

**TEXTBOOK DIAGRAMS ILLUSTRATING PHASES OF THE
MOON: GRADE 10 LEARNERS' INTERPRETATION IN
RELATION TO SPATIAL ABILITY**

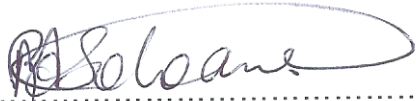
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**A thesis submitted to the Faculty of Science, University of the
Witwatersrand, Johannesburg, in fulfilment of the requirements of the degree
of Doctor of Philosophy.**

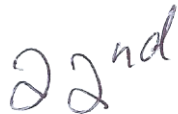
Johannesburg, 2012

Declaration

I declare that this Thesis is my own, unaided work. It is being submitted for the degree of Doctor of Philosophy at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any other degree or examination at any other University.

A handwritten signature in dark ink, appearing to read "R. Soloane", written over a horizontal dotted line.

(Signature of candidate)

A handwritten date "22nd" in dark ink, positioned above the dotted line of the date field.

..... day of June 2012 in Johannesburg

To my family

My mother — Lucia ‘Mamotlatsi Mosoloane

My sister —Lineo Caroline Mosoloane

My nephew and niece — Thabo Robert and Thokozile Josephine Maleka

My Brother and sister — Ncholo Joseph and ‘Mathabo Cecil Maleka

Abstract

Many textbooks have diagrams illustrating astronomy concepts. However, research shows that sometimes learners struggle to obtain information illustrated in diagrams. This study investigated learners' ability to interpret diagrams illustrating phases of the Moon. Three constructs formed a theoretical framework used to design the study and interpret results: a theory associated with design and interpretation of diagrams, spatial ability theory which explains how people mentally manipulate objects in space, and the theory of models which proposes issues to take into consideration when using models (e.g. diagrams) in classrooms. I collected and processed data in three phases.

In the first phase, I administered a diagnostic test to 75 learners, investigating their ideas about concepts associated with phases of the Moon. In addition, I administered six spatial ability tests to these learners, investigating their mastery of spatial ability skills needed to understand concepts associated with phases of the Moon. Results show that all the learners lacked background knowledge of these concepts. Furthermore, most of the learners lacked spatial ability skills needed to understand these concepts. I used these results to select 10 learners for participation in the third phase of the study. Five of these learners had high spatial ability skills while the other five had low spatial ability skills.

During the second phase of the study, I analyzed 28 diagrams illustrating phases of the Moon to investigate the extent to which their composition (i) might enable learners to perceive all diagrammatic information, (ii) might enable learners to understand information for which the diagrams are intended, and (iii) complies with context of intended learners. Results show that only few diagrams were designed in a way that might hinder perception of information. However, most diagrams were designed in a way that might hinder understanding of intended information, and many did not comply with context of intended viewers. These results enabled me to select four diagrams having the fewest design problems to be used in the third phase of the study.

In the third phase, I interviewed the ten learners selected during the first phase, to investigate their ability to interpret diagrams illustrating phases of the Moon. The learners were generally able to interpret aspects of diagrams which required the diagrams to be perceived in two-dimensional space. However, they struggled to interpret aspects of the diagrams which required perception and mental manipulation of the components of the Earth-Moon-Sun system in three-dimensional space. The high spatial-ability learners were better able to cope with tasks requiring mental manipulation of the Earth-Moon-Sun system in space than their low spatial ability counterparts. These results suggest the existence of a link between spatial ability and learners' interpretation of these diagrams.

Teachers should be informed about these findings to help them understand how usage of the diagrams might hinder learning. This information might help them use diagrams that have fewer design problems. Also, teacher trainers should be informed about these findings, to help them caution pre-service teachers about problems found in textbook diagrams. In addition, publishers should be informed about findings of this study to help them improve quality of diagrams in school textbooks. Furthermore, researchers should investigate strategies that can help learners (particularly

those with low spatial ability skills) to better cope with aspects of diagrams which require mental manipulation of the Earth-Sun-Moon system in space.

Keywords

Astronomy, phases of the Moon, diagram design, diagram interpretation, spatial ability

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Acronyms

CAPS	Curriculum and Assessment Policy Statement
CF-2	Hidden Figures Test
ETS	Education Testing Service
FET	Further Education and Training band
GET	General Education and Training band
RNCS	Revised National Curriculum Statement
S-1	Card Rotations Test
S-2	Cube Comparisons Test
VZ-1	Form Board Test
VZ-2	Paper Folding Test
VZ-3	Surface Development Test

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Chapter 1 Introduction

This chapter presents a brief background to the study, i.e. the context of the study, the problem motivating the study, aim of the study, research questions answered by the study, methods used in the study, and outline of the thesis.

1.1 Context of the Study

The study was conducted in Johannesburg, South Africa. The South African school system consists of two bands, the General Education and Training (GET) band and the Further Education and Training (FET) band. The GET band has three phases: the Foundation Phase consisting of Grades 1 to 3 (for learners aged approximately 6 to 8 years old), the Intermediate Phase consisting of Grades 4 to 6 (for learners aged 9 to 11 years old), and the Senior Phase consisting of Grades 7 to 9 (for learners aged 12 to 14 years old). The FET band consists of Grades 10 to 12. Grades 1 to 7 are in primary school while Grades 8 to 12 are in high school. This study focused on content knowledge prescribed for learners studying in the GET band of this system. As a result, the rest of this discussion focuses on the GET band.

At the commencement of this study in 2006, the GET band used a curriculum document called the *Revised National Curriculum Statement* (RNCS), which has eight learning areas: *Languages, Mathematics, Natural Sciences, Social Sciences, Arts and Culture, Life Orientation, Economic and Management Sciences, and Technology*. A modified version of this document, called the *Curriculum and Assessment Policy Statement* (CAPS), is being introduced now that this study is nearing completion. The CAPS is expected to be used in schools from January 2012 (Department of Basic Education, 2011). In the following sections I show relevance of the study to requirements of both the RNCS and the CAPS.

The RNCS outlines Learning Outcomes and Knowledge Strands for each of the eight learning areas. The current study focused on the *Natural Sciences* learning area. As a result, I discuss Learning Outcomes and Knowledge Strands outlined for this learning area.

1.1.1 Learning outcomes for the Natural Sciences

The RNCS outlines three Learning Outcomes for the *Natural Sciences* learning area, and defines these as “operations which the learner must be able to do on a certain range of scientific knowledge” (Department of Education, 2002:7). The first learning outcome deals with *Scientific Investigations*, the second with *Constructing Science Knowledge* while the third deals with *Science, Society and the Environment*. The current study focused on the second learning outcome elaborated as follows:

“The learner’s competence in this Learning Outcome can be seen in the ability to collect or extract information from various sources, and then to organise and analyse that information. ... Building this competence involves process skills such as interpreting information by interrogating pictures and diagrams, transforming information from one form to another ..., looking for patterns in data, or expressing a relationship between two variables” (Department of Education, 2002:9).

The CAPS document refers to the Learning Outcomes as Specific Aims, and spells out skills that can enable the Specific Aims to be achieved. Among these skills, the CAPS states that learners should be able to use tools such as written summaries, flow charts, diagrams and mind maps to analyse, evaluate and synthesise knowledge acquired from a variety of sources including people, books and internet, and to apply this new knowledge in unfamiliar contexts (Department of Basic Education, 2011).

1.1.2 Knowledge strands for the ‘Natural Sciences’ learning area

The RNCS categorizes scientific knowledge into four knowledge strands: *Life and Living*, *Energy and Change*, *Planet Earth and Beyond*, and *Matter and Materials*. The current study focused on the knowledge strand *Planet Earth and Beyond*, which deals with “the structure of the planet and how the earth changes over time, on understanding why and how the weather changes, and on the earth as a small planet in a vast universe” (Department of Education, 2002:61).

The RNCS requires Foundation Phase learners to know that “Many different objects can be observed in the sky. Examples are ... the sun, stars, the moon, planets and satellites. All these objects have properties, locations and movements that can be investigated with a view to determining patterns, relationships and trends” (Department of Education, 2002:69). On the other hand, the RNCS requires Intermediate Phase learners to know that “the moon’s apparent shape changes in a predictable way and these changes may be explained by its motion relative to the earth and sun” (Department of Education, 2002: 69). As for the Senior Phase, the RNCS requires learners to know that “most objects in the solar system are in regular and predictable motion. The motions of the earth and moon explain such phenomena as the day, the year, phases of the moon, and eclipses” (Department of Education, 2002:71).

The CAPS refers to the four Knowledge Strands as ‘Knowledge Areas’. For the Knowledge Area dealing with the planet earth and beyond, the CAPS recommends that Grade 7 learners be taught that the Sun, the planets and the Moon (appear to) have regular and predictable motion. In grade, 8, the CAPS requires that learners be taught that spatial objects have predictable motion as a result of gravitational force, and further expects learners to be taught about phases of the Moon and eclipses. For both Grades 7 and 8, the CAPS emphasises that learners need to be able to interpret diagrams, especially those illustrating three-dimensional phenomena.

