teaching and learning of Astronomy in the context of the document *Science in the New Zealand Curriculum* for Level Four (approximately Years 7-8).

I have been interested in astronomy and how to teach it for many years, and I have gradually developed the approach that is described below, which reflects the teaching-learning aims of *Science in the New Zealand Curriculum.*

A lot of thought has been given to the teaching approach that follows. By using this approach, and changing it where you think necessary, I am sure that your pupils will improve their concepts and skills in this area better than if they had been taught using a more traditional approach. Your experience and insights are essential if these ideas are to be practical and successful in your classroom.

By working alongside each other, we have a valuable opportunity to contribute towards a better understanding of how to overcome some of the difficulties associated with teaching astronomy. I value and appreciate your contribution, which is necessary to make this project possible.

Why A New Approach?

The reason that I've written this rather different sort of teaching unit is that I am trying to encourage the understanding in the learners' minds of a coherent and explanatory mental model about the solar system, rather than them learning a whole lot of facts and figures that most of them will probably forget soon after the lessons.

Two decades of research and associated classroom experiences have amply demonstrated that pupils retain non-scientific concepts despite having been taught the scientifically accepted concepts. In addition, there is increasing evidence that an approach which better addresses the pupils' prior views and allows them to re-form their ideas is more likely to promote better learning. Here are some examples of ideas which are often unaffected by science lessons:

The Phases of the Moon

Even though most people have been taught the causes of the phases of the Moon, the vast majority of them still give the wrong reason after being taught - even most university science graduates do!

> *The Moon's phases are caused by the Earth's shadow falling on it.*
> (Intermediate school teacher with keen interest in science)

This false view is common regardless of people having been taught the correct reason by traditional methods.

Earth's Shape

Perhaps somewhat surprisingly in this so-called space age, there are many pupils who remain to be convinced, despite teaching, that Earth is round like a sphere rather than being round like a plate. In interviews, pupils who had earlier indicated that they knew Earth was round explained that they saw Earth as a round plate shape surrounded by water, and around which orbited the Sun, Moon and stars. This view is held by pupils up to and including Year Eight.

The Causes of Earth's Seasons
Related to the above erroneous view of the structure of the solar system, many pupils have difficulty with the concept and causes of Earth's seasons. In interviews with nine to sixteen years old pupils in the UK, one researcher recorded the following conversations:

> T: *Why do you think it's colder here*? (points to part of Earth not facing the Sun.)
> R: *That's 'cause it's further away from the Sun there.*
>
> T: *Does this* (angle of Earth) *make any difference*?
> R: *Yes, it turns us away in the winter when we are closer.*

The pupils erroneously see the seasons as being due only to the differing distances of Earth from the Sun, probably based on their common sense experience that it's warmer nearer to a fire than further from it. This is an idea that can be easily challenged although the correct scientific notion is not easily changed, as testified by a whole class of graduate science students who all held the incorrect idea.

Relative Distances in Space
Pupils often have a hazy concept of the distances between the objects in the solar system, which is a pre-requisite for a clear picture of the causes of such things as eclipses of the Sun and Moon.

> *The stars are closer to the Earth than the planets are.* (Primary teacher trainee)
>
> *The Moon takes about a week to go around the Earth.* (Primary teacher trainee)

Such a concept would make it difficult to understand the causes of the phases of the Moon, or the causes of eclipses.

Gravity
As to the central role of gravity in the operation of the solar system, various researchers have found that pupils have a variety of non-scientific ideas. Many think that gravity is associated with the atmosphere:

> *The force of gravity is our atmosphere.* (9 years old)
>
> *It's a force that's something in the atmosphere.* (F3 girl)

Because of this, people logically argue that there is no gravity in space. In particular, many argue that there is no gravity on the Moon because there is no air there:

> *...on the moon there is no gravity because there is no air.* (9 years old)
>
> *...there's no gravity on the moon.* (F1 boy, F3 boy)
>
> *People can take large steps on the Moon because there is no gravity.* (Form Four boy)

This view can lead perfectly logically to some surprising predictions, such as that a spanner released from an astronaut's hand on the Moon would float upwards - a view that is common among pupils. These, and other examples of non-scientific ideas held by learners who have

successfully passed through our schools, demonstrate quite clearly that teaching is not the same as learning. An alternative approach to the more traditional method of teaching astronomy is urgently needed. This proposed unit is offered as another teaching approach.

Some difficulties with teaching astronomy

This unit arose out of the difficulties which teachers often say they have with teaching astronomy. They say that:

1. few teachers are confident about their knowledge of astronomy, few have developed correct astronomy concepts themselves, and few are familiar with its particular flavour.
2. there are few resources available to teachers other than slide sets, videos and books - all of which appear to suggest passive learning modes.
3. traditional approaches to astronomy often rely mainly on teacher talk plus library projects.
4. there is little support available to teachers, other than the supply of more facts from professional astronomers.
5. some teachers and pupils may have religious objections, particularly over concepts such as cosmology and the age of the universe.
6. practical work is difficult - the time needed, schools are 'in' during day, astronomy events take place slowly, astronomy objects cannot be manipulated in the normal laboratory sense, and sending pupils outside at night for observational work clearly has safety risks.
7. many of the ideas, such as the large distances, are beyond the personal experience and real understanding of the learners and teachers.
8. the language used even by astronomers is geocentric, and does not represent what they actually know.
   For example, they refer to "sunset" rather than "the time when the Earth has rotated sufficiently to occult the Sun below the local horizon".
   For example, they talk of finding Jupiter "in" Scorpius, when they know this is merely a useful analogy.
9. it is often seen as a male preserve, despite the large number of women who have contributed to astronomy, such as the New Zealander Beatrice Tinsley and the Americans Annie Jump Cannon and Henrietta Leavitt.
10. it is often seen as a Pakeha activity, yet Maori, as did most cultures, used astronomy for the same purposes of navigation, time-keeping, cosmology, and aesthetic appreciation.

This Astronomy Unit and the New Zealand Science Curriculum

This unit is designed to help children acquire the knowledge, attitudes and skills which are specified in the contextual strand *Making Sense of Planet Earth and Beyond*, and to help them move closer towards the scientists' mental model and concepts. However, a key feature of this new unit is its additional focus on the strand *Developing Scientific Skills and Attitudes*. This integrating strand interweaves and supports the four Contextual Strands so that pupils will come to have a greater understanding of how scientific concepts develop over time.

To this end, the teaching unit is designed so that pupils are given the opportunity to:

(a) critically evaluate their own and others' astronomy ideas;
(b) be involved in using and evaluating the Investigative Skills;
(c) critically evaluate the use of scientists' models, particularly the orrery;
(d) become aware that astronomy ideas have changed over time;

Critiquing the Model

This is **the** major process skill that the learners will develop, as they engage in mental model building and interpreting the orrery.

The term 'critiquing the model' means that the class notes the pluses, minuses, and neutrals of the model at the particular stage. That is, they note which features of the model (as known at the current stage) fit the observed facts, which features of the model do not fit the observed facts (and thus suggest changes to the model or to the mental model), and which features of the model need further investigation because they do neither of the above.

This emphasis is clearly related to the integrating strand *Developing Scientific Skills and Attitudes*. For example, on page 43, it is written that "Problem solving includes...reaching a decision regarding the merit of the chosen method or device." That this decision is seen as a step on the scientific pathway is enhanced in the statement on page 43, that learners are further encouraged to come to "...an acceptance of the provisional nature of scientific explanation."

Further support from the curriculum statement that 'critiquing the model' is a major aim is that an achievement objective for Levels 3 and 4 pupils is stated as "use organised data and scientific ideas to suggest an answer to their (pupils') selected questions and problems, and make an evaluation of their investigation" (page 46). This then leads to the question "What else do we need to know to improve our model?" This, in turn, leads to the focus question for the next lesson.

A task sheet for the pupils to complete at each stage, as their model develops, is provided on pink paper, for both your own and the pupils' notes.

Using the Orrery

The orrery from the side

The orrery was chosen as a central feature of this teaching unit for a number of reasons:-

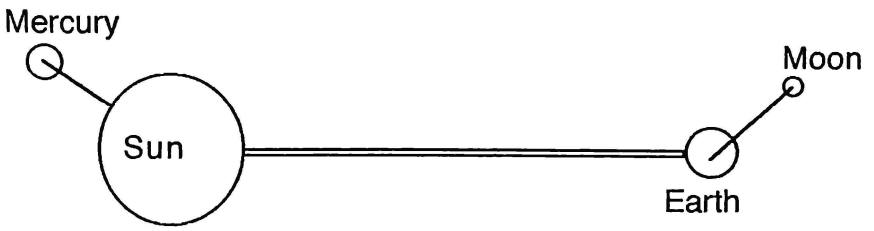
(a) it models the scientists' view of the Sun-Earth-Moon system quite well, in contrast to the views held by some of the pupils;

(b) it explains some features, such as day and night, seasons and years, very well;

(c) it explains some features, such as phases of the Moon, reasonably well. This then provides the pupils with opportunities for critical evaluation;

(d) it fails quite noticeably to explain some other features, such as the relative distances and sizes of the Sun, Earth and Moon. This also provides the pupils with opportunities for critical evaluation.

The orrery from above



Thus the orrery is a very good example of a model as used by scientists in that it has positive, neutral and negative features. That is, while being very useful once we understand it, it is not the full story, and can, in fact, be misleading if not observed thoughtfully. Otherwise it would not be a model, of course. Important features of models are that they are very useful but need to be critically examined as to the extent of their usefulness. Going beyond that limit leads the learner into thinking that the model **is** reality and that it can be used for predictive purposes beyond its limited scope.

Using the orrery gives the pupils the opportunity to develop an overall mental model of the Sun-Earth-Moon system which can be used to link together and explain all the separate concepts they have about such things as eclipses, seasons, and phases of the Moon. Critically evaluating the usefulness of the orrery will help the pupils to develop their thinking, and move towards the scientists' concept of an **over-riding** mental model that explains the effects we observe, rather than developing separate mini-theories.

The Approach of the Teaching Unit

The approach is based on a serious consideration of the title of the contextual strand *Making Sense of Planet Earth and Beyond.* The "making sense" part refers to the **pupils** being able to make sense of it all, of course, but it does not mean that everybody's 'sense' is the equal of everybody else's 'sense'. The process is one of starting from the pupils' 'sense' of an idea and intervening to try to get them to move closer towards the scientists' 'sense' of that idea. It allows the pupils to own the ideas and knowledge that develop in the lessons.

In addition, this teaching unit interweaves other strands within *Science in the New Zealand Curriculum*, including *Development of Scientific Skills and Attitudes*, which encourages an appreciation of the provisional nature of science. Related to that is the development of how scientists use models, both concrete and mental, in their development of concepts.

Of course, you will have your own thoughts and contributions as we work on this unit together. I would therefore very much hope that you will feel free to make changes within the general structure and sequence, especially in view of your knowledge of this particular class. For example, in the *Using the Mental Model to Solve Problems* phase, outlined below, you may prefer that the whole class works on all the problems, or you may prefer that groups of pupils each work on one problem and then report back to the whole class.

While the sequence of the lessons has been developed in a logical sequence, you may find it is more practicable to make some alterations within your own classroom. It is the overall philosophy that is important, rather than the detail.

The title of the teaching unit is *Mind-modelling The Solar System.* The topic area is the solar system and how it affects us. The aim is for the pupils to build for themselves the scientists'

mental model of the Sun-Earth-Moon system, with the aid of the orrery, that will describe and explain related concepts and that will allow for predictions that can be tested.

The Structure of the Unit

The following is a precis of the approach, based on the generative teaching model, which is itself based on the constructivist learning theories that have been developed at the University of Waikato.

Overall, the lessons will be constructed on the basis of the four phases of:-

1. **Focus on the Mental Model** - obtain and share prior views, for example the causes of the phases of the Moon or what causes tides. Determine the pupils' views and alert them to the idea that there is a variety of sincerely held views within their class.
2. **Mental Model-Building and Critiquing** - build the mental model by considering the differing views, obtain the information which is needed to differentiate between those views and devise tests by which the class can select the most likely viewpoint.

   It will deal with the following topics:
   (i) appearances of planets and Moon
   (ii) sizes of planets
   (iii) distances from Sun of the planets
   (iv) orbits around Sun of the planets
   (v) size, distances of orrery objects - Sun, Earth, Moon, Mercury
   (vi) orbital and rotation times of orrery objects - Earth, Moon and Mercury
   (vii) phases of Moon
   (viii) eclipses of Moon
   (ix) eclipses of Sun
3. **Using the Mental Model to Solve Problems** - apply the mental model to new problems, such as:
   a. years and days on other planets
   b. tides
   c. if Earth had two Moons

This phase should be completed by the pupils working in groups when researching the new problems.

4. **Reflection** - groups come together to report on their findings from the *Using the Mental Model to Solve Problems* phase.

Also, within many lesson there will be the three phases of:-

1. Focus - focus question(s) from the teacher about the concept under consideration.
2. Challenge - critique the concept with the data we currently have.
3. Review - critique the concept and the scientists' mental model.

The structure is represented by the diagram on the next page.

Note Re Colour-coding of Components

The clear-file prepared for the teacher includes the following:

(a) The teacher guides - on white paper.
(b) Notes and activities for the pupils - on blue paper.
(c) Factual information needed by the pupils to complete the activities - on yellow paper.
(d) Activity for critiquing the orrery - on pink paper

(e) Pre-survey - blue paper;
Post-survey - green paper;
Post-post survey - red paper.

Phases	Time-line and Content	Principles and Features	Whole Class / Group Work
Focus on the Mental Model	**Lesson 1:** Discuss pre-survey views	G1,G2,G3 F1,F2,F3,F7	
Mental Model Building and Critiquing	**Lesson 2:** Appearances & Sizes	G1,G2,G3,G4 F5	
	Lesson 3: Distances	G1,G2,G3,G4, F5	
	Lesson 4: Orrery 1: sizes & distances	G1,G2,G3,G4, F2,F3,F4,F5, F6	
	Lesson 5: Orrery 2: Day, Month, Year of Earth	G1,G2,G3,G4, F2,F3,F4,F5, F6	
	Lesson 6: Orrery 3: Seasons on Earth	G1,G2,G3,G4, F1,F2,F3,F4, F5,F6,F7	
	Lesson 7: Orrery 4: Eclipses	G1,G2,G3,G4 F1,F2,F3,F4,F5, F6,F7	
	Lesson 8: Orrery 5: Phases of Moon	G1,G2,G3,G4 F1,F2,F3,F4,F5, F6,F7	
Using the Mental Model to Solve Problems	**Lessons 9 &10:** Novel problems, e.g.days, years & seasons on other planets (see page 103 for full list)	G1,G3,G4 F1,F3,F6,F7	Groups solve novel problems
Reflection	**Lessons 11,12:** Groups report back their solutions of the novel problems	G1,G2,G3,G4 F3,F6,F7	Groups interactively report back their findings from lessons 9 and 10

Pupil Booklets

A clear-file is provided for each group of pupils. It contains items (b), (c) and (d) above, in the colours indicated.

RESOURCES USED IN THE INTERVENTION

Books

1. Abell: Exploration of the Universe
2. Arny: Explorations - An Introduction to Astronomy
3. Asimov: The Constellations
4. Asimov: The Earth's Moon
5. Bickel: The Southern Universe
6. Carter Observatory Handbook !996
7. Couper & Henbest: Telecopes & Observatories
8. Dixon: Dynamic Astronomy
9. Dole: Habitable Planets for Man
10. Hesse: Astronomy - A Brief Introduction
11. Hoyle: Astronomy
12. Jackson: Pictorial Guide to the Planets
13. Kaler: Astronomy!
14. Kaufman: Discovering the Universe
15. Kuhn: In Quest of the Universe
16. Life Library: The Universe
17. Moore: New Guide to the Planets
18. Moore: The Southern Stars
19. Moore: The Story of Astronomy
20. Pasachoff: Astronomy From the Earth to the Universe
21. Ronan & Hardy: The Universe
22. Whipple: Earth, Moon & Planets
23. Zeilik: Conceptual Astronomy

Wallcharts

1. Phases of the Moon
2. Moon Eclipse
3. Observations of the Moon
4. Our Solar System

Video

1. BBC one on Orerry - lasts 5 minutes

Materials

1. Orrery
2. Teacher's Guide to the Unit
3. 11 Pupils' Guides
4. 2x large sheet of yellow card
5. Expanded polystyrene balls - all sizes
6. micrometer
7. 11x scissors
8. colouring pens
9. 4x A3 sheets of Sun-Earth-Moon models
10. ball of string
11. sellotape
12. Earth-globe
13. light meter
14. metre ruler
15. blutak
16. matches
17. OHPT of Solar eclipse
18. OHPT of lunar eclipse
19. Photos of eclipses of Sun & Moon
20. E-M string model
21. Index cards with circles drawn in them
22. OHPT - Moon causes tides
23. OHPT - Sun & Moon cause tides

THE *FOCUS ON THE MENTAL MODEL* PHASE AN OVERVIEW

Lesson Theme	Group Size	Duration	Pupil Activities
Pre-Survey	Individual	About 30 minutes	Pupils focus on their own pre-concepts with respect to the solar system and the role of scientific modelling.
Pre-views. Conference opens: pupils state own views and listen to other pupils' views.	Whole class.	Lesson 1	Pupils learn that a variety of views about the solar system exists in their classroom and that resolution of different views will be by investigation.

THE *MENTAL MODEL BUILDING AND CRITIQUING* PHASE, ONE AN OVERVIEW

Lesson Theme	Group Size	Duration	Pupil Activities
Appearances and sizes. Make models of objects in the solar system, using polystyrene balls. Place in order across the room.	Groups	Lesson 2	Obtain visual models of solar system members.
Critique the solar system model.	Groups, then whole class.		Answer questions: What do the objects look like? What do we need to know? Is this a sufficient model of the solar system? Are all the objects the same size? What else do we need to know?
Using data, construct a model of the solar system, with objects to the correct scale size. Place in correct order across room.	Groups, then whole class.		Answer questions: How big are the objects? Is this a sufficient model of the solar system? What distances apart are the solar system objects? What else do we need to know?

THE *MENTAL MODEL BUILDING AND CRITIQUING* PHASE, TWO AN OVERVIEW

Lesson Theme	Group Size	Duration	Pupil Activities
Distances. Using data, attempt to construct model of solar system, with objects to correct distance scale. Place in correct order across room.	Groups, then whole class.	Lesson 3	Answer questions: How much room do we need for our model? Is this a sufficient model for the solar system? Come to understanding that solar system scale model can be correct for sizes or distances but not for both.
			Answer questions: Are the planets all in a straight line out from the Sun? What else do we need to know?
Orrery 1: Sizes and distances. Observe and describe the orrery (Sun-Earth-Moon model). Focus on sizes and distances.	Whole class, then groups, then whole class.	Lesson 4	Observe and describe. Answer questions: What is an orrery? Does the orrery accurately model the sizes and distances? Does the orrery show elliptical or circular orbits? What else do we need to know? Critique the orrery.
Orrery 2: Day, Month, Year. Observe and describe the orrery in terms of its spin and orbital times.	Whole class, then groups, then whole class.	Lesson 5	Observe and describe. Answer questions: Does the orrery accurately model Earth's spin time? Earth's orbital time? Moon's orbital time? What do we need to know? Critique the orrery.
Orrery 3: Seasons. Observe and describe orrery's modelling of seasons.	Groups, then whole class, then groups.	Lesson 6	What are seasons? What do you think causes the seasons? Observe and describe as Earth orbits the Sun. Now what do you think causes the seasons? How can we find out by experiment?

THE *MENTAL MODEL BUILDING AND CRITIQUING* PHASE, THREE AN OVERVIEW

Lesson Theme	Group Size	Duration	Pupil Activities
Orrery 4: Eclipses Observe and describe orrery: eclipses of the Moon.	Groups, then whole class.	Lesson 7	What is an eclipse of the Moon? What are the conditions for one to occur? Observe and describe what you see. What is an eclipse of the Moon? How do they occur? How often do they occur? Is the orrery accurate? What do we need to know? Critique the orrery?
Observe and describe orrery: eclipses of the Sun.	Groups, then whole class.		What is an eclipse of the Sun? What are the conditions for one to occur? Observe and describe what you see. What is an eclipse of the Sun? How do they occur? How often do they occur? Is the orrery accurate? What do we need to know? Critique the orrery?
Orrery 5: Phases of the Moon. Observe and describe orrery: phases of the Moon.	Groups, then whole class.	Lesson 8	What are phases of the Moon? What is their sequence? What do we need to know? Observe and describe what you see on the orrery. What are phases of the Moon? What is their sequence? Critique the orrery.

THE *USING THE MENTAL MODEL TO SOLVE PROBLEMS PHASE*, ONE

AN OVERVIEW

Lesson Theme	Group Size	Duration	Pupil Activities
Investigation 1 Orrery: days, years and seasons on Mercury.	Groups.	Lessons 9a and 10a	On the orrery, observe, describe and measure spin times, orbit times and axis tilt of Mercury. How long is a Mercury day? How long is a Mercury year? Does Mercury have seasons? Is the orrery correct? What else do we need to know? Critique the orrery.

THE *USING THE MENTAL MODEL TO SOLVE PROBLEMS* PHASE, TWO AN OVERVIEW

Lesson Theme	Group Size	Duration	Pupil Activities
Investigation 2. Faces of Moon and Mercury.	Groups.	Lessons 9b and 10b	Observe and describe what you see. Answer questions: Do we always see the same face of the Moon, on the orrery? Is the orrery accurate? What do we need to know? Why do we always see the same face? Critique the orrery?
	Groups.		Observe and describe what you see. Answer questions: Does the Sun always "see" the same face of Mercury, on the orrery? Is the orrery accurate? What do we need to know? Critique the orrery.
Investigation 3. Effect on Earth if we had zero or two moons.	Groups.	Lessons 9c and 10c	Questions: How would it affect Earth if we had no Moon? How would it affect Earth if we had two moons?
Investigation 4.Tide heights and Moon set times. Whether the Moon is the only object to affect tides.	Groups	Lessons 9d and 10d	Questions: Does the Moon affect tides? If so, is it the only cause of tides? Observe and describe tide heights and Moon set data. Then: Does the Moon affect tides? Is it the only cause? What might other causes be?
Investigation 5.Tide heights and Moon phases. Another cause of tides.	Groups	Lessons 9e and 10e	Observe and describe tide heights and Moon phases data. Infer from data: Does the Moon affect tides? Do the Moon's phases affect tides? How can they? What is another cause of tides?
Investigation 6.Days and Years on other planets.	Groups	Lessons 9f and 10f	Questions: What is a day? What is a year? Do other planets have days? Do other planets have years? How long are they? What do we need to know? From data, answer the questions about days and years on other planets.
Investigation 7. Seasons on Other Planets.	Groups	Lessons 9g and 10g	Questions: What are seasons? Do other planets have seasons? What are they like? What do we need to know? From data, answer questions about seasons on other planets.

THE *REFLECTION* PHASE

AN OVERVIEW

Lesson Theme	Group Size	Duration	Pupil Activities
Moon and tides. Debate Moon as cause of tides.	Groups report back to whole class.	Lesson 11	Questions: Does the Moon cause tides? How does the Moon cause tides? Is the Moon the only cause of tides? Learn that the Moon is NOT the only cause of tides. Discuss other possible causes of tides.
Sun Moon and tides. Debate another cause of tides.	Groups report back to whole class.		Questions: What else causes tides? Why do we get two tides each day? Infer that Sun also causes tides.
Reporting. All groups report back.	Groups report back to whole class.	Lesson 12	Share their understandings about the solar system and how it affects Earth. Listen to group reports. Are there still things we do not know? Overall critique of orrery and Sun-Earth-Moon mental model.
Post-survey.	Whole class.		Pupils reveal their post-concepts about the solar system, the Sun-Earth-Moon mental model and scientists' use of models.

Lesson 0: The Pre-Survey

Lesson 0: Pre-Survey: Eliciting Learner Prior Views
Learning Objectives
By the end of this lesson, the pupils will have been given the opportunity to:
a) Content
1. demonstrate their prior knowledge and understanding of the topics to be covered in the astronomy intervention.
2. demonstrate their prior understanding about scientists' use of models.
Materials
Class set of "My Ideas About the Solar System".

Teacher Moves	Pupil Moves
Reassure pupils that this is a survey, not a test. That it will be used to find out what they do and do not know and understand - so that the class can concentrate on their genuine understanding of what the science curriculum suggests they need to understand.	Complete the pre-surveys.

Conference Opening Session

Opening Address By Conference Chairperson

Delegates, welcome to this inaugural astronomy conference on the **solar system** and how it affects us here on Earth. My name is **Professor Connelly**, and I am responsible for the overall conference, ably assisted for the duration of the conference by **Professor Taylor**. As many of us are from different places, could you all please wear your conference badge at all times so that other delegates will know your names? Your badge should display your name, the institution you represent, and your title, such as Doctor or Professor.

Would you please complete your conference badge, complete with any decorations, before the next session. Then everyone can refer to everyone else by their correct name and title.

The aim of the conference is that we all become more knowledgeable about the structure and workings of our solar system. To make sure we do not cover ground that everyone already knows, we will begin with a survey of the ideas that people already have. Where there are disagreements, as there always are when scientists get together, we will resolve them in a proper scientific way, using evidence and logical investigation.

So to begin, would each of you complete the suvey forms in front of you. It is a survey to find out what you know and understand at the **start** of the conference - it is **not** a test.

SHARING OUR IDEAS

Now that each one of you has had the chance to complete the survey, we will briefly share everyone's ideas about some aspects of the solar system.

Remember, we are only introducing the ideas at this stage, It doesn't matter if they are right or wrong, because we will be investigating them later, in a proper scientific way.

We want delegates to form into groups of three people. Then complete the attached form. This means that you first of all **state your own views**, then you **discuss** each view with the other members of your group to see if you all agree. You just need to **record what the views are** and **whether the group holds them unanimously or not**.

Work on each question one at a time.

It doesn't matter what order you answer the questions in, just so long as your group works on the same questions at the same time.

After that, we will stick all the groups' views up on the conference notice board for everybody to see. We will start our investigations tomorrow to see how it works out.

Lesson 1

Lesson 1: Sharing Pupils' Views of the Solar System

Learning Objectives

By the end of this lesson, the pupils will have been given the opportunity to:

a) Content

1. share their views with the rest of the class about the solar system.

2. learn that there is a variety of views within the class about the solar system.

Materials

Cartridge paper, pens, rulers, wallchart showing the numbers of pupils who hold each of the five views about the Sun-Earth-Moon system, maps of London Underground.

Teacher Moves	Pupil Moves
Use the theme of the class acting as members of a conference which is investigating ideas about the solar system. Put pupils into groups named Earth, Jupiter, Mars, Mercury, Moon, Neptune, Pluto, Saturn, Sun, Uranus, Venus.	Take part in discussions, listening respectfully to others' views. Complete a chart, for classroom display, of their group's views.
Teacher explains what a model is, using the map of the London Underground as an example.	Critique the London Underground map.

Our Group's Name is:

Question	What Our Group Thinks	Was Our View Unanimous?
1. Can we make a scale model of the solar system that fits in this room? Why do you think that?		
2. What is a day? What causes days?		
3. What is a year? What causes years?		
4. What is a month? What causes months?		
5. What are phases of the Moon? What causes phases of the Moon?		
6. What are seasons? What causes seasons?		
7. What is an eclipse of the Sun? What causes them?		
8. What is an eclipse of the Moon? What causes them?		
9. What causes the tides? How do you know?		
10. Do other planets have days and years? If so, what are they like?		
11. Do other planets have seasons? If so, what are they like?		
12. What difference would it make to Earth if we had no moons?		
13. What difference would it make to Earth if we had two moons?		

Lesson 2

Lesson 2: Scale Model of Sun and Planets - Sizes

Learning Objectives

By the end of this lesson, the pupils will have been given the opportunity to:

a) Content

1. find the scale size of their group's solar system object, given that Earth is modelled at one cm in diameter.

2. make a scale model of their solar system object, showing its surface features.

b) Skills

1. observe and describe the models of the other groups' solar system objects.