The preceding discussion shows that the RNCS and the CAPS expect learners in intermediate and senior phases of the GET band (approximately aged 9 to 14 years) to learn about concepts

associated with changing configurations of the components of the Earth-Moon-Sun system, and to interpret diagrams illustrating science concepts. These two ideas formed the focus of the study.

1.2 Problem motivating the study

Several scholars have conducted research dealing with concepts associated with the Earth-Moon-Sun system, including day and night, seasons, phases of the Moon, and eclipses. This research shows that many students and teachers find astronomy concepts difficult to understand, both locally (e.g. Cameron, 2007; Kelfkens & Lelliott, 2006; Lelliott, 2007; Mosoloane, 2005) and internationally (e.g. Atwood & Atwood, 1996; Bakas & Mikropoulos, 2003; Vosniadou, Skopeliti & Ikospentaki, 2005).

The current study focused on phases of the Moon, which is only one aspect of the Earth-Moon-Sun system. Most research dealing with moon phases investigated conceptual difficulties held by students and teachers about moon phases (e.g. Baxter, 1989; Mant & Summers, 1993; Wilhelm, 2009a), and impact of teaching interventions on understanding of these concepts (e.g. Bell & Trundle, 2008; Jones & Lynch, 1987; Trumper, 2006). Findings of this research show that many students and teachers struggle to understand these concepts even after undergoing instruction in astronomy.

To help learners understand science concepts, most textbooks provide diagrams and textual information dealing with these concepts. However, literature shows that some textbooks contain information that might hinder learners' understanding of information intended by publishers (e.g. Sebastia & Torregrosa, 2005; Vosniadou, 1991). Furthermore, literature shows that some students struggle to obtain information illustrated in diagrams. Some of the problems include an inability to perceive associated symbols as linked (e.g. du Plessis, Anderson & Grayson, 2003), not reading diagram captions (e.g. Ametller & Pinto, 2002), being unable to interpret depth cues (e.g. Liddell, 1997; Nicholson & Seddon, 1977), linking diagrams with irrelevant text (e.g. Khanyane, 2002), paying attention to some and not other areas of diagrams (e.g. du Plessis et al., 2003), and giving more information than provided in diagrams (e.g. Stylianidou, Ormerod, & Ogborn, 2002). These problems may possibly add to difficulties encountered when learning about phases of the Moon.

Many scholars argue that learners need to use spatial ability skills in order to understand concepts associated with the Earth-Moon-Sun system (e.g. Hans, Kali & Yair, 2008; Mulholland & Ginns, 2008). For example, they should be able to imagine observing the system from space and from the Earth, and also to imagine revolutions and rotations of the Earth and the Moon in three-dimensional space in order to understand changes in the phases of the Moon (Callison & Wright, 1993). However, research shows that some students and teachers lack these spatial skills (e.g. Callison & Wright, 1993; Rochford & Sass, 1988; Suzuki, 2003). Learners who lack these skills may encounter problems of understanding concepts associated with the Earth-Moon-Sun system.

The problem is that many learners (i) find astronomy concepts difficult to understand, (ii) struggle to obtain information illustrated in diagrams, and (iii) lack spatial ability skills needed to interpret these diagrams and to understand information illustrated in the diagrams.

1.3 Significance of the study

I have indicated that the bulk of research dealing with moon phases has investigated conceptual difficulties held by respondents about moon phases. Review of literature shows that most of this research paid attention to respondents' ideas about the cause of moon's phases (e.g. Baxter, 1989; Mulholland & Ginns, 2008; Sharp, 1996) and interventions intended to help learners understand the cause of these phases (e.g. Jones & Lynch, 1987; Sherrod & Wilhelm, 2009; Subramaniam & Padalkar, 2009). Literature further shows that less attention has been paid to students' understanding of other concepts associated with phases of the Moon. The current study investigated students' understanding of these concepts. Findings of the study extend the existing body of knowledge about students' understanding of the Earth-Moon-Sun system.

I have also indicated that several scholars have conducted research involving diagrams. However, most of this research investigated impact of diagrams on understanding textual information (e.g. Hannus & Hyona, 1999; Mathai & Ramadas, 2009; Winn & Solomon, 1993), impact of background knowledge on interpretation of diagrams (e.g. Kindfield, 1993/1994; Kozma, 2003; Lowe, 1988), impact of animations on learning information (e.g. Hoffler & Leutnar, 2007; Lewalter, 2003), and impact of cognitive load on interpretation of diagrams (e.g. Sweller, Chandler, Tierney, & Cooper, 1990). Less research has been conducted to investigate the nature of diagrams found in school textbooks. In fact, literature reviewed for this study shows only four studies which investigated the nature of diagrams illustrating phases of the Moon. Three of these studies dealt with diagrams found in school textbook; Engeström (1991) who analysed diagrams illustrating phases of the Moon in textbooks approved for use in a Finnish secondary school, Martinez-Pena and Gil-Quilez (2001) who analysed diagrams illustrating phases of the Moon in Spanish primary and secondary schools, and Dove (2002) who analysed a diagram found in a textbook recommended for use in UK primary schools. The fourth study analysed illustrations in 80 American children's story books (Trundle, Troland, & Pritchard, 2008). It is worthy to note that none of the four studies investigated syntactic problems found in diagrams illustrating phases of the Moon, i.e. problems associated with perception of information illustrated in these diagrams. Furthermore, only Trundle and her associates investigated semantic problems found in these diagrams, i.e. problems associated with obtaining information illustrated in these diagrams (but their analysis touched on only a few of these problems). Additionally, none of the studies investigated pragmatic problems found in these diagrams, i.e. problems associated with suitability of the diagrams to context of intended viewers. The current study investigated all syntactic, semantic and pragmatic problems found in diagrams illustrating phases of the Moon. Findings of the study extent our understanding of semantic problems found in these diagrams (in addition to Trundle et al.'s work), and contribute new knowledge by making us understand syntactic and pragmatic problems found in the diagrams.

In addition to analysis of diagrams found in school textbooks, a review of literature shows that very little research has been conducted to investigate learners' ability to interpret these diagrams (e.g. Ametller & Pinto, 2002; Colin, Chauvet, & Veinnot, 2002; Khanyane, 2002). Furthermore, no research has been conducted to investigate learners' interpretation of diagrams illustrating phases of the Moon. The current study investigated the extent to which learners understand information presented in these diagrams. Findings of the study contribute new knowledge to the field of astronomy education by helping us understand the extent to which diagrams serve the purpose intended by publishers and textbook writers.

Further to analysis and interpretation of diagrams, literature shows that very little research has been conducted to investigate links between spatial ability and astronomy concepts, despite arguments of many scholars that understanding astronomy concepts requires usage of spatial ability skills. In fact, literature reviewed for this study shows only five studies conducted to investigate links between spatial ability and students' understanding of astronomy concepts. Three of these studies investigated correlations between spatial ability and students' understanding of astronomy concepts (Black, 2005; Kikas, 2006; Rudmann, 2002). The fourth investigated links between spatial ability and conceptual change as students learned about astronomy concepts (Callison & Wright, 1993). The fifth investigated links between gender differences, spatial ability and conceptual change as students learned about phases of the Moon (Wilhelm, 2009b). It is worthy to note that only Wilhelm investigated links between spatial ability and learners' understanding of moon's phases. However, her study paid no attention to learners' interpretation of diagrams illustrating this concept. In fact I found no studies which have investigated links between spatial ability and learners' interpretation of diagrams illustrating phases of the Moon. The current study investigated this link. Findings add new knowledge which can be used to design interventions that might help learners to better understand phases of the Moon. In addition, information about students' spatial abilities extends the existing body of knowledge about spatial ability skills of learners in this part of the world (very little research has been done in Africa, e.g. Sanders's (2004) paper).

1.4 Aim of the study

This study was carried out to investigate (i) learners' understanding of concepts associated with phases of the Moon in addition to the cause of these phases, (ii) the extent to which textbook diagrams illustrating phases of the Moon comply with design principles recommended in literature, (iii) learners' ability to obtain information illustrated in these diagrams, and (iv) links between spatial ability and learners' interpretation of these diagrams.

Findings of this study might help teachers to realise problems with the diagrams, so as to select and use diagrams with fewer design problems. Furthermore, these findings could help publishers to improve the quality of textbook diagrams illustrating these concepts (improved diagrams might help learners to better understand phases of the Moon). Additionally, the findings might help us understand the extent to which these diagrams convey information intended by teachers and textbook writers to learners.

1.5 Research questions

The following research questions have been answered by the study:

1. What is the level of Grade 9 Natural Science learners' understanding of astronomy concepts associated with phases of the Moon?
2. What is the level of Grade 9 Natural Science learners' spatial ability skills?
3. To what extent does the composition of diagrams illustrating phases of the Moon (in South African school textbooks) comply with design principles recommended in literature?
4. What interpretations do learners assign to components of diagrams illustrating phases of the Moon, and what does this imply about learners' interpretation of conventions used in these diagrams?
5. What links (if any) exist between learners' spatial ability skills and interpretation of diagrams illustrating phases of the Moon?