2. critique the solar system model developed by the whole class, suggesting ways to improve the model.

Materials

Appendix 1, variety of spheres, cardboard, felt tip pens, scissors, string, sellotape, glue.

Teacher Moves	Pupil Moves
Provide data for Appendix 1 so that each group can make a scale model of its solar system object.	Using data in Appendix 1, each group makes a model of its solar system object. All models are made available for viewing by the whole class.
Bring class' models together for all class to see. Initiate critique of models by noting that the next step is to suspend the models from the ceiling - where shall we put them?	Critique the solar system model. Discuss what needs to be known to improve the model.
Close the session, with promise to bring the data for the next lesson.	

MODELLING THE SOLAR SYSTEM, 1

Now we have everyone's ideas about the solar system, and how it affects us, we are going to jointly build a model of it. This model, and one provided by the Chairperson, will be used to scientifically choose between all the different viewpoints that have arisen about seasons and tides and other things.

The Conference Chairperson will ask delegates to form into eleven working groups. The working groups will stay together for the remainder of the Conference.

Each working group will be responsible for one major part of the solar system to build our model.

What are the eleven major parts of the Solar System?
The eleven major parts of the Solar System are:

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

Some other parts of the Solar System are:

.....

.....

.....

.....

.....

.....

.....

The members of my working group are:

.....

.....

.....

.....

Our Group's Name is:

.....

MODELLING THE SOLAR SYSTEM 2: APPEARANCE &SIZE

Are all the major solar system objects the same size? (Y/N) .....

Our solar system object's name is .....

Its diameter is ..... km

The diameter of Earth is ..... km

So, if Earth is to be modelled with a size of 1 cm, then our object will have to be modelled with a size of ..... cm. **(See Appendix 1)**

As a group, make the scale model of your solar system object, and use the felt-tip pens to illustrate its appearance.

How practical is it to make the model and to show what it looks like? .....
.....
.....
.....
.....

After that, get together with the whole conference, with the aim of creating a semi-permanent model of the solar system in our conference room.

Critique the solar system model.

Discuss, and agree on, how the solar system model is to be constructed.

Where will we place the solar system objects? What else do we need to know?

.....
.....
.....
.....
.....
.....

Appendix 1: Data Re Diameters of Sun, Moon and Planets

Object	Size (kilometres)	Scale Size Relative to Earth (centimetres)
Mercury	4,900	0.4
Venus	12000	1.0
Earth	13,000	1.0
Mars	6,800	0.5
Jupiter	140,000	11.0
Saturn	120,000	9.4
Uranus	51,000	4.0
Neptune	51,000	4.0
Pluto	2,200	0.2
Sun	1,400,000	110
Moon	3,500	0.3

Lesson 3

Lesson 3: Distance and Size Scale Models of Sun and Planets

Learning Objectives

By the end of this lesson, the pupils will have been given the opportunity to:

a) Content

1. find the scale distance from the Sun of their solar system object, using same scale as for sizes.

2. note the scale distances of other solar system objects, using the same scale.

3. know that all models have positive and neutral features.

b) Skills

1. model and critique the possibility of constructing a visible scale model of the solar system.

2. construct a model of the solar system across the classroom.

3. critique the map of the London Underground.

Materials

Appendices 2 and 3, models from lesson 1, string, sellotape, scissors, map of London Underground.

Teacher Moves	Pupil Moves
Form same research groups as in previous lesson, with same solar system object for each group. Provide data from Appendices 2 and 3 so each group can remodel the solar system to consider distances as well as sizes and appearances.	
	Using research data, groups find out the scale distances of their solar system object. Use Appendix 2.
Class:- critique our solar system model for appearance, sizes, distances and relative positions.	
	Compare the scale distances of all the objects. Why do we call it "space"? Critique the solar system model for sizes and distances. Is it possible to make a scale model?
	Place the models across the classroom. Use Appendix 3. Critique the solar system model.
Question: Should they all be in a straight line? What else would we need to know?	
Show map (model) of London Underground. Questions: What is it? Describe it. What are its strengths and weaknesses?	Critique the map (model) of the London Underground.

MODELLING THE SOLAR SYSTEM 3: APPEARANCE, SIZE & DISTANCE

Are all the major solar system objects the same distance from their parent body? (Y/N) .....

[The parent body for the planets is .....
The parent body for the Moon is .....]

Our group's object is .....

Its distance from its parent body, ..., is ..... km

The diameter of Earth is ..... km

So, if Earth is to be modelled with a size of 1 cm, then our object will have to be modelled at a distance of ..... m from .....
(Use Appendix 2)

How practical is it to make the model, and show what it looks like, and place it at a scale distance from its parent body - in our conference room?

.....
.....
.....
.....

Critique the solar system model.

After that, get together with the whole conference, with the aim of creating a semi-permanent model of the solar system in our conference room.

Discuss, and agree on, how the model is to be constructed.
(Use Appendix 3)

Where will we place the solar system objects? Will they all be in a straight line across the room? (Y/N) .....

Get together with the rest of the class for the Course Director to show you another model.

The model (map) the teacher is showing the class is

.....
.....

Now **critique** it:

It is **very good** for showing

.....
.....
.....

It is **quite poor** at showing

.....
.....

Appendix 2: Data Re Distances of Planets From Sun

Object	Distance (Millions of km)	Scale Distance x Earth Diameter of 1 cm (metres)
Mercury	58	45
Venus	100	80
Earth	150	115
Mars	230	180
Jupiter	780	600
Saturn	1,400	1,100
Uranus	2,900	2,200
Neptune	4,500	3,500
Pluto	6,000	4,600
Sun	-	-
Moon	0.38 (from Earth)	0.3 (from Earth)

Appendix 3: Scale Model of Solar System that Fits into Classroom

Object	Size (km)	Distance (million km)	Scale Size (MIllionths of cm)	Scale Distance (m)
Mercury	4,900	58	8.2	0.1
Venus	12000	100	20	0.2
Earth	13,000	150	21.7	0.25
Mars	6,800	230	11.3	0.38
Jupiter	140,000	780	233	1.3
Saturn	120,000	1400	200	2.3
Uranus	51,000	2900	85	4.8
Neptune	51,000	4500	85	7.5
Pluto	2,200	6000	3.7	10
Sun	1,400,000	-	2333	-
Moon	3,500	0.38 (from Earth)	5.9	0.0006 (0.06 cm) (from Earth)

Lesson 4

Lesson 4: Observing the Orrery: Sizes and Distances of Sun, Earth, Moon and Mercury

Learning Objectives

By the end of this lesson, the pupils will have been given the opportunity to:

a) Content

1. describe in their own words what an orrery is.

b) Skills

1. observe, describe and list features of the orrery.

2. critique the orrery as a model of the Sun-Earth-Moon system in respect to sizes and distances.

Materials

Orrery, rulers, Appendix 4, "Critique the Orrery" sheet, Orrery video + question sheet, Wallchart of the pupuls' different Sun-Earth-Moon mental models.

Teacher Moves	Pupil Moves
Show the video.	Pupils answer questions related to the orrery video.
This is an orrery. What do you think it does? What is it? It is the scientists' view of the Sun-Earth-Moon mental model. It is like model (e). Operate it. Look closely and list all the things you can see about it.	Observe, describe and list the visible features of the orrery.
Do you think the sizes of the Sun. Earth, Moon and Mercury are to the correct scale? How can we find out?	Determine the accuracy of the orrery with respect to sizes.
Do you think the distances between the Sun, Earth, Moon and Mercury are to the correct scale? How can we find out?	Determine the accuracy of the orrery with respect to distances. Critique the orrery with respect to sizes and distances.

Questions For The Orrery Video

1. How many planets have been known for thousands of years? .....
   .....
2. How far away is Saturn? .....
3. How many times is Saturn bigger than Earth? .....
4. What might the rings of Saturn be made of? .....
   .....
5. Where is the place called *Orrery*? .....
   .....
6. In what year did the Earl of Orrery order his model of the solar system? .....
7. What is an orrery? .....
   .....
8. Where is the only place in Britain that orreries are still made? .....
   .....
9. Are those orreries made to the correct scale for:
   sizes? .....
   distances? .....
   relative movements? .....
10. Does the Sun spin on its own axis? .....
11. What is the order of the planets out from the Sun? .....
    .....
    .....
12. What are Jupiter's first four satellites (moons) called? .....
    .....
    .....
13. How many satellites of Saturn are shown on the orrery video? .....
    Is that number accepted by scientists now? .....

INTRODUCING THE ORRERY: SIZES & DISTANCES

I think an **orrery** is .....
.....
.....
.....

Looking at the orrery, We notice the following things:-
(a) The four objects in it are .....
.....
.....
.....

..... orbits the Sun, while ..... orbits Earth.
We notice that Earth spins on its axis (Y/N) .....
We notice that the Moon spins on its axis (Y/N) .....
We notice that Mercury spins on its axis (Y/N) .....

(b) The size of ..... is ..... cm
(c) The size of ..... is ..... cm
(d) The size of ..... is ..... cm
(e) The size of ..... is ..... cm

How accurate does your group think the scale **sizes** of the four objects are?
.....
.....
.....
[Hint: **use Appendix 4**]

Looking at the orrery, We notice the following things:-
(f) the distance from ..... to Sun is ..... cm,
and its orbit is/is not a circle .....

(g) the distance from ..... to Sun is ..... cm,
and its orbit is/is not a circle .....

(h) the distance from ..... to Earth is ..... cm,
and its orbit is/is not a circle .....

How accurate does your group think the scale **distances** of the three objects are?
.....
.....
.....
.....

[Hint: **use Appendix 4**]

Critique the orrery, using the red sheet provided.

Appendix 4: Data Re Sizes and Distances of Earth, Mercury and Moon

Object	Mercury	Earth	Sun	Moon
Size (km)	4,900	13,000	1,400,000	3,500
Distance from Sun (million km)	58	150	-	0.38 (from E)

Critiquing the Orrery

Date	Ways in which the orrery is definitely accurate	Ways in which the orrery is definitely not accurate	Ways in which we aren't yet sure if the orrery is accurate or not accurate

Lesson 5

Lesson 5: Observing the Orrery 2: Day, Month and Year on Earth

Learning Objectives

By the end of this lesson, the pupils will have been given the opportunity to:

a) Content

1. state what they think causes an Earth day.
2. state what they think causes an Earth year.
3. state what they think causes an Earth month.

b) Skills

1. observe from the orrery that a day is the time for Earth to rotate once on its axis.
2. observe from the orrery that a year is the time for Earth to orbit the Sun once.
3. observe from the orrery that a month is the time for the Moon to orbit Earth once.
4. measure the number of orrery days in an orrery year.
5. measure the number of orrery months ion an orrery year.
6. critique the orrery.

Materials

Orrery, darkened room, Wallchart of the pupils' Sun-Earth-Moon mental models, Appendix 5.

Teacher Moves	Pupil Moves
What is a day? What causes it? What is a year? What causes it? What is a month? What causes it?	Groups discuss the questions, try to reach concensus and report back to the class.
Do you all have the same ideas about days, months and years? Let's see how the orrery models them. Operate the orrery, asking questions to find out what the class sees as how the orrery models days, months and years.	Class observes, describes abnd infers how the orrery models days, months and years.
On the orrery, how many days are there in a year? How many months are there in a year?	Measure, to answer the questions.
How accurate is the orrery in terms of days, months and years?	Critique the orrery.
Can the other mental models explain days, months and years?	Answer question by reference to the wallchart of the mental models.

TIME & THE ORRERY

Looking at the orrery, we notice the following things about **movements** of the objects:-

Earth orbits .....
and spins on its axis (Y/N) .....

Moon orbits.....
and spins on its axis (Y/N) .....

Mercury orbits.....
and spins on its axis (Y/N) .....

The Sun spins on its axis (Y/N).....

Looking at the orrery:-

(a) what does your group think a **day** is? .....
.....
.....

(b) what does your group think a **month** is? .....
.....
.....

(c) what does your group think a **year** is? .....
.....
.....

According to the orrery:-

(a) how many **days** are there in a **year**?.....
(b) how many **days** are there in a **month**?.....
(c) how many **months** are there in a **year**?.....

How many days are there **really** in a year? .....
How many days are there **really** in a month? .....
How many months are there **really** in a year? .....

Critique the orrery on the red sheet, using Appendix 5, with respect to days, months and years.

Appendix 5: Data Re Revolutions and Rotations of Earth, Mercury and Moon

Object	Mercury	Earth	Moon
Rotation Time(days)	59	1	27.322
Revolution Time(days)	88	365.25	27.322

Critique the Orrery

Date	Ways in which the orrery is definitely accurate	Ways in which the orrery is definitely not accurate	Ways in which we aren't yet sure if the orrery is accurate or not accurate

Lesson 6

Lesson 6: Orrery 3 - Seasons on Earth

Learning Objectives

By the end of this lesson, the pupils will have been given the opportunity to:

a) Content

1. state their prior views on the causes of the seasons on Earth.
2. listen to other class members' views of the causes of seasons on Earth.

b) Skills

1. design an experiment to distinguish between the different views regarding the causes of seasons on Earth.
2. infer that the main cause of the seasons is the tilt of Earth's axis.
3. infer that a second, more minor, reason for Earth's seasons is the varying distance of Earth from the Sun.
4. critique the orrery.

Materials

Orrery with Moon and Mercury removed, Earth-globe, light meter, metre ruler, match, bluetak, Wallchart of models.

Teacher Moves	Pupil Moves
Class:- Q: What causes the seasons? Go into groups.	Each group share its ideas - attempts to get a consensus - reports back
Class:- Write up the different viewpoints. Q: How do we resolve the differences? Are there any that can be eliminated without expt? What expt can we carry out to decide between the others?	Class designs experiment to see which of the competing ideas is most likely. Experiment is conducted.
Class:-Q; What causes seasons?	
Place small "persons" on Hamilton & London. Q: Observe & describe what you notice about them.	Infer cause of seasons.
Demo orrery. Q: Is it accurate in this respect?	Observe and describe their shadow length in different seasons and the amount of daylight time in different seasons.
Q: Can the other models explain the seasons?	Critique the orrery with respect to the seasons.

SEASONS ON EARTH

Each person in your group is to individually answer the following multiple-choice question, and then record each answer in the table alongside the possible responses:-

When it is summer in New Zealand, it is because: Names

A. the tilt of Earth's axis means New Zealand gets more concentrated energy at that time.
B. the tilt of Earth's axis means New Zealand is nearer to the Sun at that time.
C. Earth's orbit means New Zealand is nearer to the Sun at that time.
D. The Sun radiates more heat and light energy at that time.

Now get together. Discuss the questions **until you all agree on the answer.**

The conference director will then reconvene the conference.
Are all groups agreed on what seasons are, and what causes them? (Yes/No) .....

If everyone, including the conference director, agrees, then that is the end of the subject. WE have our answer.

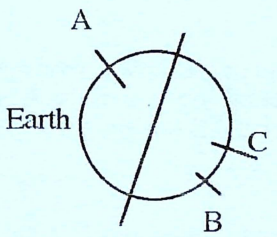
If there **is** disagreement, then it has to be resolved scientifically, by designing a practical test of the competing theories. The conference director will help in doing this.

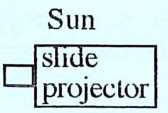
Critique the orrery, on the red sheet.

Experiment Re Cause of Seasons - Distance or Axis of Rotation?

Method A

is to use a model of Earth with a small figure placed on New Zealand, and Earth tilted at 23°.





A is a person in England
B is a person in New Zealand
C is a person on the equator

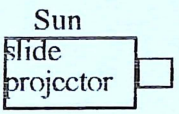
Observe Earth rotating (days and nights) at this position.

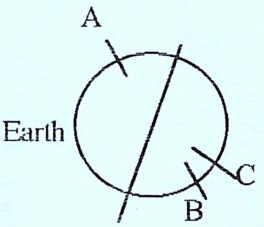
Which person will be having summer? The person in .....
Which person will be having winter? The person in .....

Which person casts the shortest shadow? The person in .....
Why is this? .....
.....
.....

Which person is in daylight for the longest time during one rotation (day) of Earth?. It is the person in .....

Six months later, Earth is round the other side of the Sun:





Observe Earth rotating (days and nights) at this position.
Which person will be having summer? The person in .....
Which person will be having winter? The person in .....

Which person casts the shortest shadow? The person in .....
Why is this? .....
.....
.....

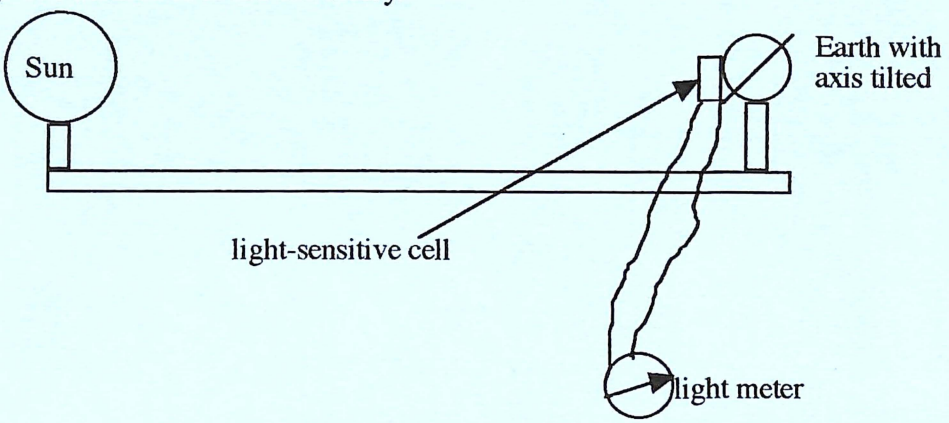
Which person is in daylight for the longest time during one rotation (day) of Earth?. It is the person in .....

So what causes the seasons? .....
.....
.....

To really sort it out, teacher may have to utilise the more formal approach of:

Method B

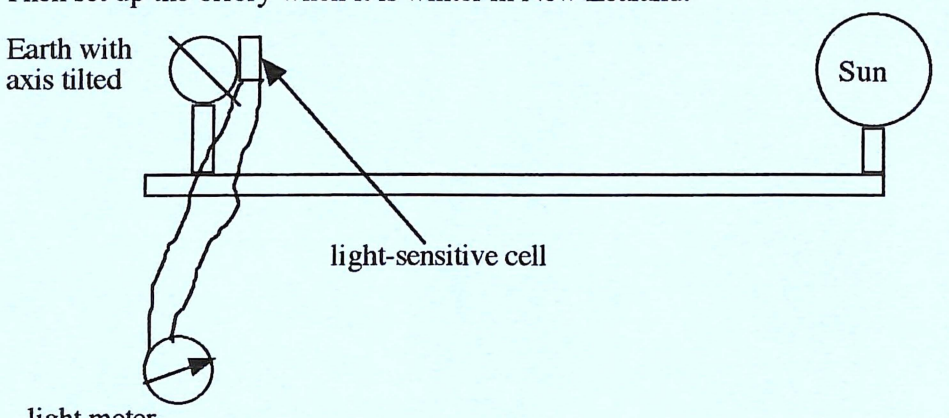
is to use a light meter at the appropriate distances from the Sun, and at the appropriate angles from the Sun, in a room as dark as possible, so the meters do not record the room lighting. One method is to use the orrery:



To check whether distance is the major factor, note the light meter reading when it is perpendicular to the Sun and Earth is at perihelion (its nearest point to the Sun). Then repeat when Earth is at aphelion (its furthest point from the Sun). Record the results.

To check whether the angle of tilt is the major factor, set up the orrery as above, where it is summer in New Zealand. Note the light meter reading.

Then set up the orrery when it is winter in New Zealand.



Note the light meter reading.
Complete a table of results such as:

reading perpendicular to Sun with Earth at perihelion =
reading perpendicular to Sun with Earth at aphelion =
reading in New Zealand in Summer =
reading in New Zealand in Summer =

Critique the Orrery

Date	Ways in which the orrery is definitely accurate	Ways in which the orrery is definitely not accurate	Ways in which we aren't yet sure if the orrery is accurate or not accurate

Lesson 7

Lesson 7: Orrery 6 - Eclipses of Sun &Moon

Learning Objectives

By the end of this lesson, the pupils will have been given the opportunity to:

a) Content

1. share their various ideas on the causes of eclipses.
2. describe how an eclipse of the Sun occurs.
3. describe how an eclipse of the Moon occurs.
4. state in which ways the orrery is misleading with respect to eclipses.

b) Skills

1. observe and describe an eclipse of the Sun on the the orrery.
2. observe and describe an eclipse of the Moon on the the orrery.
3. critique the orrery with respect to eclipses of the Sun & Moon.

Materials

Orrery, OHPT & diagram of eclipse of Sun, OHPT & diagram of eclipse of Moon, photos of eclipses of Sun & Moon,E-M-string model, Wallchart of the 5 mnodels.

Teacher Moves	Pupil Moves
Class:- Q: What causes eclipses of the Sun & the Moon?	Groups: reach consensus on ideas, to report back.
Class:- have we all agreed? Demonstration on orrery of eclipse of Sun & of Moon.	Describe in own words the conditions for eclipses of Sun & Moon.
OHPTs to show conditions for eclipses of Sun & Moon. Q: How good is the orrery for showing eclipses?	Critique orrery in terms of eclipses of Sun & Moon.
Can any of the other models explain eclipses?	Answer the Q re the wallchart of the 5 models.

ECLIPSES OF THE SUN & MOON

What do **you** think is an eclipse of the Sun?

What do **you** think **causes** an eclipse of the Sun?

Get together with your usual group. Discuss these questions, and complete the top half of the next page - **after you all agree.**

The conference now reconvenes and hears and sees what each group thinks. Does everyone, including the conference director, agreed on what **is** an eclipse of the Sun, and what **causes** them? (Yes/No) .....

Conference observes the orrery working, with particular emphasis on the Moon orbiting Earth. As the Moon comes between the Sun and Earth, observe and describe what happens on the surface of Earth.

What would the people in the shadow zone experience? .....
.....
.....
.....
.....

Draw a diagram to show the conditions for an eclipse of the Sun.

What do **you** think is an eclipse of the Moon?

What do **you** think **causes** an eclipse of the Moon?

Get together with your usual group. Discuss the questions, and complete the bottom half of the next page - **after you all agree.**

The conference now reconvenes and hears and sees what each group thinks. Does everyone, including the conference director, agreed on what **is** an eclipse of the Moon, and what **causes** them? (Yes/No) .....

Conference observes the orrery working, with particular emphasis on the Moon orbiting Earth. As the Moon passes on the far side of Earth from the Sun, observe and describe what happens to the Moon.

What would the people on that side of Earth see? .....
.....
.....
.....
.....

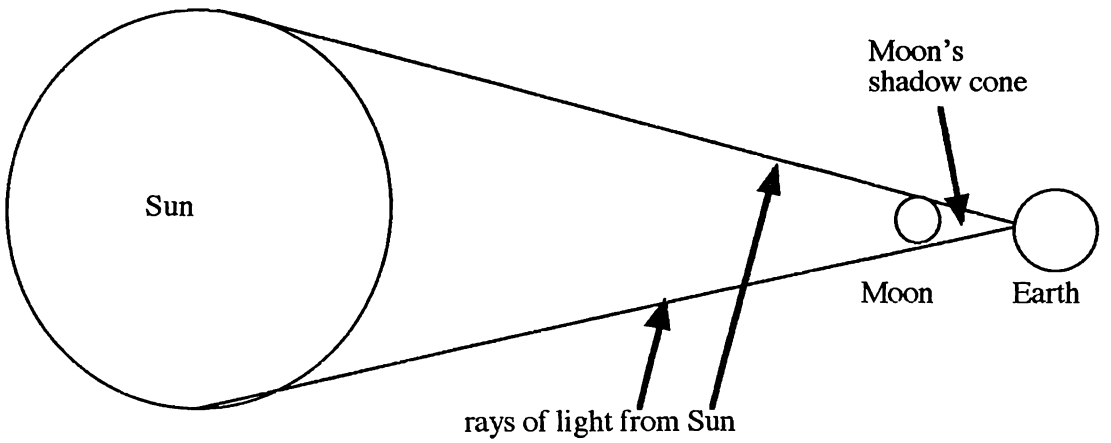
Draw a diagram to show the conditions for an eclipse of the Moon.

Critique the orrery, on the red sheet.

ECLIPSES OF THE SUN	
Our **group** thinks eclipses of the Sun **are:**	Our **group** thinks eclipses of the Sun are **caused by:**
ECLIPSES OF THE MOON	
Our **group** thinks eclipses of the Moon **are:**	Our **group** thinks eclipses of the Moon are **caused by:**

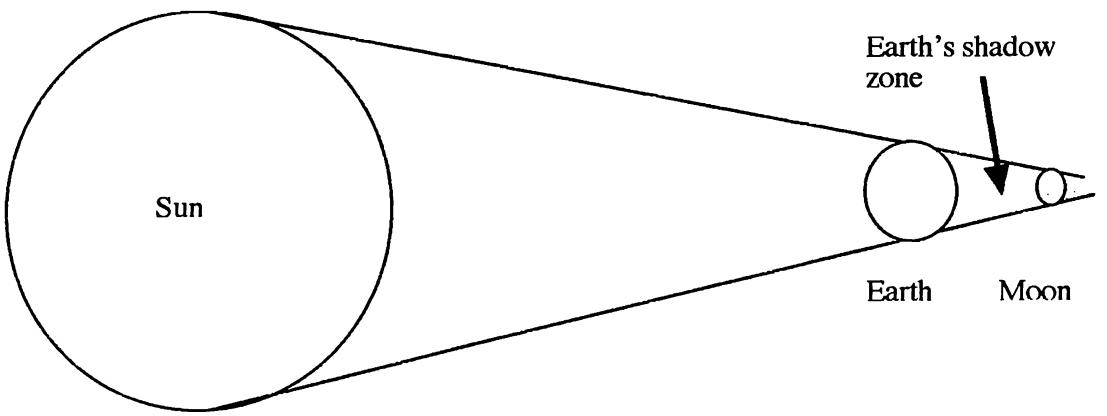
Eclipse of the Sun
These occur **only** when

a. Sun Earth and Moon are **exactly** lined up as below; and
b. the Moon's shadow is long enough to reach Earth.



Eclipse of the Moon
These occur **only** when

a. Sun Earth and Moon are **exactly** lined up as below; and
b. Earth's's shadow is long enough to reach the Moon.



Critique the Orrery

Date	Ways in which the orrery is definitely accurate	Ways in which the orrery is definitely not accurate	Ways in which we aren't yet sure if the orrery is accurate or not accurate

Lesson 8

Lesson 8: Orrery 5: Phases of the Moon

Learning Objectives

By the end of this lesson, the pupils will have been given the opportunity to:

a) Content

1. describe the pattern of the phases of the Moon.
2. describe the pattern of Moon sets each succeeeding day.
3. describe how the Moon's phases are a sort of optical illusion.

b) Skills

1. infer the pattern of the phases of the Moon.
2. infer that the Moon sets later each day.
3. calculate that the Moon sets, on average, 50 minutes later each day.
4. infer that the Moon must be in the day-time sky as often as it is in the night-time sky.
5. critique the orrery with respect to the phases of the Moon.

Materials

Orrery, Moon phases wallchart, Wallchart of the pupils' Sun-Earth-Moon mental models, eight index cards with circles drawn on them.

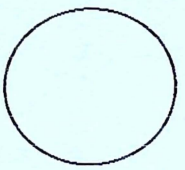
Teacher Moves	Pupil Moves
What does the Moon phases wallchart tell us about the appearance of the Moon? Introduce terms: full, new, crescent, gibbous. How often is the Moon in the day-time sky? How often in the night-time sky? Is there a pattern to when the Moon serts? What is it? How much later does it set each day, on average? Does the orrery show the same pattern as our data of the Moon's phases? How accurate is the orrery for the phases of the Moon? What are the phases of the Moon? What causes them? Can any of the Sun-Earth-Moon models explain the phases of the Moon?	Discussd moon phase data in groups. Groups answer the questions. Observe and discuss the orrery's representation of phases of the Moon. Critique the orrery with respect to phases of the Moon. Answer the questions.