1.6 Theoretical framework

Publishers include diagrams in textbooks because of the belief that the presence of diagrams enhances learning. Several authors argue that spatial relations between objects are more easily observed from diagrams than from text (e.g. Braden, 1994; Gilbert & Boulter, 1998; Gobert & Buckley, 2000; Crawford & Cornell, 2004). It is not surprising, therefore, that diagrams are used to illustrate concepts associated with the Earth-Moon-Sun system. Understanding these concepts requires learners to use spatial ability skills.

Spatial ability: Spatial ability is a measure of people's ability to perceive and manipulate objects in space (Carroll, 1993; Lohman, 1979). Researchers have identified three distinct spatial ability skills; (i) spatial perception which is a measure of people's ability to perceive spatial objects, (ii) spatial orientation which is a measure of people's ability to imagine rotating objects in space or viewing objects from different perspectives, and (iii) spatial visualization which is a measure of people's ability to perform several mental transformations on objects (Barratt, 1953; Linn & Petersen, 1985). All these skills are needed to understand astronomy concepts. For example, spatial perception enables people interpreting moon phase diagrams to focus on certain images of the Moon while provisionally ignoring other images of the Moon in the diagram. Spatial orientation enables people to understand, for example, why rotation of the Earth on its axis causes day and night. Spatial visualization, on the other hand, enables people to understand complex relationships between rotations and revolutions of the Earth and the Moon about the Sun.

Understanding this complex association helps to explain, for example, why earth viewers see only one side of the Moon.

I administered tests measuring the three components of spatial ability and used results to gain understanding of learners' spatial ability skills. Furthermore, I used these results to investigate links between spatial ability and learners' interpretation of diagrams illustrating phases of the Moon.

Models and modelling: The diagrams used in this study represent a model of the Earth-Moon-Sun system conceptualised by scientists. Research shows that sometimes students struggle to identify similarities and differences between models and target concepts (e.g. Grosslight, Unger, Jay, and Smith, 1991). Gilbert, Boulter and Rutherford (1998b) argue that students who are not fully aware of these analogies are likely to develop inadequate understanding about information conveyed by the models. For this reason, they suggest that illustrators spell out similarities and differences between models and targeted concepts. I used these ideas to investigate whether, and the extent to which illustrators of diagrams illustrating phases of the Moon provide information to help learners make accurate mappings between diagrammatic information and targeted concepts.

Diagram-related issues: Illustrators use conventions to communicate information through diagrams, e.g. omitting devices used to hold apparatus in place (Henderson, 1999). Several researchers recommend principles/guidelines for using these conventions to convey messages in diagrams (e.g. Braden, 1994; Fredette, 1994; Gropper, 1965). Kosslyn (1989) classifies these principles into three categories: syntactic principles which focus on perception of marks (symbols and words), semantic principles which focus on interpretation of messages conveyed by the marks, and pragmatic principles which focus on suitability of diagrams to intended audiences.

Students' ability to obtain information illustrated in diagrams depends on many factors which can be grouped into two main categories; picture-related factors and student-related factors (Reid, 1990). Picture related factors include the nature of information illustrated in diagrams, e.g. the number of elements that have to be processed, the extent to which the elements interact, and the accuracy with which diagrams illustrate this information. On the other hand, student-related factors include students' conceptual understanding of information illustrated in diagrams, their familiarity with conventions used in the diagrams, and their possession of skills needed to interpret the diagrams (Fredette, 1994; Lowe, 1986; Schönborn, Anderson & Grayson, 2002).

I used these ideas to investigate the extent to which diagrams illustrating phases of the Moon comply with design principles recommended in literature, and to further investigate learners' ability to interpret conventions used in these diagrams.

Summary: The preceding discussion shows that three constructs formed a theoretical framework used to design the study and interpret results: (i) the spatial ability theory which helped me understand learners' ability to execute spatial ability skills and to investigate links between spatial ability and learners' interpretation of diagrams illustrating phases of the Moon, (ii) the theory of models which helped me interpret results obtained from analysis of these diagrams, and (iii) the theory of diagrams which helped me interpret results obtained from analysis and interpretation of these diagrams.

1.7 Methodology

I administered six tests to measure learners' spatial ability skills. Data obtained from these tests provided an answer to the first research question. In addition, I administered a diagnostic test to investigate learners' understanding of concepts associated with phases of the Moon, and to further investigate their ability to mentally manipulate celestial objects in space. Data obtained from the diagnostic test provided an answer to the second research question. Additionally, I analyzed textbook diagrams illustrating phases of the Moon to investigate the extent to which their composition complied with design principles recommended in literature. Data obtained from this analysis provided an answer to the third research question. I used spatial ability test scores to select learners who interpreted diagrams illustrating phases of the Moon. Furthermore, I used diagram-analysis results to select diagrams that I used during interviews. Having selected the diagrams and the learners, I conducted interviews to investigate learners' interpretation of diagrams illustrating phases of the Moon. Results of diagram interpretation provided answers to the last two research questions.

1.8 Outline of the report

Chapter 1 has given introduction of the study, which includes context of the study, problem motivating the study, and research questions answered by the study.

Chapter 2 presents literature relating to phases of the Moon and theoretical constructs used in the study. The first part reviews literature related to conceptual difficulties associated with phases of the Moon, possible causes of these difficulties, and application of spatial ability in astronomy education. The second part reviews literature relating to three constructs used to design the study and interpret findings. First this section defines *spatial ability*, discusses tests used to measure this construct, presents literature about students' spatial ability skills, and discusses mental processes and strategies used when answering spatial ability tests. After this, the chapter defines a *model*, discusses types of models, and discusses the Earth-Moon-Sun system as a model. Then the chapter discusses literature describing importance of *diagrams*, principles recommended for composition of diagrams, and problems associated with diagram design and interpretation.

Chapter 3 describes the paradigm on which the study was based, sampling methods used in the study, and methods used to collect and process data obtained in the study, bearing validity and reliability issues in mind.

Chapter 4 presents results obtained from administration of the diagnostic test, and gives an answer to the first research question. Thereafter, the chapter discusses conceptual knowledge related to phases of the Moon, held by learners selected to participate in interviews.

Chapter 5 presents results obtained from administration of spatial ability tests, and then gives an answer to the second research question. Thereafter, the chapter explains how the spatial ability scores informed selection of learners interviewed about diagrams illustrating phases of the Moon.

Chapter 6 presents results obtained from analysis of textbook diagrams illustrating phases of the Moon, and further gives an answer to the third research question. Thereafter, the chapter explains how diagram-analysis informed selection of diagrams used for interviews.

Chapter 7 presents learners' interpretation of two diagrams illustrating phases of the Moon. Thereafter, the chapter discusses links between spatial ability and learners' interpretation of these diagrams.

Chapter 8 presents learners' interpretation of two other diagrams illustrating phases of the Moon, and discusses links between spatial ability and learners' interpretation of these diagrams. Thereafter, the chapter presents answers to the last two research questions.

Chapter 9 consolidates findings of the study, relates them to the theoretical framework, and discusses implications of the results to learning about phases of the Moon.

1.9 Definition of terms

This glossary defines the terms and phrases as used in the current thesis.

Inscriptions: Alphabetical and numerical symbols used in a diagram. These writings label components of diagrams and/or explain what happens in parts of diagrams.

Symbols: Graphical symbols found in diagrams.

Marks: Both symbols and inscriptions used in a diagrams.

Terminator line: Interface between illuminated and unlit parts of the Moon.

Earth shape: The shape representing the Earth in diagrams illustrating the Earth-Moon-Sun system.

Moon shapes: Shapes representing the Moon in diagrams illustrating the Earth-Moon-Sun system. 'Moon shape' refers both to shapes representing phases of the Moon, and shapes representing the Moon as it orbits the Earth.

Cut-out moon shape: Shapes representing phases of the Moon cut out from Diagram 21b. These shapes were used during interviews (referred to mainly in Chapters 7, 8 and 9).

1.10 Conclusion

The chapter has given introduction to the study. The next chapter discusses literature associated with phases of the Moon, and theoretical constructs and research findings that guided design of the study and interpretation of results.

Chapter 2 Literature review and theoretical framework

The first section of this chapter discusses literature related to understanding astronomy concepts with particular reference to phases of the Moon. The second section discusses theories used to design the study and guide interpretation of results.

2.1 Understanding concepts associated with phases of the Moon

Several scholars have conducted research investigating people's understanding of astronomy concepts including shape of the Earth (e.g. Nussbaum, 1985; Vosniadou & Brewer, 1990), day and night (e.g. Baxter, 1989; Klein, 1982), seasons (e.g. Atwood & Atwood, 1996; Sharp, 1996), phases of the Moon (e.g. Dove, 2002; Trumper 2000), eclipses (e.g. Barnett & Morran, 2002; Mohapatra, 1991), and the solar system (e.g. Diakidoy, Vosniadou & Hawks, 1997). This research shows that school learners (Kikas, 1998; Mosoloane, 2005), pre-service teachers (Atwood & Atwood, 1996; Callison & Wright, 1993) and practicing teachers (Mant & Summers, 1993; Parker & Heywood, 1998) struggle to understand these concepts. The current study focused on only one of these concepts, i.e. phases of the Moon. As a result, the rest of this discussion deals with literature associated with phases of the Moon. First I discuss literature explicating conceptual difficulties associated with phases of the Moon. Then I discuss literature showing possible causes of these difficulties, and end the section by paying special attention to spatial ability as one of these possible causes.