PHASES OF THE MOON

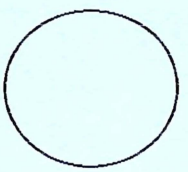
Look at the wallchart of the Phases of the Moon.

Discuss **in your group** to complete the following:
The changing shape of the Moon can be described in the following way .....
.....
.....
.....
.....
.....

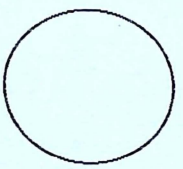
Sketch (a) a full moon:



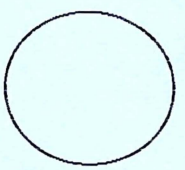
(b) a new moon:



(c) a crescent moon



(d) a gibbous moon



Look at the times that the Moon sets each day:
What pattern do you notice? .....
.....
.....
.....

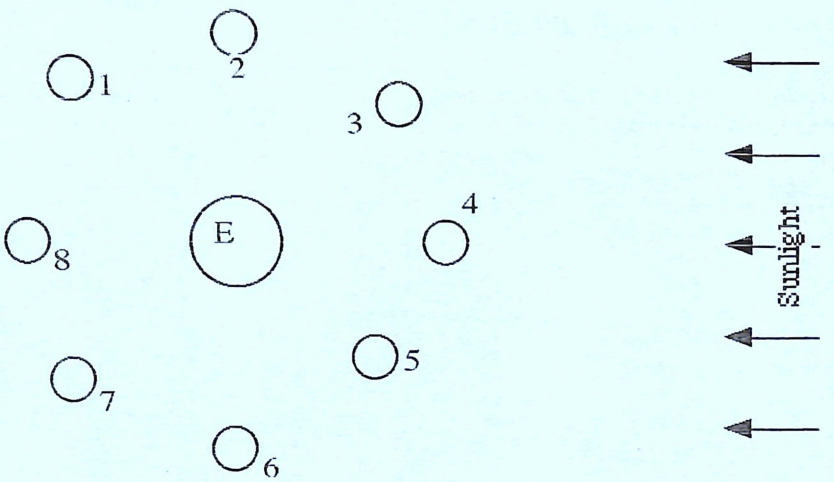
How often is the Moon visible at night? .....
How often is the Moon visible in the day? .....
On average, how much later does the Moon set each day? ..... mins

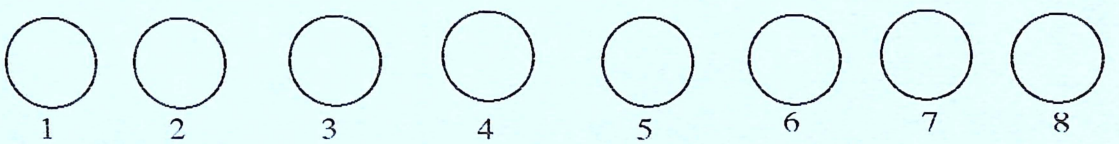
Observe the conference director use the orrery in a darkened room, with the Moon orbiting Earth:

The Moon is placed in position 1 relative to Earth, as shown in the diagram below. A member from one group observes the Moon as it looks from Earth's north pole on the orrery, and sketches the Moon's shape - in the **larger** circle (among the horizontal circles) next to position 1. The rest of the conference copies that sketch in their circle alongside position 1 in the diagram below.

The Moon is moved to position 2, and a member of another group repeats the observation and sketching.

This is repeated in this order until the Moon in all the positions shown has been observed and sketched.





Does the pattern that is built up show the phases of the Moon? (Yes/No/Mostly/Partly) .....

At which position(s) does the pattern break down? It breaks down at position number .....

What happens instead at this position?

At position number ..... we get .....
At position number ..... we get .....

The reasons for these breakdowns in the pattern will be explained later by the conference director.

The phases of the Moon are caused by .....
.....
.....
.....

The phases of the Moon are:

A. real changes in the shape of the Moon
B. a sort of optical illusion.

Critique the orrery in terms of the phases of the Moon.

Critique the Orrery

Date	Ways in which the orrery is definitely accurate	Ways in which the orrery is definitely not accurate	Ways in which we aren't yet sure if the orrery is accurate or not accurate

Lessons 9 and 10

Activity	Group Activities: Lessons 9 & 10 Group Name										
	Earth	Jupiter	Mars	Mercury	Moon	Neptune	Pluto	Saturn	Sun	Uranus	Venus
Orrery: Day, Year & Seasons on Mercury											
Orrery: Faces of Moon & Mercury											
Earth with Zero or Two Moons											
Moon & Tides 1: High Tides & Moon Set Times											
Moon & Tides 2: High Tide Times & Phases of Moon											
Days & Years on Other Planets											
Seasons on Other Planets											

Lessons 9a and 10a

Lessons 9a & 10a: Orrery - Day, Year &Seasons on Mercury
By the end of this lesson, the pupils will have been given the opportunity to:
a) Content
1. state their ideas of what life would be like on Mercury if one day is the same as one year.
2. understand that the our knowledge about Mercury has changed since this orrery was built about 30 years ago.
3. state their ideas of what life would be like on Mercury with our updated ideas about days & years there.
b) Skills
1. observe & describethe rotation & orbit of Mercury on the orrery.
2. infer from the orrery that Mercury's year is the same as its day.
3. infer from the up-to-date data in Appendix 13 that 1 Mercury day is about two-thirds of a Mercury year.
4. observe that Mercury's angle of tilt is zero.
5. infer there are no seasons on Mercury
6. critique the orrery with respect to days & years on Mercury.
Materials
Orrery with Moon removed, Appendix 11.

Teacher Moves	Pupil Moves
What do you notice about the axis of rotation of Mercury on the orrery?	Observe the orrery. Note that its angle of axis of rotation is zero.
What does a zero angle of axis of rotation tell us (about the seasons on Mercury)?	Infer the lack of seasons on Mercury. Decribe what that means to a "Mercurian" living at 38^{o} South (as Hamilton is).
What do you notice about Mercury's times of rotation & orbit on the orrery? What does that tell us? But is it right? What else do we need to know?	Observe that 1 day = 1 year on Mercury. Discuss the implications for a Mercurian living there.
Tell class the orrery is wrong because that's what was "known" when this orrery was built. We've learned since.	Look at Appendix 11. Infer the real relationship between Mercury days & years. Critique the orrery with respect to Mercury.

INVESTIGATION 1:DAY, YEAR & SEASONS ON MERCURY

This activity will be completed by either one or two groups. Each participating group will prepare a 10-minute report to the rest of the conference delegates.

Observe the orrery. Note Mercury.

How many degrees is its axis of rotation tilted from the vertical? .....
How long does does it take to orbit once around the Sun compared to how long it takes to spin once on its axis? .....
.....
.....

Now get together with your group to answer the following questions. **All group members must agree before you write anything down.**
With the angle measured above, what will the seasons be like for a 'Mercurian' living in Mercury's southern hemisphere? .....
.....
.....
.....

With the spin and orbit times noted above, what does that mean in terms of a Mercurian's day and a Mercurian's year? .....
.....
.....
.....

Look at **Appendix 6**. Is the information above totally correct? (Yes/No) .....
Where it is not totally correct? What is the accurate information? .....
.....
.....
.....

What would the **real** seasons be like for a 'Mercurian' living in Mercury's southern hemisphere? .....
.....
.....
.....

With the **accurate** spin and orbit times noted in **Appendix 6**, what does that mean in terms of a Mercurian's day and a Mercurian's year? .....
.....
.....
.....

Critique the orrery with respect to Mercury.

Appendix 6: Mercury Data

Object	Length of day (days)	Length of year (days)	Seasons
Mercury	59	88	
Earth	1.0	365	Summer, Autumn Winter, Spring

Critique the Orrery

Date	Ways in which the orrery is definitely accurate	Ways in which the orrery is definitely not accurate	Ways in which we aren't yet sure if the orrery is accurate or not accurate

Lessons 9b and 10b

Lesson 9b &10b: Investigation 2: Orrery - Moon & Mercury Faces

Learning Objectives

By the end of this lesson, the pupils will have been given the opportunity to:

a) Content

1. explain that we only see one side of the Moon because its rotation & orbital times are the same.

2. know that the orbital & rotation times of Mercury are not the same.

b) Skills

1. observe from the orrery that we only see one face of the Moon.

2. observe from the orrery that we only see one face of Mercury.

3. measure the rotation and revolution times of the Moon.

4. model how it can occur that we see only one face of the Moon.

5. critique the orrery with respect to Moon's & Mercury's rotations & orbits.

Materials

Orrery, with marker on side of Moon facing Earth, photos of Moon at different times, Appendix 5 & 6.

Teacher Moves	Pupil Moves
Q: Over a full year, how much of the Moon do we see? Use photos to establish we see only half of it. Use orrery to show that from Earth we only see one side of Moon, and that only one side of Mercury ever faces Sun.	Observe Orrery with respect to orbit of Moon around Earth, and Mercury around Sun.
Is the model actually true for Moon & Mercury? What do we need to know?	**Analyse Appendix 5 & 6** for Moon & Mercury.
Class: demo orbit & rotation around chair for Moon-compare to Moon data. What causes same face to be seen? Does Mercury always point same face to Sun?	Critique the orrery.

INVESTIGATION 2: MOON & MERCURY FACES

This activity will be completed by either one or two groups. Each participating group will prepare a 10-minute report to the rest of the conference delegates.

Your group observes the orrery working, with particular emphasis on the Moon, which has a small black dot on the side facing Earth at the **start** of the operation.

Does the Moon orbit around Earth? (Yes/No) .....
Does the same side of the Moon always face Earth? (Yes/No) .....
Is this true in real life? (Yes/No) .....
(The conference director has some photos of the Moon at various times of the year to help you answer this question).

Does the Moon spin on its axis while it orbits around Earth? (Yes/No) .....
If everone, including the conference director, agrees, then that is the end of the matter.

If everyone can't agree, then the situation will be modelled using a person (as the Moon) orbiting around a chair (as Earth).

Looking at the person (Moon) orbiting the chair (Earth), what is the **only** relationship between the time for one orbit and the time for one spin so that the same face of the Moon always points towards Earth? .....
.....
.....
.....

Is the orrery correct in this respect, for the Moon? (Yes/No/Don't know) .....
What do we need to know to find out? .....
.....
.....

We can find it in Appendix 5.
Is the orrery correct in this respect, for the Moon? (Yes/No/Don't know) .....

Conference now observes orrery working, with particular emphasis on Mercury.
Does Mercury orbit around the Sun? (Yes/No) .....
On the orrery, does the same side of Mercury always face the Sun? (Yes/No) .....
Is this true in real life? (Yes/No/Don't know) .....
What do we need to know to find out? .....
.....
.....

We can find it in Appendix 6.
Is the orrery correct in this respect, for Mercury? (Yes/No/Don't know) .....

In your group, critique the orrery with respect to the faces of the Moon and Mercury.

Appendix 5: Data Re Revolutions and Rotations of Earth, Mercury and Moon

Object	Mercury	Earth	Moon
Rotation Time(days)	59	1	27.322
Revolution Time(days)	88	365.25	27.322

Appendix 6: Mercury Data

Object	Length of day (days)	Length of year (days)	Seasons
Mercury	59	88	
Earth	1.0	365	Summer, Autumn Winter, Spring

Critique the Orrery

Date	Ways in which the orrery is definitely accurate	Ways in which the orrery is definitely not accurate	Ways in which we aren't yet sure if the orrery is accurate or not accurate

Lessons 9c and 10c

Lessons 9c & 10c: Investigation 3: Earth with Zero or Two Moons
By the end of this lesson, the pupils will have been given the opportunity to:
a) Content
1. describe what life would be like on Earth if we had no Moon.
2. describe what life would be like on Earth if we had two Moons.
b) Skills
1. interpret the data about Earth's Moon, and apply it to a new problem.
Materials
Activity sheet, Carter Observatory Handbook.

Teacher Moves	Pupil Moves
Group:- Qs: What would it be like on Earth if we had no Moon? What would it be like on Earth if we had two Moons?	Groups share prior ideas in response to the Qs. Groups work through activity sheet "Earth With Two Moons or No Moons". Group prepares a report for the rest of the conference.

INVESTIGATION 3: EARTH WITH EITHER ZERO OR TWO MOONS

This activity will be completed by either one or two groups. Each participating group will prepare a 10-minute report to the rest of the conference delegates.

Think about all the ways that the Moon affects people and things on Earth - as a group - don't write things down unless **everybody** in the group agrees.

Then answer the following questions.
Use the Carter Observatory Handbook.

Do any planets have **no** moons orbiting them? (Yes/No) .....

The planets with **no** moons are .....
.....
.....
.....

Do any planets have **two** moons orbiting them? (Yes/No) .....

The planets with **two** moons are .....
.....
.....
.....

How would it affect people if Earth had **no** Moon? .....
.....
.....
.....
.....
.....
.....

How would it affect people if Earth had **two** moons? .....
.....
.....
.....
.....
.....
.....

Now prepare your report, using the above questions and answers.

If you finish in plenty of time, you may choose another activity.

Lessons 9d and 10d

Lessons 9d & 10d: Investigation 4: Moon and Tides: Tide Heights & Moon Set Times Data

Learning Objectives

By the end of this lesson, the pupils will have been given the opportunity to:

a) Content

1. state their views on the possible causes of tides.
2. describe how the Moon causes tides - twice a day.
3. list other possible causes of tides.

b) Skills

1. infer from their Moon and tide observations that the Moon is probably a cause of tides.
2. infer from their Moon and tide observations that the Moon cannot be the only cause of the tides.

Materials

Moon and tide data, Appendix 7a, Appendix 7b.

Teacher Moves	Pupil Moves
Group:-Q: Does the Moon cause tides? How? Is it the only cause of the tides?	Group share prior ideas in response to Qs. Work through activity sheet "Moon & Tides". Prepare a report for the rest of the conference.

INVESTIGATION 4: TIDE HEIGHTS & MOON SET

This activity will be completed by either one or two groups. Each participating group will prepare a 10-minute report to the rest of the conference delegates.