2.1.1 Conceptual difficulties related to phases of the Moon

The bulk of moon phase research shows that many people have misconceptions about the cause of moon phases (scientists believe that the Moon appears to change shape as seen from the Earth because of changing configurations of the components of the Earth-Moon-Sun system). I define misconceptions as ideas that 'differ from the standard conceptions of science' (after Girvy and Roth, 2006:1086). Appendix G(i) illustrates some misconceptions about the cause of phases of the Moon reported in literature reviewed for this study. The appendix reports studies conducted in different parts of the world involving participants at different levels of education, e.g. primary school students in the USA (Hobson, Trundle & Saçkes, 2010), secondary school students in the USA (Rider, 2002), university students in Israel (Trumper, 2000), pre-service teachers in South Africa (Kelfkens & Lelliott, 2006), and practicing teachers in the UK (Mant & Summers, 1993; Parker & Heywood, 1998). The following section discusses the misconceptions illustrated in Appendix G(i).

The cause of moon phases

Appendix G(i) shows five misconceptions commonly held about the cause of moon phases. One of these misconceptions is that the Moon changes shape so that viewers on Earth see different phases in the course of a month. This idea has been given by very few individuals who participated in three of 22 studies illustrated in the appendix, i.e. one of three six-to-eight year-olds who participated in Wilhelm's (2009a) study, 13% of 39 seven-to-seventeen year-olds who participated in Roald and Mikalsen's (2001) study, and a non-specified fraction of 32 middle school students who participated in Rider's (2002) study. It is worthy to note that participants in the three studies were reasonably younger in age (i.e. no pre-service or practicing teachers gave this idea). According to the response given by these participants, the Sun plays no role in the cause of moon phases. This suggests that the respondents had a very naïve idea of associating moon phases with the Moon only, not with the relationship between the Moon and the Earth-Sun system. It is worthy to note that all the studies reporting this idea used interviews to collect data. The fact that the studies employed interviews suggests that the idea came from the participants, not from hints given to participants as would be the case with multiple-choice questions.

Six studies reported a response in which participants said that the Sun's shadow obscures earth viewers from seeing (fraction of) the Moon. This idea appears to be very naïve since the Sun is the source of light in the solar system, and is not expected to have a shadow. The idea has been reported in research involving high school students, except in Mulholland and Ginns's study where the participants were pre-service teachers. It seems surprising that high school students and pre-service teachers do not understand that the Sun cannot have a shadow. This suggests that they had poor understanding of concepts associated with optics, which would enable them to understand that a source radiating light in all directions does not have a shadow, unless otherwise in presence of another source of light (Martinez-Pena and Gil-Quilez (2001) found that some pre-service Spanish teachers lacked this knowledge). Also notable is the fact that this idea has been reported in studies that used multiple-choice questions to obtain data (Mulholland & Ginns, 2008; Trumper 2001a, 2001b) and in studies that used interviews to get data (Baxter, 1989; Rider, 2002; Trundle, Atwood, Christopher & Saçkes, 2010). Participants who answer multiple-choice questions might select responses without necessarily understanding the idea in a response. However, the fact that the idea has been found through interviews suggest that this (apparently naïve) idea was held firmly in the minds of some participants.

Another response, reported in 16 of the 22 studies, is that phases of the Moon are caused by obstacles obscuring (a fraction of) the Moon from sight of earth viewers. These obstacles include clouds (e.g. Baxter, 1989; Sharp, 2006), and other planets than the Earth (e.g. Kucukozer, 2008; Trundle et al., 2010). This misconception has been reported in research involving young children (e.g. Sharp, 1996; Stahly, Crockover & Shepardson, 1999; Roald & Mikalsen, 2001; Wilhelm, 2009a), high school students (e.g. Herman & Lewis, 2003), pre-service teachers (e.g. Callison & Wright, 1993) and practicing teachers (e.g. Mant & Summers, 1993). It is surprising that this misconception has been reported in research involving older participants. One would expect them to understand that obstacles such as clouds cannot block the Moon at regular intervals so that earth viewers see a regular pattern of moon phases during each lunar circle.

Five papers reported a response in which learners said that the Earth's rotation causes phases of the Moon. The Sun is not mentioned in these responses, suggesting that respondents mistakenly associated moon phases with the Earth-Moon system only. This surprising response has been given not only by young children (Barnett & Morran, 2002; Sharp, 1996; Trundle et al., 2010), but also by pre-service teachers (Kelfkens & Lelliott, 2006; Trundle, Atwood & Christopher, 2002). It is worrying that all the five studies that reported this misconception used interviews to collect data, which means the response has been given by respondents, not selected from multiple-choice distracters.

The most common misconception, reported in 19 of the 22 papers, is that the Earth's shadow causes phases of the Moon. Unlike the previous (mostly naïve) ideas which have been given mainly by young children, this idea has been given by participants at all levels of education, i.e. young children (Hobson et al., 2010), secondary school students (Kucukozer, 2008), pre-service teachers (Callison & Wright, 1993), and practicing teachers (Parker & Heywood, 1998). According to this misconception, the Earth casts a shadow on the Moon so that earth viewers see a fraction of the Moon that is not covered by the Earth's shadow. This conception seems to be closer to the scientific conception because it makes reference to the Earth, the Sun and the Moon, unlike other misconceptions which refer, for example, to the Earth-Moon system without making reference to the Sun. However, respondents giving this misconception seem to lack understanding of the fact that the Moon's orbital path is tilted at 5° to the Earth's orbital path, so that the Moon is only rarely in line with the Earth-Sun system (which is why eclipses occur only rarely).

Other concepts associated with phases of the Moon

In addition to the cause of moon phases, research shows that some people have poor scientific understanding of other concepts associated with phases of the Moon. One of these concepts is the rate of change of moon phases (*the Moon takes 29.5 days to complete its lunar phases; Figure 4.4, page 88 summarises time lapse between phases of the Moon*). Mulholland and Ginns (2008) gave 72 pre-service teachers a multiple-choice test which had questions requiring respondents to select alternatives that indicate time lapse between phases of the Moon as illustrated in Table 2.1.

Table 2.1 Pre-service teachers' ideas about the rate of change of the Moon's phases (Mulholland & Ginns, 2008)

Time lapse between the following moon phases	Percentage of 72 pre-service teachers giving a correct answer	
	Pre-test	Post-test
New Moon and First Quarter	48.6	56.9
New Moon and Last Quarter	20.8	34.7
Full Moon and Last Quarter	1.4	22.2

The table shows that about half of the participants selected a correct answer for the time lapse between New Moon and First Quarter in the pre-test. However, only about 21% of the participants selected a correct response for time lapse between New Moon and Last Quarter, while only about 1% selected a correct response for the time lapse between Full Moon and Last Quarter. Table 2.1 shows that many participants gave incorrect ideas in the post-test, suggesting that the teaching intervention did not help the majority to understand this concept. It is tempting to interpret these results as suggesting that the majority of participants had poor understanding of the rate at which phases of the Moon change. However Mulholland and Ginns indicate that at least two of the questions required respondents to interpret diagrams while answering these questions. There is a possibility that the respondents' low performance in these questions reflect their inability to visualize what the diagrams illustrated, rather than misconceptions about information illustrated in the diagrams (I show in Section 2.2.3 (pages 48-52) that sometimes learners struggle to interpret information illustrated in diagrams).

Closely related to the rate of the change of the Moon's phases, research shows that some people have inaccurate ideas about duration of the Moon's orbit around the Earth (the Moon takes 29.5 days to orbit the Earth). For example, Schoon (1992) administered a multiple-choice test to a sample of 1 213 elementary students, high school students and adults. One question asked the participants about the duration of the Moon's orbit around the Earth. Thirty six percent selected 'day' as the best estimate of this duration, while 20% selected 'year' as the best estimate of this duration. These responses indicate that many participants did not know the duration of the Moon's orbit around the Earth (Schoon did not indicate the percentage of participants who selected the correct answer). Like Schoon, Trumper administered a multiple-choice test which had a question asking participants to select a distractor best estimating duration of the Moon's orbit around the Earth. The distractors were hour, day, week, month, and year (month was the best estimate). Trumper's research involved 76 university students (Trumper, 2000), 448 Junior high school students (Trumper, 2001a) and 378 senior high school students (Trumper, 2001b), all in Israel. Only three of the university students had previously studied physics (which included astronomy concepts), while none of the high school students had encountered formal instruction on astronomy concepts. In the first study, 61% of the university students selected 'month' as the best estimate. In subsequent studies, 58% of junior high school students and 70% of senior high school students selected 'month' as the best estimate. These results indicate that the majority of participants correctly estimated the duration of the Moon's orbit without formal instruction in astronomy.

More recently, Mulholland and Ginns (2008) administered a multiple-choice test which had a question asking respondents about duration of the Moon's orbit around the Earth. The respondents had to select a correct response among the following: less than a day, one day, one week, two weeks, one month, 6 months, one year, and more than a year (where 'month' was the correct answer). Just over 50% of the participants selected a correct answer for this question. Mulholland and Ginns interpreted these results as suggesting that the participants had a good idea about the answer to this question. It is noteworthy that 'month' was the only distractor close to 29.5 days in Trumper and Mulholland and Ginns's studies. As a result, selection of this distractor implies that participants knew that the Moon takes about a month to orbit the Earth. However, the questions

give no information about learners' knowledge of the exact duration of the Moon's orbit around the Earth.

Also notable from literature, is the fact that some people have poor understanding of terminology used in astronomy. One of the confusing areas is usage of the terms 'rotation' and 'revolution'. **Rotation** in space is the term used to describe the spin of planetary bodies on their axes; for example the turning of the Earth and of the Moon on their axes, while **revolution** is the term used to describe the movement of planetary bodies along a path, for example the movement of the Moon around the Earth, and the movement of the Earth around the Sun. Research shows that some children (e.g. Stahly et al., 1999) and pre-service and practicing teachers (e.g. Parker & Heywood, 1998) use the two terms interchangeably. Interestingly, Lelliott and Rollnick's (2010) review of astronomy education research shows that even researchers sometimes use these terms interchangeably. Another problem of terminology is associated with the names given to phases of the Moon. Some of these names can be confusing, e.g. New Moon confusingly refers to the phase when the Moon cannot be seen, while First Quarter and Last Quarter refer to phases in which Earth viewers see a 'half moon' (not a quarter). Research shows that some people have problem with these terms. For example, some Spanish pre-service teachers who participated in Martinez-Pena and Gil-Quilez's (2001) research thought First Quarter meant that a quarter of the visible surface of the Moon could be seen from Earth, while in actual fact half of the visible surface can be seen. This confusing terminology might be one of the reasons why people develop misconceptions about particular aspects of astronomy.

Effect of teaching interventions

Many of the conceptual difficulties discussed in the previous section resist change, i.e. they continue to exist after teaching interventions. Appendix G(ii) illustrates studies which report interventions intended to help young children (e.g. Kikas, 2006; Trundle, Atwood & Christopher, 2007b), high school students (e.g. Dove, 2002; Herman & Lewis, 2003), and university students (e.g. Barab, Hay, Barnett & Keating, 2000; Hansen, Barnett, MaKinster & Keating, 2004a, 2004b) gain better understanding of concepts associated with phases of the Moon.

The interventions used different learning activities in addition to the usual talk and chalk method. These learning activities included observation of the Moon, usage of physical models, and usage of computer software. Moon observations required participants to observe the Moon for at least one complete cycle of lunar phases and record observations on a moon chart. These observations were intended to help participants realise that the Moon changes shape in the course of a month as seen from the Earth. Furthermore, the purpose of moon observation was to enable participants to determine the pattern of moon phases and the duration of a complete circle of these phases.

Unlike moon observations, models were used mainly to help participants understand the cause of moon's phases. The participants used models to simulate the movement of the Moon around the Earth, and to determine configurations the Earth-Moon-Sun system responsible for each of the eight phases of the Moon seen from the Earth. Only one study used models for a different purpose (i.e. Subramaniam and Padalkar, 2009). Subramaniam and Padalkar asked participants to imagine

looking at physical objects while trying to understand the cause of Moon phases. Models were given only to those participants who failed to create mental images.

Computer simulations, on the other hand, were used to display shape of the Moon seen from the Earth for a given configuration of components of the Earth-Moon-Sun system (as was the case with manipulation of models). In addition, the software allowed participants to observe the pattern of lunar phases and the duration of a complete circle of these phases. In general, the studies discussed in Appendix G(ii) reported improvement in learners' performance after interventions. However, all studies reported that some participants struggled to understand these concepts even after interventions. These findings indicate that the concepts associated with the Earth-Moon-Sun system are difficult to understand (a point also noted by Rudmann, 2002 and Trundle, Atwood & Christopher, 2007a).

2.1.2 Possible causes of these difficulties

There are many possible causes of difficulties encountered when learning about moon phases. These include lack of personal experience of phenomena associated with phases of the Moon, and inability to imagine looking at spatial objects from different perspectives.

Lack of personal experience of concepts associated with moon phases

Several responses demonstrate that some people lack personal experience of concepts associated with moon phases. For example, some people are not able to correctly reason about moonrise and moonset (*the Moon generally rises in the east and sets in the west. Each day the Moon rises about 50-60 minutes later as compared to the previous day*). Ogan-Bekiroglu (2007) asked 36 pre-service teachers to answer questions about moonrise and moonset. Only 14% of the participants gave scientifically acceptable answers. Six percent incorrectly said that the Moon rises in the west and sets in the east, 36% said that the Moon does not rise and set (suggesting that they were not aware that the Moon appears to rise and set as seen from Earth due to the Earth's spin), while the rest gave other scientifically unacceptable explanations. These responses indicate that the majority of the participants had poor conceptual understanding of the rising and setting of the Moon. Some of the participants giving these conceptions claimed to have seen the Moon in the sky. Ogan-Bekiroglu suspected that they had not paid full attention to movement of the Moon in the sky.

More recently, Plummer and her associates conducted a series of studies investigating primary school students' and pre-service teachers' ideas about motion of celestial objects including the Sun, the Moon and the stars (Plummer 2009a, 2009b; Plummer & Krajcik, 2010; Plummer, Wasko & Slagle 2011, Plummer, Zahm & Rice, 2010). The majority of their participants believed that the Moon rises and sets in opposite sides of the horizon. However, some gave responses suggesting that (i) the Moon does not move, but is fixed in one location in the sky, (ii) the Moon does not rise and set, but circles the sky, and (iii) the Moon rises and sets at the same location in the horizon. Incorrect ideas about moonrise and moonset suggest that the participants did not fully understand facts associated with the Earth's spin.

Another point illustrating that some people lack personal experience of astronomical phenomena is apparent lack of awareness of shape of the Moon seen in the sky during different phases. Trundle and her associates have conducted several studies intended to improve students' and pre-service teachers' understanding of concepts associated with phases of the Moon. Their research usually required participants to make daily moon observations, recording shape of the Moon observed each day over a nine-week period. In three of their studies, Trundle and her associates asked 50 pre-service teachers (Bell & Trundle, 2008), 21 Grades two-to-three students (Hobson et al., 2010), and 20 Grade 8 students (Trundle et al., 2010) to draw shapes of the Moon they expected to see before making moon observations. Results show that 98% the pre-service teachers, 95% of the Grade 8 students, and all of the Grades two-to-three students drew at least one shape incorrectly. Sixteen of the pre-service teachers had completed at least one course in astronomy. Fifteen of these participants drew at least one non-scientific shape. The number of non-scientific shapes ranged between 2 and 12. These results show that some pre-service teachers had poor conceptions about phases of the Moon even after instruction.

In a separate study, Plummer (2009a) asked 60 primary school students whether the Moon in the sky changes shape as seen from the Earth. She asked the students to draw (or describe) the Moon. Fifty three students drew at least two phases of the Moon correctly. Of the remaining seven learners, two could not draw or describe the Moon at all while 5 made drawings that were all inaccurate. These results show that some students and pre-service teachers have inaccurate conceptions about the changing shapes of the Moon.

Inability to mentally perform simultaneous rotations and revolutions

Another possible cause of these problems is that some respondents struggle to mentally perform simultaneous rotations and revolutions. For example, some people struggle to understand why only one side of the Moon is visible from earth (*the Moon spins on its axis at the same rate as it orbits the Earth due to a phenomenon called tidal locking. As a result, earth viewers see only one side of the Moon*). Ogan-Bekiroglu (2007) asked 36 pre-service teachers to explain whether earth viewers see the same side of the Moon throughout the Moon's orbit around the Earth. Only 6% of the participants gave the correct answer, saying that earth viewers see the same side of the Moon because the Moon spins on its axis at the same rate as it orbits the Earth. Fifty six percent said that we see the same side of the Moon, but could not give a correct explanation. Thirty six percent said that we do not always see the same side of the Moon. When asked the same question, 46% of 98 secondary school students (Dove, 2002), 25% of 448 junior high school students (Trumper, 2001a), 20% of 378 senior high school students (Trumper, 2001b), and 20% of 76 university students (Trumper, 2000) gave the correct response. In addition, 10% of 251 university students in Zelik, Schau, and Matten's (1998) study gave the correct answer in the pre-test, while 40% gave the correct answer in the post-test. These responses show that several participants had poor understanding of the rate of the Moon's rotation and the rate of the Moon's orbit around the Earth.

Inability to imagine looking at spatial objects from different perspectives

Another possible cause of these difficulties is people's inability to imagine looking at astronomical phenomena from different perspectives. For example, some people struggle to imagine looking at the Moon from different locations on Earth (*in each day, viewers from all parts of the Earth see the same phase of the Moon*). Several researchers asked participants to state whether the Moon appears to be in the same phase to viewers at different locations on earth in one particular day, e.g. Full Moon in Indiana and Australia (Schoon, 1992), Full Moon in New York and California (Rider, 2002), Full Moon in Turkey and America (Ogan-Bekiroglu, 2007), Full Moon in USA and Australia (Mulholland and Ginns), and First Quarter in Johannesburg and Australia (Mulholland & Ginns, 2008). Table 2.2 illustrates results found by these researchers.