Analyse Appendix 7a and Appendix 7b to answer the following questions - as a group - **don't write things down unless everybody in the group agrees.**

Does the Moon cause tides? (Yes/No) .....
What evidence do you have for your answer? .....
.....
.....
.....
.....

How does your group think the Moon can cause tides? .....
.....
.....
.....
.....

Can the Moon be the **only** cause of tides? .....
.....
.....
.....
.....

If you answered "no" to the previous question, what else could cause tides? .....
.....
.....
.....
.....

Now prepare your report, using Appendix 7a and Appendix 7b and the above questions and answers.

If you finish in plenty of time, you may choose another activity.

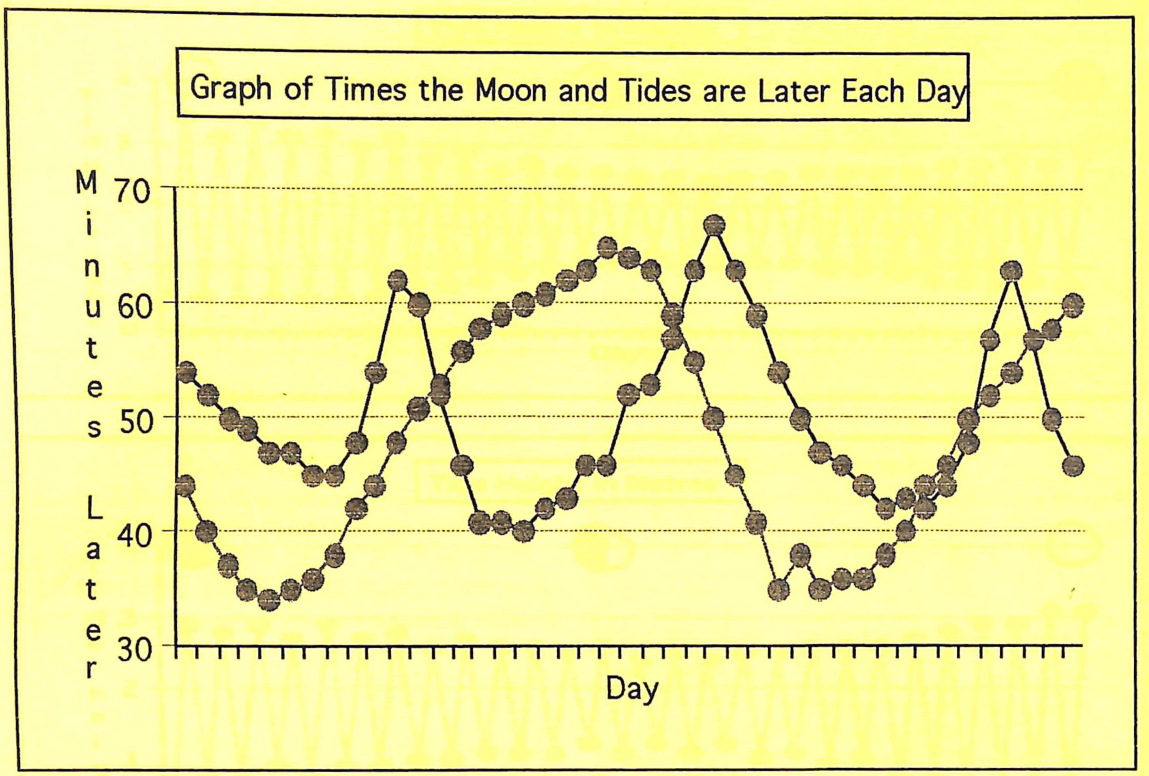
Appendix 7A: Data for Moon Sets and High Tide Times at Auckland

Date	Moon Set Times	Moon Sets Later (mins)	Tide Sets Later (mins)	High Tide Time	Moon Phase
11/8	6.54	44	54	7.19	Full
12/8	7.34	40	52	8.11	
13/8	8.11	37	50	9.01	
14/8	8.46	35	50	9.51	
15/8	9.2	34	47	10.37	
16/8	9.55	35	47	11.24	
17/9	10.31	36	45	12.09	
18/8	11.09	38	45	12.54	
19/8	11.51	42	48	13.42	
20/8	12.35	44	54	14.36	
21/8	13.23	48	62	15.38	
22/8	14.14	51	60	16.38	
23/8	15.07	53	53	17.31	
24/8	16.03	56	46	18.16	
25/8	17.01	58	41	18.57	
26/8	1800	59	41	19.38	New
27/8	19.01	60	40	20.18	
28/8	20.01	61	43	21.01	
29/8	21.03	62	43	21.43	
30/8	22.06	63	46	22.28	
31/8	23.11	65	46	23.14	
2/9	0.15	64	52	0.03	
3/9	1.21	63	53	0.56	
4/9	2.17	59	57	1.53	
5/9	3.12	55	63	2.56	
6/9	4.02	50	67	4.03	
7/9	4.47	45	63	5.09	
8/9	5.28	41	59	6.08	
9/9	6.03	35	54	7.02	Full
10/9	6.41	38	50	7.52	
11/9	7.16	35	47	8.39	
12/9	7.52	36	46	9.25	
13/9	8.29	36	44	10.09	
14/9	9.06	38	42	10.52	
15/9	9.46	40	43	11.35	
16/9	10.3	44	42	12.17	
17/9	11.16	46	44	13.01	
18/9	12.06	50	48	13.49	
19/9	12.58	52	57	14.46	
20/9	13.52	54	63	15.49	
21/9	14.49	57	57	16.46	

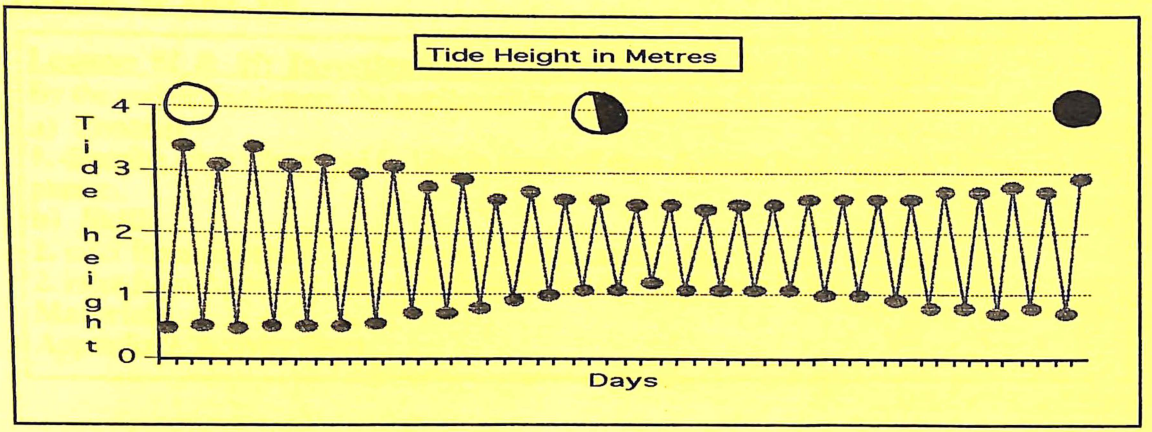
On average, Moon sets 50 minutes later each day.

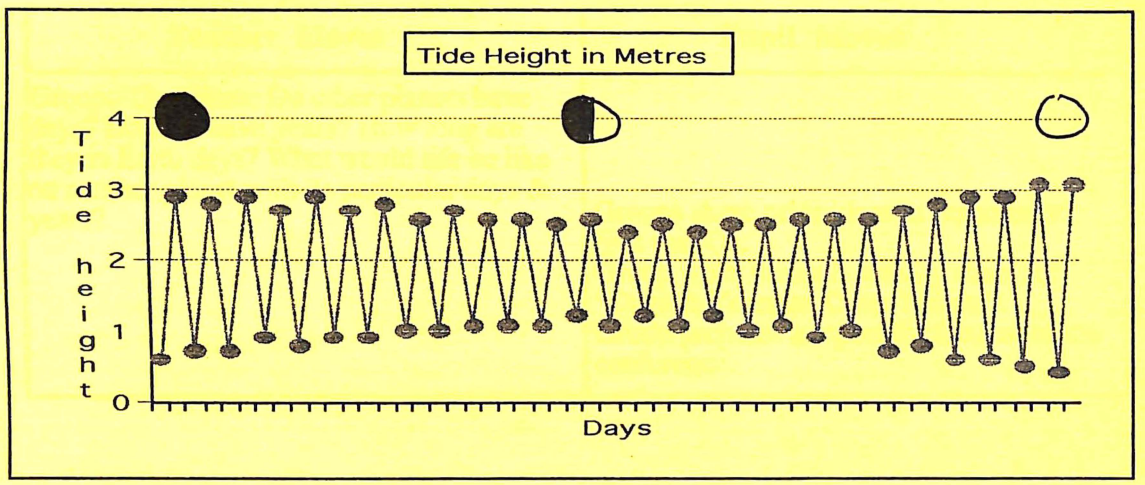
On average, high tide is 50 minutes later each day.

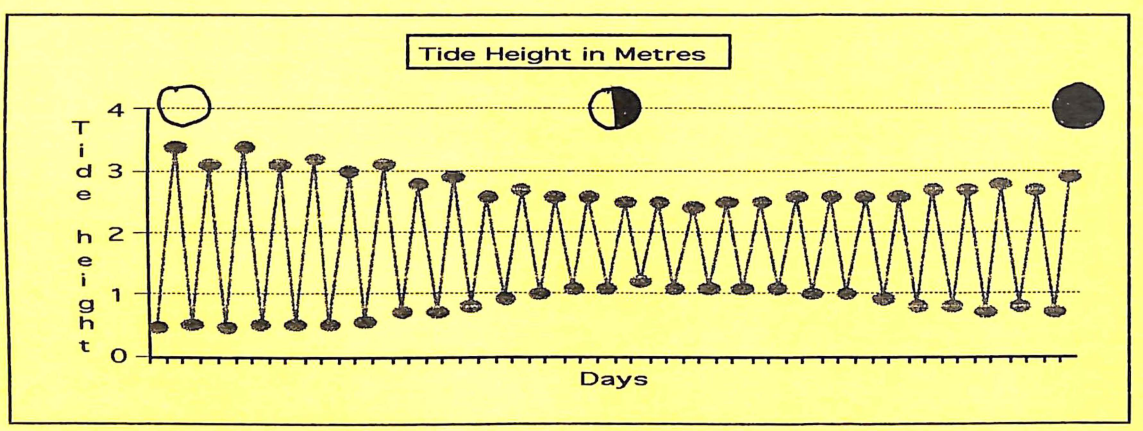
Appendix 7B: Graph Showing the Times the Tides and Moon are Later Each Day



Appendix 8: Tide Heights and Phases







Lessons 9f and 10f

Lessons 8f & 9f: Investigation 6: Days & Years on Other Planets
By the end of this lesson, the pupils will have been given the opportunity to:
a) Content
1. describe what life would be like in terms of days & years for a "person" living on two planets.
b) Skills
1. infer from Appendix 9 the lengths of days on the planets in the solar system.
2. infer from Appendix 9 the lengths of years on the planets in the solar system.
Materials
Appendix 9, Activity Sheet

Teacher Moves	Pupil Moves
Group:- Questions: Do other planets have days? Do they have years? How long are they in Earth days? What would life be like on another planet with its particular days & years?	Groups share prior ideas in response to first two Qs. Group woks through activity sheet for "Days & Years on Other Planets". Group prepares a report for the rest of the conference.

INVESTIGATION 6: DAYS & YEARS ON OTHER PLANETS

This activity will be completed by either one or two groups. Each participating group will prepare a 10-minute report to the rest of the conference delegates.

Analyse Appendix 9 to answer the following questions - as a group - don't write things down unless **everybody** in the group agrees.

Do other planets have the same length of **days** as on Earth? (Yes/No) .....
What evidence do you have for your answer? .....
.....
.....
.....
.....
.....

Do other planets have the same length of **years** as on Earth? (Yes/No) .....
What evidence do you have for your answer? .....
.....
.....
.....
.....
.....

Our group has chosen the following planet .....
If some people lived on this planet, their days and years would be .....
.....
.....
.....
.....
.....
.....

Now prepare your report, using Appendix 9 and the above questions and answers.

If you finish in plenty of time, you may choose another planet or another activity.

Our group has chosen the following planet .....
If some people lived on this planet, their days and years would be .....
.....
.....
.....
.....
.....
.....

Appendix 9: Data From Carter Re Rotation Times and Revolution Times of Planets

Object	Rotation Times (Earth days)	Revolution Times (Earth years)
Mercury	59	0.24
Venus	240**R**	0.62
Earth	1.0	1.0
Mars	1.0	1.9
Jupiter	0.41	12
Saturn	0.43	29
Uranus	0.65**R**	84
Neptune	0.77	160
Pluto	6.4	250

Note: the letter **R** indicates that the planet spins (rotates) on its axis in the opposite direction to its orbit (or revolution).

Lessons 9g and 10g

Lessons 9g & 10g: Investigation 7: Seasons on Other Planets

By the end of this lesson, the pupils will have been given the opportunity to:

a) Content

1. describe what life would be like during the course of a year for a "person" living on another planet.

2. describe the seasons on some of the other planets.

b) Skills

1. infer from Appendix 10 which of the other planets have seasons.

Materials

Appendix 10, Activity sheet.

Teacher Moves	Pupil Moves
Group:- Questions: Are there seasons on other planets? What would they be like? How would a person living at 38° South on a selected planet live over that planet's year?	Groups share prior ideas in response to first two Qs. Groups work through activity sheet "Seasons on Other Planets". Group prepares a report for the rest of the conference.

INVESTIGATION 7: SEASONS ON OTHER PLANETS

This activity will be completed by either one or two groups. Each participating group will prepare a 10-minute report to the rest of the conference delegates.

Analyse Appendix 10 to answer the following questions - as a group - don't write things down unless **everybody** in the group agrees.

Do other planets have seasons? (Yes/No) .....
What evidence do you have for your answer .....
.....
.....
.....

Do the planets all have the same seasons? (Yes/No) .....
.....
.....
.....

Do other planets have the same length of **years** as on Earth? (Yes/No) .....
What evidence do you have for your answer? .....
.....
.....
.....

Our group has chosen the following planet .....
If some people lived in the southern hemisphere on this planet, their seasons and years would be .....
.....
.....
.....
.....
.....

Now prepare your report, using Appendix 10 and the above questions and answers.

If you finish in plenty of time, you may choose another planet and/or another activity.

Our group has chosen the following planet .....
If some people lived in the southern hemisphere on this planet, their seasons and years would be .....
.....
.....
.....
.....
.....

Appendix 10: Data From Carter Re Tilt of Axis and Revolution Times of Planets

Object	Tilt of Axis (°)	Orbital Time
Mercury	0	0.24
Venus	177	0.62
Earth	23.5	1.0
Mars	24	1.9
Jupiter	3	12
Saturn	27	29
Uranus	98R	84
Neptune	30	160
Pluto	123R	250

Note: the letter **R** indicates that the planet's spin (rotation) is in the opposite direction to its orbit (rotation).

Lesson 11

Lesson 11: Moon & Tides
By the end of this lesson, the pupils will have been given the opportunity to:
a) Content
1. know how the Moon causes tides on Earth.
2. know that the Moon is mostly but not entirely responsible for the tides.
b) Skills
1. infer that there must be an extra cause of tides, in addition to that of the Moon.
Materials
Appendix 7, Appendix 12, Appendix 14

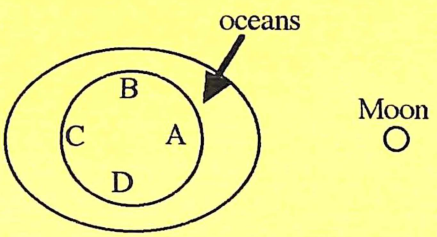
Teacher Moves	Pupil Moves
Class:- Qs: Does Moon cause the tides? How do you know? Class: teacher explains how Moon causes the tides, using Appendix 13. Introduces Appendix 7 & Appendix 13 to show that it can't be the full cause of the tides - there must be something else.	Class discusses Appendix 7 to realise that Moon seems to cause tides.

Appendix 11: The Moon and Tides

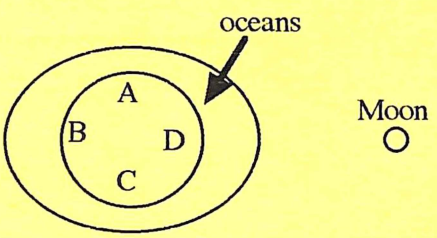
How can the Moon **cause** tides?
The tides are caused by the Moon's gravitational pull on the oceans. They can be explained by:

Appendix 11: The Moon and Tides

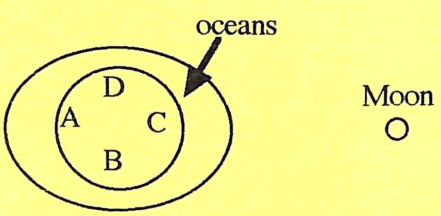
ATime Zero



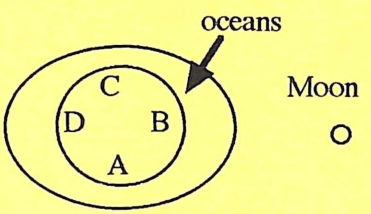
After 6 hours, 12.5 minutes



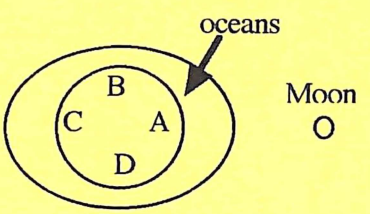
After 12 hours, 25 minutes



After 18 hours, 37.5 minutes



After 24 hours, 50 minutes



MOON & TIDES

The conference comes together for the last two sessions.

The group(s) who studied "Tide Heights and Moon Sets" reports back.
Does the Moon cause tides? (Yes/No) .....

How do we know? .....
.....
.....
.....
.....
.....
.....

Is the Moon the **only** cause of tides? (Yes/No) .....

How do we know? .....
.....
.....
.....
.....
.....
.....

Conference director will use a Wallchart or an OHPT to explain how the Moon is a cause of tides.

Lesson 11

Lesson 11: Sun, Moon & Tides
By the end of this lesson, the pupils will have been given the opportunity to:
a) Content
1. know how the Sun & Moon causes Spring & Neap tides on Earth.
2. know that the there are still other factors responsible for the tides.
b) Skills
1. infer that Sun also causes tides.
Materials
OHPT and/or Wallchart of "Sun and Moon Cause Tides" + 11 handout copies.

Teacher Moves	Pupil Moves
Using Appendix 8, at what phases of the Moon do we get the Spring tides? When do we get Neap tides? How do we get these phases of the Moon?	
	Class discusses the data to realise that the position of the Sun & Moon have an effect on tides.
Class: teacher explains how Sun & Moon cause the Spring & Neap tides, using OHPT and/or Wallchart. Could anything else affect the tides?	
	Class discusses the Question & lists other factors that might have an effect on the tides.

Appendix 12: The Two Tides Each Day Are Caused By Both the Sun and the Moon

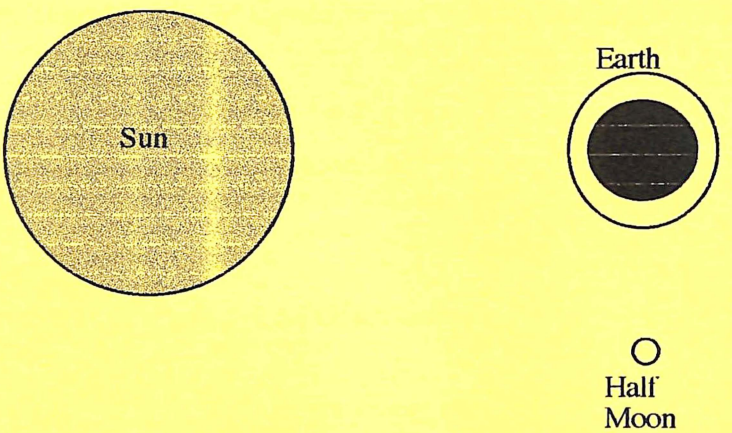
The clue is in the times of very high high tides (**spring tides**) and the times of particularly low high tides (**neap tides**). Remember that our tides graph showed that all high tides are not the same value.

Astronomers noticed that **spring tides** occur when we get either New Moons or Full Moons. That is, **when the Earth, Sun and Moon are lined up**:

[Or New Moon when Moon is between Sun and Earth]

That is, the gravitational forces of the Sun and the Moon add up.

Astronomers also noticed that **neap tides** occur when we get half-Moons. That is, when **Earth, Sun and Moon are at right angles** to each other.



That is, the gravitational forces of the Sun and Moon pull in directions at right angles to each other.

MOON, SUN & TIDES

The conference comes together for the last four sessions.

The groups who studied "Tide Heights and Moon Phases" report back.

Does the Moon cause tides? (Yes/No) .....
How do we know? .....
.....
.....
.....
.....
.....

Is the Moon the **only** cause of tides? (Yes/No) .....
How do we know? .....
.....
.....
.....
.....
.....

At what phases of the Moon do we get the highest tides? .....
.....
.....

These tides are called ..... tides.
How are the Sun, Earth and Moon lined up when we get those phases? .....
.....
.....
.....

At what phases of the Moon do we get the lowest high tides? .....
.....
.....

These tides are called ..... tides.
How are the Sun, Earth and Moon lined up when we get those phases? .....
.....
.....
.....

Conference director will use an OHPT and/or a Wallchart to explain how the Sun **and** the Moon are causes of tides.

What other things might affect the tides, apart from the Sun and the Moon? .....
.....
.....
.....
.....
.....
.....

Lesson 12

Lesson 12: Conference Ends
By the end of this lesson, the pupils will have been given the opportunity to:
a) Content
1. learn about days, years and seasons on other planets.
2. learn how the Moon affects life on Earth
b) Skills
1. listen to the investigating groups as they report back.
2. critique the S-E-M model.

Teacher Moves	Pupil Moves
Introduce each group in turn.	Each group has 10 to 15 minutes to report back its investigations.
Initiate discussion re which of the 5 S-E-M models makes most sense.	Take part in the discussion, giving their reasons for their support of a particular model.
Close the conference.	

Post-test: Eliciting Learner Post Views Immediately After the Intervention Lessons

By the end of this lesson, the pupils will have been given the opportunity to:

Content

1. demonstate their post knowledge about the topics to be covered in this teaching unit.
2. demonstate their post concepts about the topics to be covered in this teaching unit.
3. demonstrate their post knowledge about the use of scientific models.

Materials

Class set of the "Solar System Survey".
Mark sheet.

Teacher Moves	Pupil Moves
Reassure pupils that this is a **survey**, again, **not** a test. That it will be used to find out what they do, and do not, know and understand. It will be used to try and improve the astronomy unit they have just studied. Administer the survey.	Complete the post-test to the best of their ability.

APPENDIX B: THE TEACHER INTERVIEW SCHEDULE

Questions and Sequence Prior to the Investigation

Thank you for agreeing to help me with my investigation into teaching astronomy at intermediate school level. I am trying to find out what classroom teachers feel about teaching this part of *Science in the New Zealand Curriculum.* So I would like to hear what **your** views are about teaching it.

With your permission, I would like to use the tape recorder to more easily record what you actually say. If you find you want to change something later, that is fine by me - I will make available to you both the recording and the transcript for that purpose. Is it OK to use the tape recorder?

I will ask you some questions that could identify you, but I'd like to give you my assurance that such information is private to only you and me. Any written material that arises from this investigation will refer to you only by a code. Neither your name nor the name of your school will be released into the public domain without your permission.

Let's start with some background questions:-

1. What is your name?
   How long have you been teaching, ...?
   How much of that has been in an intermediate school?
   What is the highest academic qualification you have attained?
   [e.g. Dip.Tchg; B.Ed; M.Ed.]
   What level did you go to in science?
   [e.g. School Cert; 6th Form Cert; Bursary, at Poly; at Uni.]
   Have you ever studied any astronomy?
   If so, in what course(s)?

   We'll move on to the teaching part now, ...
2. Have you ever taught astronomy?
   When was that?
   What age level was it to?
   How did you feel, ..., about teaching astronomy?
   What do you think were the **good** things about it?

3. ..... what do you see as being the main **challenges** that you face when you teach astronomy?
   Prompts:
   (a) how do you think the pupils find the language level?
   (b) what about doing observations?
   (c) what about the huge scale of things, with the large numbers?
   (d) what about <u>doing</u> astronomy - the Investigative Skills?
   (e) what about the content knowledge needed by the teacher?
   (f) what about the resources for teaching astronomy?
   (g) what about the time needed?

4. Do you think teaching astronomy can help pupils towards attaining the Achievement Aims of *The Nature of Science and Its Relationship to Technology*?
   Prompts:
   (a) do you think your pupils can "critically evaluate astronomy ideas"?
   (b) do you think your pupils can "critically evaluate science processes"?
   (c) do you think your pupils can gain an "awareness that astronomy ideas change

over time"?

(d) do you think your pupils can get an insight into "how scientists use models"?

(e) do you think your pupils can "apply some technology to astronomy"?

(f) do you think your pupils can gain an "understanding of how technology has changed astronomy"?

(g) do you think your pupils can develop an "understanding some of the societal implications of astronomy"?

Thanks a lot for your help. That's been a big help to me and I hope it will be to other teachers.

APPENDIX C: TRIAL INTERVENTION TEACHER'S INTERVIEW SCHEDULE

1 How do you feel today, T, about teaching astronomy in this way?

2. What do you think were the good things about it?

3. T, what were the main **challenges** that you faced when you taught today's lesson using the GTM approach?

4. To what extent do you think the GTM approach got the pupils to share their prior knowledge and ideas about today's astronomy lesson?

5. Do you think the GTM approach challenged the pupils' prior views today?

6. How do you think the pupils reacted to the GTM approach today?

APPENDIX D: PUPIL INTERVIEWS (PRE- AND POST- INTERVENTION)

Thank you for agreeing to this interview. I'm Mr Taylor, from the University of Waikato, and I'm really interested in astronomy and about teaching it. I'm hoping that this interview will help us to find better ways to teach astronomy so that school pupils can learn it better. Your help is really appreciated, and what I learn from you will be used in putting together better teaching units.

Is it O.K. to tape record the interview? It's just that I find it easier than having to write like crazy. It also means that you can listen to it afterwards, and make any changes if you want to.

The reason for the interview is to find out what **you** think about various ideas in astronomy. There are no right or wrong answers, so it isn't a test **of any sort**. I shan't comment about whether I agree with you or not, and it won't be marked. I'm going to interview other people as well, to do a survey.

\While I need to ask you your name, what you say won't be revealed to anyone else at all, not even to your class teacher. If I write anything up, you'll be given a code so that no-one knows who you are.

1. What is your name?
   How old are you, ...?
   What Form/Year are you in, ...?
   Have you already learned anything about astronomy at school?
   Do you have much interest in astronomy, ...?

2. (a) ....., can you tell me what is meant by the term "the solar system"?
   (b) Can you tell me why it is called that?
   (c) Do you think it is possible for us to make a scale model of the solar system that can fit into your classroom and that we can see?
   Why do you think that?

3. (a) In **your** view, ... does the Earth go around the Sun, or the Sun go around the Earth?
   Why do you think that?
   (b) How long do **you** think it takes?
   Why do you think that?

4. (a) ....., in **your** view, does the Moon go around the Earth or the Earth go around the Moon?
   Why do **you** think that?
   (b) How long do **you** think it takes?
   Why do **you** think that?
   (c) Have you any idea what an **orrery** is?
   (d) If "yes":
   (i) what is an orrery for?
   (ii) will you briefly describe one?

5. (a) ....., would you mind putting the following astronomical objects in order from smallest to largest? (These are on separate cards, initially in alphabetical order):

   Earth, Jupiter, Mars, Moon, Pluto, Saturn, Solar System, Sun, Venus
   (b) Which planet do you think is nearest to the Sun?

(c) Which planet do you think is large, has a big red spot, and lots of satellites (moons)?