Table 2.2 Learners' ideas about shape of the Moon seen from different locations on Earth (reported in literature)

Authors	Participants	Moon phase and locations on Earth	Percentage of participants giving correct responses
Schoon (1992)	1213 elementary, high school and university students in Indiana	Full Moon in Indiana and Australia	53
Rider (2002)	32 middle school students in New York	Full Moon in New York and California	10
Ogan-Bekiroglu (2007)	36 pre-service teachers in Turkey	Full Moon in Turkey and America	39
Mulholland & Ginns (2008)	72 pre-service teachers in Australia	Full Moon in USA and in Australia	51 in pre-test, 79 in post-test
		First Quarter in Johannesburg and in Australia	33 in pre-test, 53 in post-test

Most of the researchers asked participants about Full Moon, while only one study asked participants about First Quarter (Mulholland & Ginns, 2008). The table shows that about half of the participants gave correct responses in Schoon and Mulholland and Ginns' studies (before intervention in the latter study). However, fewer participants gave correct responses in other studies e.g. 10% of 32 middle school students in Rider's (2002) study and 39% of 36 pre-service teachers who participated in Ogan-Bekiroglu's study. These responses suggest that very few participants knew that the Moon would appear to be the same for viewers at different locations on Earth. This, in turn, suggests that the majority of participants struggled to imagine looking at the Moon from different locations on Earth.

Another point illustrating this difficulty is peoples' inability to link phase of the Moon, time of day, and the Moon's location in the sky. Most researchers who investigated people's understanding of this link focused on the Full Moon phase, requiring participants to determine time of day when Full Moon rises (Zelik et al., 1998; Mulholland & Ginns, 2008) and time of day when Full Moon sets (Rider, 2002; Ogan-Bekiroglu, 2007). However, Mulholland and Ginns included questions about

position of crescent moon at sunset and time of day at which Last Quarter sets. Table 2.3 illustrates results obtained by these researchers.

Table 2.3 Students' ideas about moon phase, the Moon's location in the sky and time of day (reported in literature)

Authors	Participants	Moon phase, Moon's location and time of day	Percentage of participants who gave correct responses
Zelik et al. (1998)	251 university students in New Mexico	Local time if Full Moon was rising in the east	54 in pre-test, 75 in post-test
Rider (2002)	32 middle school students in New York	Position of Full Moon at sunrise	6
Ogan-Bekiroglu (2007)	36 pre-service teachers in Turkey	Position of Full Moon at sunrise	72
Mulholland & Ginns (2008)	72 pre-service teachers in Australia	Where to see Waxing Crescent moon at sunset	8 in pre-test, 24 in post-test
		Time at which Last Quarter moon sets	4 in pre-test, 6 in post-test
		Phase of the Moon that rises at sunset	13 in pre-test, 25 in post-test

The table shows that 72% of pre-service teachers (Ogan-Bekiroglu, 2007) and 54% of university students (Zelik et al., 1998) gave correct answers for these questions (performance of the university students increased to 75% after an intervention). However, only 6% of middle school students (Rider, 2002) and 8%, 4% and 13% of pre-service teachers (Mulholland & Ginns, 2008) gave correct answers for these questions. Performance of the pre-service teachers who participated in Mulholland and Ginns' study improved only to 24%, 6% and 25% after an intervention which required the participants to make daily moon observations for at least one complete circle of phases. Poor performance after intervention suggests that the intervention was not effective in helping the teachers to understand relationships between position of the Moon in the sky, time of day and corresponding phase of the Moon.

A further point illustrating this problem is people's inability to imagine viewing the Earth from the Moon. Martinez-Pena and Gil-Quilez (2001) asked 78 pre-service teachers to explain a situation in which an astronaut could see the Moon in its Last Quarter phase when Earth viewers see Full Moon. To get the correct answer, participants needed to determine the configuration of components of the Earth-Moon-Sun system responsible for Full Moon seen from the Earth, and to determine a position in the sky from which the Moon would appear to be in its Last Quarter phase. Some participants drew diagrams that correctly explained the situation (Martinez-Pena and Gil-Quilez did not report frequencies). Some participants drew correct diagrams but gave wrong explanations (suggesting that the participants did not fully understand the situation). Others drew incorrect diagrams,

suggesting that they struggled to visualize the situation explained in the question. In another study, Rochford and Sass (1988) administered a multiple-choice test which had a question asking participants to determine phase of the Earth seen by an astronaut on the Moon if the Moon appeared to be crescent-shaped as seen from the Earth (similar to Question 8 in Appendix B of this study). Sixty seven percent of the participants obtained a correct answer for this question (Rochford and Sass did not report the total number of participants). Results obtained in these two studies show that some students struggle to imagine seeing the Earth from the Moon.

2.1.3 Spatial ability and astronomy education

Many researchers have realised that learners struggle to understand astronomy concepts because these concepts require usage of spatial ability skills (e.g. Hans et al., 2008, Hobson et al., 2010; Mulholland & Ginns, 2008; Padalkar & Ramadas, 2011). These skills include manipulation of objects in space (Bishop, 1978; Black, 2005; Rudmann, 2002) and perceiving objects from different perspectives in space (Barab et al., 2000; Callison & Wright, 1993; Hansen et al., 2004b; Suzuki, 2003, Plummer et al., 2011). Despite the large number of researchers arguing for links between spatial ability and understanding of astronomy concepts, few have conducted research investigating these links. Appendix G(iii) provides a summary of these studies. The following trends are observable from the appendix:

- *Content covered in these studies:* A wide range of concepts have been investigated in these studies. These include concepts associated with the Earth-Sun system (Kikas, 2006); the Earth-Moon-Sun system including day and night, seasons, moon's phases and eclipses (Callison & Wright, 1993; Rudmann, 2002); phases of the Moon (Wilhelm, 2009b); and Earth Sciences concepts including the Earth-Moon-Sun system, map work and meteorology (Black, 2005).
- *Astronomy tests administered in these studies:* Some researchers administered tests measuring learners' understanding of general astronomy concepts (i.e. Black, 2005; Callison & Wright, 1993; Kikas, 2006; Rudmann, 2002). Others administered tests assessing specific skills needed in astronomy education, e.g. rotation and revolution. For example, Wilhelm (2009b) administered a Lunar Phase Concept Inventory; a test assessing learners' mastery of skills relevant to understanding phases of the Moon. On the other hand, Rudmann (2002) administered an Astronomy Based Geometric Tests (ABGT); a test measuring learners' mastery of skills needed in astronomy, e.g. rotation and revolution.
- *Spatial ability tests administered in these studies:* The following spatial ability tests were administered in the studies:
 - Callison and Wright (1993), Kikas (2006) and Rudmann (2002) administered tests measuring Spatial Orientation (as defined in Section 2.2.1, p 26 of this thesis).
 - Black (2005) administered tests measuring three spatial ability skills: Spatial Perception, Spatial Orientation, and Spatial Visualization.

- Wilhelm (2009b) administered a Geometry Spatial Assessment (GSA). The GSA appeared to consist of items obtained from other spatial tests (but details are very sketchy in the article).
- *Other tests administered in these studies:* Callison and Wright (1993) administered a test measuring logical thinking. On the other hand, Kikas (2006) administered two tests; one measuring contour extraction and the other measuring memory.
- *Aim of these studies:* Two studies investigated correlations between spatial ability and students' performance in astronomy tests (Black, 2005; Rudmann, 2002). Two other studies investigated links between spatial ability and conceptual change as students learned about astronomy concepts (Callison & Wright, 1993; Kikas, 2006). The fifth study investigated links between gender differences and conceptual gains after an intervention targeting phases of the Moon (Wilhelm, 2009b). That is, Wilhelm's study is the only one which did not report on links between spatial ability and participants' understanding of astronomy concepts.

Mixed results have been obtained about links between spatial ability and understanding of astronomy concepts. For example, Callison and Wright found no correlations between spatial ability and pre-service teachers' ability to understand concepts associated with phases of the Moon after an intervention. However, Kikas (2006) found both positive and negative correlations between spatial ability and students' learning of concepts associated with the Earth. Kikas interviewed 176 Grade 1 children who had not formally learned about the Earth, and interviewed the same children again in Grade 2 after they had learned about the Earth. Her interview consisted of two types of questions, factual questions and generative questions. Factual questions tested learners' **factual knowledge** of concepts associated with the Earth (this knowledge might be obtained by recall). Generative questions tested learners' **understanding** of concepts associated with the Earth (the learners needed to deduce answers from various sources of information). Generative questions produced two types of responses: scientific responses and synthetic responses. Synthetic responses are non-scientific responses produced as learners attempt to reconcile their preconceived ideas with knowledge taught in school. These responses indicate that learners attempted but failed to construct fully scientific responses.