6. (a) It's day-time here in New Zealand, ... What do **you** think - is it day-time all over the world at the moment?
(b) If answer is "no", then:- where do **you** think it is night time just now?
(c) What do **you** think causes day and night?
(d) What do **you** think happens to the Sun at night?

7. (a) How do **you** know when a year has passed, ...?
(b) What do **you** think a year is?
(c) What do **you** think causes a year?

8. (a) What do **you** mean by the word "season", ...?
(b) Do **you** think it is the same season in New Zealand all year?
(c) Do **you** think it is the same season in Europe as it is in New Zealand just now?
(d) What do **you** think causes the seasons?

9. (a) Can we ever see the Moon during the day-time?
If "yes", (i) about how often?
(ii) where do **you** think the Moon goes during the day?
(b) What do **you** think is meant by the term "the phases of the Moon"?
(c) Would you describe for me a full moon?
(d) Would you describe for me a new moon?
(e) Would you describe for me a crescent moon?
(f) Would you describe for me a gibbous moon?
(g) What do **you** think causes the phases of the Moon?

10. (a) ....., what do **you** think "tides" are?
(b)How often do **you** think we get high tides?
(c) What do **you** think causes the tides?
(d) Why do you think that?

11. (a) What do **you** think an eclipse of the Sun is, ...?
(b) How do **you** think they are caused?

12. (a) ....., what do **you** think an eclipse of the Moon is?
(b) How do **you** think they are caused?

13. (a) We often hear about scientists using and making models.
What do **you** think is meant by this?

(b) Can you think of a model that scientists use?
(d) If so, tell me about it.

Thanks a lot for all your help,..... That's been really helpful to me, and your answers are really interesting - I've learned a lot.

APPENDIX E: THE ASTRONOMY SURVEY INSTRUMENT

MY IDEAS ABOUT THE SOLAR SYSTEM

We've all got our own ideas about the solar system - what is in it and how it is structured. This is a **survey** to help you and me sort out your present ideas. Later, we can build from these ideas so that we all have a better understanding.

This is **not** a test, and won't be assessed for test purposes or a course grade.

My Name is.....

I am a boy/girl..... **I am in Year**.....

Please answer the following multiple choice questions in the usual way. That is, draw a circle around which **one** of the alternatives you think is the **best** answer to the question.

e.g. The largest town or city in the Waikato is:

(A) Ngaruawahia (B) Hamilton (C) Morrinsville (D) Cambridge

Remember, don't try and guess what a scientist might think. It is **your** ideas that are important. In fact, there's no point at all in guessing.

Some of the questions are in two parts. Do remember to answer both parts.

Part A

A1. Which planet is nearest to the Sun?

(A) Mercury (B) Mars (C) Earth (D) Venus

A2. Which planet is the next one out from the Sun after Earth?

(A) Uranus (B) Saturn (C) Mars (D) Jupiter

A3. Which planet is large, has a big red spot, and many satellites (moons)?

(A) Mars (B) Jupiter (C) Uranus (D) Saturn

A4. Which planet is red, has dust storms, and has ice caps at its poles?

(A) Uranus (B) Saturn (C) Venus (D) Mars

A5. The smallest planet is:

(A) Saturn (B) Venus (C) Earth (D) Pluto

A6. The largest planet is:

(A) Earth (B) Jupiter (C) Saturn (D) Mars

Part B

B1. Think about the following table of data:

Planet	Time for one rotation (spin)	Time for one orbit of Sun	Tilt of Axis (^{0})
Mercury	59	0.24	0
Venus	240	0.62	177
Earth	1	1	23.5
Mars	1	2.4	24
Jupiter	0.41	12	3
Saturn	0.43	29	27
Uranus	0.65	84	98
Neptune	0.77	160	30
Pluto	6.4	250	123

a. In the above table, the planet that has the shortest day is:

(A) Earth (B) Jupiter (C) Mercury (D) Venus

b. In the above table, the planet that has the shortest year is:

(A) Mercury (B) Earth (C) Pluto (D) Uranus

c. In the above table, the planet with the strongest seasonal effects is:

(A) Mercury (B) Jupiter

(C) Venus (D) Mars

B2. The tides are **mainly** caused by:

(A) the Moon.
(B) the Sun.
(C) the Earth changing its shape.
(D) the planets.

B3. The Sun affects the tides:

(A) only when the Sun, Earth and Moon line up.
(B) all the time.
(C) not at all.
(D) only during the day.

Part C

C1.a Compared to Earth's time to orbit the Sun, Mars:

(A) takes less time than Earth does
(B) takes longer than Earth does
(C) takes the same time that Earth does

b. This is because

(A) planets further from the Sun take longer to orbit the Sun.
(B) you can't tell how long it takes, because there's no pattern between distance and orbit times.
(C) planets further from the Sun take less time to orbit the Sun.
(D) all planets take the same time to orbit the Sun.

C2.a. When we look at all the Moon phases that occur during a whole year, we will have seen:

(A) about a quarter of it.
(B) about a half of it.
(C) about three-quarters of it.
(D) all of its sides.

b. This is because the Moon:

(A) doesn't spin on its axis.
(B) spins on its axis twice as it orbits Earth once.
(C) does a half spin on its axis as it orbits Earth once.
(D) spins on its axis once as it orbits Earth once.

C3.a. We can sometimes see the Moon in the daytime sky:
(A) Yes (B) No

b. This is because the Moon is in the sky:

(A) only at night.
(B) sometimes during the day but more often at night.
(C) more often during the day than at night.
(D) as often during the day as it is at night.

C4.a. The phases of the Moon are because of its changing:

(A) light output.
(B) distance from Earth.
(C) apparent shape.
(D) apparent size.

b. The phases of the Moon are caused by:

(A) people on Earth always seeing half the Moon, but from different angles at different times.
(B) planets casting a shadow on the Moon.
(C) the Sun lighting different parts of the Moon at different times.
(D) different parts of Earth's shadow falling on it at different times.

C5.a. Eclipses of the Sun are when:

(A) the Moon crosses the face of the Sun.
(B) the Sun crosses the face of the Moon.
(C) planets cross the face of the Sun.
(D) the Sun crosses the face of Earth.

b. Eclipses of the Sun are caused by:

(A) Earth moving between the Sun and the Moon.
(B) the Sun moving between the Moon and Earth.
(C) the Moon moving between Earth and the Sun.
(D) a large planet moving between the Sun and Earth.

C6.a. Eclipses of the Moon are when:

(A) the Moon crosses the face of the Sun.
(B) the Sun crosses the face of the Moon.
(C) the Moon's shadow crosses Earth's surface.
(D) Earth's shadow crosses the face of the Moon.

b. Eclipses of the Moon are caused by:

(A) Earth moving between the Sun and the Moon.
(B) the Sun moving between the Moon and Earth.
(C) the Moon moving between Earth and the Sun.
(D) a large planet moving between the Moon and Earth.

C7.a. When it is summer in New Zealand, in Europe it is:

(A) summer (B) winter (C) autumn (D) spring

b. This is because the **main** reason for summers in New Zealand is:

(A) The tilt of Earth's axis means New Zealand gets more solar energy at that time.
(B) The tilt of Earth's axis means New Zealand is nearer to the Sun at that time.
(C) Earth's orbit brings New Zealand closer to the Sun at that time.
(D) the Sun radiates more heat at that time.

C8.a. A day on Earth is close to:

(A) 24 hours.
(B) the time it is light.
(C) the time it is dark.
(D) 12 hours.

b. The length of a day depends on the time for:

(A) the Sun to go around Earth.
(B) Earth to spin once on its axis.
(C) Earth to go around the Sun.
(D) the Moon to go around Earth.

C9.a. A year on Earth is **closest** to:

(A) 12 lunar months.
(B) when all four seasons have happened.
(C) 365 days.
(D) 28 days.

b. The length of a year depends on:

(A) the time for the Sun to go around Earth.
(B) the time it takes for Earth to spin once on its axis.
(C) the time for Earth to go around the Sun.
(D) the time for the Sun to spin once on its axis.

C10.a. The duration of a lunar month on Earth:

(A) is always one-twelfth of a year.
(B) is the time for a season to happen.
(C) varies between 28 and 31 days.
(D) is always 28 days.

b. A lunar month on Earth depends on the time for:

(A) the Sun to go around Earth.
(B) Earth to spin once on its axis.
(C) Earth to go around the Sun.
(D) the Moon to go around Earth.

C11.a. When it is midnight in New Zealand, it is also midnight:

(A) nowhere else on Earth.
(B) everywhere in the northern hemisphere.
(C) everywhere else on Earth.
(D) in parts of both north and south hemispheres.

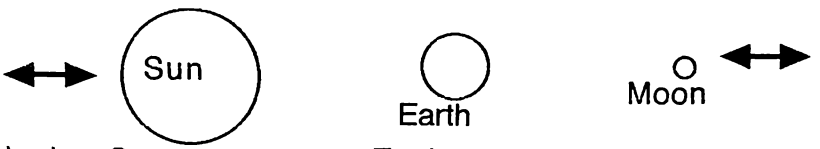
b. My answer is because:

(A) the Sun orbits from the southern hemisphere to the northern hemisphere.
(B) the Sun orbits from our half of Earth to the other side.
(C) Earth spins on an axis through its north and south poles.
(D) Earth spins on an axis through its equator.

Part D

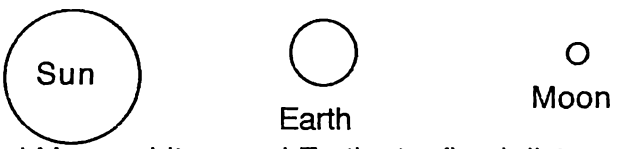
D1. Below are drawn five possible models of the Sun-Earth-Moon system. Which of the following five descriptions would you choose?

Model A



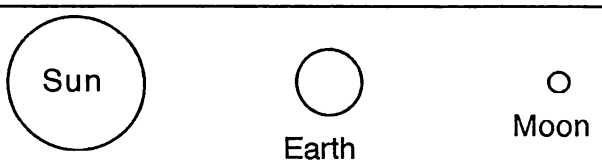
In day, Sun moves nearer Earth and Moon moves away.
At night, Sun moves away from Earth and Moon moves nearer.

Model B



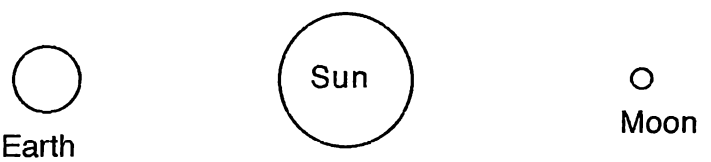
Sun and Moon orbit around Earth at a fixed distance from Earth, and on opposite sides.

Model C



Sun and Moon orbit around Earth on opposite sides, and their distances from Earth vary.

Model D



Earth and Moon each orbit around Sun, and their distances from Sun vary.

Model E

Moon orbits around Earth, which orbits Sun.
The distances vary.

I think the model that best represents the Earth-Moon-Sun model is:

(A) (B) (C) (D) (E)

D2. An orrery is:

(A) an instrument to measure the sizes of the stars.
(B) a type of telescope.
(C) a mechanical model of the Sun-Earth-Moon system.
(D) an instrument to measure the distances to stars.

D3. Can we build a scale model of the solar system [that uses the same scale for sizes **and** distances] that would fit into our classroom **and** have the planets big enough to be seen?

(A) Yes (B) No

b. This is because, to fit into our classroom, it can be built to be accurate for:

(A) neither the sizes nor the distances between the Sun, Moon and planets.
(B) only the distances between the Sun, Moon and planets
(C) only the sizes of the Sun, Moon and planets
(D) both the sizes and the distances between the Sun, Moon and planets.

D4.a. Other than an orrery, an example of a scientists' model is:

b. What is the purpose of models?

c. How do you think scientists use models?

D5. For the following table, put a tick in the first column to show what an orrery is very good for demonstrating,
or in the second column to show what an orrery is poor at demonstrating.
Then, in the space below your tick, say **why** you answered that way.

	very good	poor
(A) tides		
(B) phases of the Moon		
(C) eclipses		
(D) relative sizes		
(E) relative orbit times		
(F) the seasons		

Thank you very much for completing this survey.

APPENDIX F: INTERVENTION TEACHER'S POST-INTERVENTION INTERVIEW SCHEDULE

I'd like to discuss things further with you now that you have experienced this teaching approach.

1. How do you feel about teaching astronomy in this way?
   What do you think were the good things about it?
2. ....., what were the main challenges that you faced when you taught astronomy using this approach?
   Prompts:
   (a) how did you and the pupils find the language?
   (b) what about doing observations?
   (c) what about the huge scale of things, with the large numbers?
   (d) what about **doing** astronomy - the Investigative Skills?
   (e) what about the content knowledge you needed?
   (f) what about the resources for teaching astronomy?
   (g) what about the time you needed? Was that about right, or not?
3. Do you think teaching astronomy in this way helped pupils towards attaining the Achievement Aims of *The Nature of Science and Its Relationship to Technology*?
   Prompts: do you think your pupils did:
   (a) critically evaluate astronomy ideas?
   (b) gain an awareness that astronomy ideas change over time?
   (c) get an insight into how scientists use models?
4. ....., do you think this approach met the curriculum requirements for astronomy at Level Four?
5. Do you think this approach met the curriculum requirements in terms of the recommended science Investigative Skills?
6. Do you think this approach met the curriculum requirements in terms of the pupils making sense of the scientists' view?
7. How practicable do you think this approach was?
8. Do you think this approach got the pupils to share their prior knowledge and ideas about astronomy?
9. Do you think this approach challenged the pupils' prior views?
10. How do you think the pupils reacted to having their views challenged?
11. How do you think classroom management, including control, was affected by this approach?
12. Do you think that the classroom materials provided were sufficient for a classroom teacher to be able to teach this unit in a constructivist way?
13. Do you think it was appropriate for the pupils to work in groups?
14. How do you think the pupils reacted to this approach?
15. Do you think the approach was successful in moving the pupils' concepts towards the scientists' ones?
16. Overall, does this approach make sense to you with respect to your knowledge of how pupils at this age learn?

Thanks a lot for your help, Darryl. It's been a big help to me and I hope it will be to other teachers.

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