Kikas found positive correlations between spatial ability and Grade 1 learners' responses to factual questions, but found negative correlations between spatial ability and these learners' synthetic responses. Students with low spatial ability scores developed more synthetic responses in the second grade (but no information is given about understanding of learners with high spatial ability skills in the second grade).

Other studies have reported only positive correlations between spatial ability and understanding of astronomy concepts. For example, Black (2005) found significant positive correlations between spatial ability and learners' performance on Earth Sciences tests. In the same way, Rudmann (2002) found some relationships between Cube Comparisons Test scores (measuring Spatial Orientation) and learners' ideas about the cause of seasons. Learners holding scientifically

acceptable ideas about the cause of seasons obtained high scores in the Cube Comparisons and Geometry-Based Astronomy Tests, while other learners obtained low scores in these tests.

Furthermore, Rudmann (2002) found that Cube Comparisons Test scores were highest for learners giving scientifically acceptable explanations about the cause of seasons (the tilt of the Earth's axis is fixed as the Earth orbits the Sun), intermediate for those giving the wobbly-tilt explanation (the tilt of the Earth's axis changes to give seasons), and lowest for those giving the elliptical-orbit explanation (the Earth's orbital path is oval in shape, so that the Sun is closer to the Earth in summer than in winter). In addition, scores obtained on the Geometry-Based Astronomy Test were highest for learners giving the scientifically acceptable explanation and low for learners giving the other two explanations. Rudmann concluded that spatial ability partially determined explanations that learners found plausible.

Some links have been found between spatial ability and achievement levels in other science subjects, e.g. Natural Sciences (Piburn, 1980), Life Sciences (Rochford, 1985; Sanders, 2001), Physics (Pallrand & Seeber, 1984) and Chemistry (e.g. Ferk, Vrtacnik and Blejec, 2003; Pribyl & Bodner, 1987). Pribyl and Bodner found significant correlations between spatial ability and performance on a chemistry test, especially when questions required higher order cognitive skills rather than recall/memory. Furthermore, Pribyl and Bodner found that students with high spatial ability skills were more likely to draw additional structures when answering questions, and that these structures enabled them to perform better than students with low spatial ability skills. In Ferk et al.'s study, students with high spatial ability skills outperformed their low spatial ability counterparts in a test measuring ability to perceive and mentally manipulate molecular structures. In another study, Rochford (1985) administered spatial and anatomical tests to university medical students. Performance of high and low spatial-ability students was almost the same on anatomy questions requiring no mental manipulation of objects in space. However, high spatial-ability students outperformed their low spatial-ability counterparts on questions requiring mental manipulation of objects in space. Rochford's results provide further information suggesting that spatial ability correlates with students' understanding of science concepts.

2.1.4 Summary

The above literature shows that many learners and teachers struggle to understand concepts associated with phases of the Moon, and further shows that many struggle to understand these concepts even after interventions. Additionally, the literature shows that learners struggle to mentally manipulate components of the Earth-Moon-Sun system in space (e.g. changing reference frames to imagine viewing the Earth from the Moon) to understand concepts associated with phases of the Moon. I used this literature to design a diagnostic test investigating learners' understanding of the cause of the Moon's phases, their understanding of other concepts associated with phases of the Moon, and their ability to mentally manipulate celestial objects in space (skills needed to understand phases of the Moon). Furthermore, I used this literature to interpret and discuss findings obtained from the diagnostic test.

The last section of this review shows that very little research has investigated links between spatial ability and students' understanding of astronomy concepts. The current study was conducted to extend our understanding of links between spatial ability and students' understanding phases of the Moon. The study focused on diagrams illustrating phases of the Moon because the review of the literature shows that very little research has investigated issues related to these diagrams, despite abundance of these diagrams in school textbooks. Thus, the current study investigated issues related to phases of the Moon, with particular focus on spatial ability and textbook diagrams. The next section deals with constructs associated with spatial ability and diagrams.

2.2 Theoretical framework

A theoretical framework is a set of theories and research findings used to “inform and guide the research and interpretation of results” (LeCompte & Preissle, 1992:847). Theoretical frameworks enable researchers to ensure that “research design ... and/or data analysis flow logically and soundly from theory” (Caliendo & Kyle, 1996:225).

This chapter describes constructs which formed a theoretical framework for the study. Section 2.2.1 discusses the construct ‘spatial ability’. I discuss this construct because interpretation of diagrams illustrating the Earth-Moon-Sun system requires people to mentally manipulate objects in space. Section 2.2.2 discusses models. I included this section because the study focused on diagrams illustrating a model of the Earth-Moon-Sun system. Section 2.2.3 deals with theories associated with diagram design and interpretation.

2.2.1 Spatial Ability

Spatial ability was established from research involving mental tests. Mental testing started during industrial revolution, the revolution which resulted in large populations in places like the United States of America (Eliot, 1987). The increase in populations resulted in a need to train people for different occupations (Eliot, 1987; Smith, 1964). Mental tests were developed to assess people's ability to cope with these occupations. The original tests consisted of verbal material only, but subsequent tests included nonverbal material to cater for people who were not fluent in English and those who could not read and write (Carroll, 1993; Eliot, 1987).

An English psychologist, Charles Spearman, investigated possible correlations between scores obtained by people answering these tests (Carroll, 1993). He found moderate to high correlations between the scores. He argued that if all the scores had correlations of 1.0, then all the tests would be measuring one common factor, which he named general ability. The fact that these correlations were less than 1.0 suggested to him that each test measured general ability and a factor specific to each test (Carroll, 1993; Eliot, 1987). Further research resulted in establishment of several factors measured by these tests. One of these factors was called ‘spatial ability’. However, there was some scepticism as to whether the tests claimed to measure this construct really measured the construct.

Several researchers undertook to investigate mental processes and strategies employed by people answering spatial ability tests.

In the following sections, I discuss three approaches used to study the construct ‘spatial ability’: the *Psychometric Approach* which established existence of the construct, the *Information Processing Approach* which investigated mental processes undertaken by people answering spatial ability tests, and the *Strategic Approach* which investigated strategies used by people answering these tests. This discussion helps to show that the tests used in this study indeed measured the skills they were designed to measure.

The Psychometric Approach

This approach was marked by definition of the construct ‘spatial ability’, identification of components of this construct, and design of tests measuring each of the components.

Definition of ‘spatial ability’

Spatial ability was established as early as the 1930s and 40s (McGee, 1979; Smith, 1964). However, researchers could not agree about the exact definition of the construct (Eliot & Hauptman, 1981; Eliot & Smith, 1983). Review of literature shows that to date, investigators doing research on ‘spatial ability’ employ different definitions of this construct. It becomes important, therefore, that I acknowledge the spectrum of definitions existing about the construct ‘spatial ability’, and to explicate the definition (and therefore conception) applicable to the current study.

Table 2.4 lists some definitions of spatial ability put forward by different authors. Analysis of these definitions indicates that spatial ability involves generation, storage and manipulation of mental images. That is, people should be able to perceive objects and create mental images of the objects. Mumaw and Pellegrino (1984) point out that these mental images should be ‘precise’ representations of the objects. Having created mental images, people should be able to manipulate these images in space. This manipulation includes rotation, twisting, and rearrangement of objects. People should be able to store the images while doing the mental manipulations. This storage enables people to recall previous orientations and positions when undertaking a series of mental transformations on the images.

Learners interpreting diagrams illustrating phases of the Moon need to (i) generate mental images of information illustrated in the diagrams, (ii) mentally manipulate these images (e.g. rotating shapes), and (iii) store these images in mind while doing mental manipulations. Out of the definitions discussed in Table 2.4, Lohman’s definition appears to encompass these processes, i.e. generation, manipulation and retention of mental images. As a result, I adopt it as an appropriate definition of spatial ability in this thesis. Thus the current study defines spatial ability as “the ability to generate, retain, and manipulate abstract visual images” (after Lohman, 1979:188).

Table 2.4 Definitions of spatial ability found in literature

Source	Definition
Burt (1949; cited by Eliot & Smith, 1983:5)	“The ability to perceive, interpret, or mentally rearrange objects as spatially related”.
Carroll (1993:304)	“How individuals deal with materials presented in space - whether in one, two or three dimensions, or with how individuals orient themselves in space”.
El Koussy (1935; cited by McGee, 1979:890)	“Ability to obtain and the facility to utilize spatial imagery”.
Eliot & Hauptman (1981:60-61)	“Both the ability to organize the distributional aspects in the representation of information <i>and</i> as the ability to generate, retain, and manipulate visual images”.
Linn & Petersen (1985:1482)	“Skill in representing, transforming, generating, and recalling symbolic, nonlinguistic information”.
Lohman (1979:188)	“The ability to generate, retain, and manipulate abstract visual images”.
Mumaw & Pellegrino (1984:936)	“Ability to establish sufficiently precise and stable internal representations of unfamiliar visual stimuli that can be subsequently transformed or operated on with a minimal information loss”.
Thurstone (1938; cited by Eliot, 1987:45)	“Facility in holding a mental image and mentally twisting, turning, or rotating it to a different position and then matching this transformed image with suggested solution”.
Truman Kelly (1928; cited by Smith, 1964:46)	“An ability involving the seeing and retention of geometric forms” and “a facility in the mental manipulation of spatial relationships”.

Components of Spatial Ability

Researchers agree that spatial ability consists of several components (e.g. Ekstrom, French, Harman & Dermen, 1976; Eliot 1987; McGee, 1979). However, there is no agreement about the names and number of these components. It is advisable that I discuss components of spatial ability (and their names) as conceptualised in this study. This would help readers to know what each term means (different researchers use different terms to refer to different components).

Appendix G(iv) shows that spatial ability can be classified into three components associated with perception of objects, manipulation of objects, and manipulation of components of objects. Accurate interpretation of diagrams illustrating phases of the Moon requires viewers to (i) pay attention to each of the shapes representing the Moon as it orbits the Earth, (ii) to imagine looking at the Earth-Moon-Sun system from the Earth and from space, and (iii) to imagine the Moon changing position relative to the Earth and the Sun. Based on these requirements and on information presented in Appendix G(iv), I adopt the following names and definitions for components of spatial ability:

- ***Spatial Perception***: “An ability to perceive spatial patterns accurately and to compare them with each other” (French, 1951; cited by Eliot & Smith, 1983:4). This involves “the ability to hold a

given visual ... configuration in mind so as to disembed it from other well defined perceptual material” (Ekstrom et al., 1976:19).

- ***Spatial Orientation***: “Ability to rotate a two or three dimensional figure rapidly and accurately” (Linn & Petersen, 1985:1483), “and the ability to imagine how a stimulus ... will appear from another perspective” (Lohman, 1979:188).
- ***Spatial Visualization***: “The mental ability to see or observe the spatial relationship of objects involved in dynamic situations ... (when the) objects involved change their positions in space relative to one another” (Barratt, 1953:21).

Tests measuring spatial ability

Several tests have been developed to measure spatial ability (see Eliot, 1980). I selected six spatial ability tests from the *Kit of Factor Referenced Cognitive Tests* developed by Ekstrom et al. (1976) at the Education Testing Service (ETS) in Princeton (see Table 2.5 on page 27). Appendix G(v) discusses demands of each test, and further discusses similarities and differences between these demands and skills required to understand phases of the Moon. Understanding phases of the Moon requires people to perform a series of mental processes, i.e. to imagine the Earth turning on its axis so that all earth viewers see the Moon in one particular day, and to imagine the Moon orbiting the Earth so that the Moon goes through different phases in the course of a lunar circle. Understanding moon phases from diagrams requires diagram viewers to consider the Moon in each position around the Earth (and temporarily ignore the Moon in other positions which might serve as distracting background), to understand why the Moon goes through each phase in the course of a lunar cycle.

The following discussion shows that the six spatial ability tests measured skills needed to understand phases of the Moon. The Hidden Patterns Test measures learner’s ability to mentally detach a figure from a distracting background, analogous to perceiving the Moon in one position while temporarily ignoring the Moon in other positions. The Card Rotations and Cube Comparisons Tests measure learner’s ability to mentally rotate objects, analogous to mentally spinning the Earth on its axis, and mentally orbiting the Moon around the Earth. The Form Board, Paper Folding and Surface Development Tests measure learner’s ability to undertake several mental processes on objects, analogous to rotating the Earth on its axis while orbiting the Moon around the Earth, and perceiving the Moon in each position around the Earth.

However, there exist differences between skills measured by the spatial ability tests and skills needed to understand phases of the Moon. The Hidden Patterns, Card Rotations, and Form Board Tests measure manipulation of two-dimensional shapes, contrary to Moon phase diagrams which require manipulation of spherical objects. Furthermore, these tests measure manipulation of objects in two-dimensional space (e.g. plane of the paper), while understanding moon phases requires manipulation of objects in three-dimensional space. The Cube Comparisons, Paper Folding and Surface Development Tests on the other hand, measure manipulation of three-dimensional objects in three-dimensional space. However, these tests use three-dimensional shapes other than spheres

needed to understand phases of the Moon. Despite these differences, I used these tests because they appeared to be suitable for measuring spatial ability skills needed to understand phases of the Moon.

These spatial ability skills require students to perform functions at the **formal operational level** of Piaget (1964). People who have reached this level are capable of abstract conceptual thinking. According to Piaget, 12 year olds should be fully at the formal operational level. However, people who replicate Piaget's experiments show that some adults do not reason at the formal operation level (see for example Tomlinson-Keasey, 1972). Thus, Piaget's findings regarding the age at which children are able to cope with abstract reasoning are somewhat questionable.

The current study focused on content knowledge prescribed for learners in Grades 4 to 9 of the South African school system (approximately 9 to 14 years of age). According to Piagetian levels of development, 9-11 year olds are likely to struggle undertaking mental processes required to understand the Earth-Moon-Sun system, while the 12-14 year olds should undertake these mental processes with ease.

Each of the six tests has two parts, both parts measuring the same construct. Table 2.5 illustrates the number of items and the total score in each test.

Table 2.5 Total scores obtainable in each of the six spatial ability tests administered in this study

Test	Number of items in each part	Total number of items	Maximum score for each item	Total score
Hidden Patterns Test	20	40	10	400
Card Rotations Test	10	20	8	160
Cube Comparisons Test	21	42	1	42
Form Board Test	24	48	5	240
Paper Folding Test	10	20	1	20
Surface Development Test	6	12	5	60

When studying spatial ability, some researchers administer one part while others administer both parts of each test. The following discussion deals with literature reporting to have used the 1976 ETS kit from which I selected the test. I have used this literature when discussing results obtained in the current study.

Review of literature shows that many researchers use tests developed by the Education Testing Service. However, some use a kit designed in 1963 while others use a modified version of this kit, published in 1976 (the same kit used in the current study). Below I discuss findings from research that administered the 1976 kit. I use these findings when discussing results obtained in the current study. Appendix G(vi) illustrates results obtained by researchers who reported to have administered one part of each test, and results obtained by researchers who appear to have administered both

parts of each test. The following discussion explains why I consider the latter group of researchers to have administered both parts of each test.

- Researchers in seven studies reported to have administered both parts of each test (Abdel-Rahim, Nagoshi & Vandenberg, 1990; Allen, Kirasic, Dobson, Long & Beck, 1996; Geary, Salthouse, Chen & Fan, 1996; Geary & Widaman, 1987; Miyake, Friedman, Rettinger, Shah & Hegarty, 2001; Smalley, Thompson, Spence, Judd & Sparkes, 1989; Wickett, Vernon & Lee, 2000).
- Three studies did not report whether one or both parts were administered. However, the following facts indicate that the researchers administered both parts of each test:
 - Peters, Laeng, Latham, Jackson, Zaiyouna and Richardson (1995) reported mean scores higher than the total score obtainable in one part of each test.
 - Barnea and Dori (1999) reported a mean score higher than the total score obtainable from one part of this test (on the Card Rotations Test after an intervention).
 - Kozhevnikov and Hegarty (2001) reported maximum scores (when calculating range) higher than total scores obtainable in one part of the tests.

Studies discussed in Appendix G(vi) indicate mean scores obtained by people who answered each test. I converted these mean scores to percentages for ease of comparison of performance in each test. The following patterns are observed from the appendix.

Hidden Patterns Test (CF-2): Burton and Fogarty (2003) reported a mean score of 23% while Miyake et al. (2001) reported a mean score of 27%. On the contrary, Smalley et al. (1989) reported a mean score of 43% while Wickett et al. (2000) reported a mean score of 60%. Thus, learners in the latter two studies scored twice as high as learners in the previous two studies. There appears to be no link between age levels of participants and mean scores reported in this test.

These results suggest that some participants (who obtained low mean scores) encountered more difficulty in mentally detaching a figure from a complex configuration while others (who obtained higher mean scores) were fairly able to mentally detach a figure from a complex configuration.

Card Rotations Test (S-1): Abdel-Rahim et al. (1990) reported a mean score in the 20s while Geary et al. (1996) reported a mean score in the 30s for older adults. Barnea and Dori (1999) and Miyake et al. (2001) reported mean scores in the 40s. However, Barnea and Dori reported an improved mean score (in the 50s) after some intervention. Three studies (Geary et al., 1996 [for younger Chinese adults]; Sanders, 2004 and Smalley et al., 1989) reported mean scores in the 50s. However, Sanders reported improved mean scores (in 50s and 60s) after an intervention. Five studies (Burton & Fogarty, 2003; Geary & Widaman, 1987; Kozhevnikov & Hegarty, 2001; Mayer & Massa, 2003 [for female undergraduate students] and Peters et al., 1995) reported mean scores in the 60s.

These results show that high school students tended to obtain lower mean scores in this test, i.e. 24% in Abdel-Rahim et al.'s study, 48% in Barnea and Dori's study (although this score improved

to 54% after an intervention), and 56% in Sanders's study (although this score improved to 64% after intervention for the experimental group, but decreased to 54% after intervention for the comparison group). A sample consisting of young and old people (12 years and older in Smalley et al.'s study) obtained an intermediate mean score of 55%. Undergraduates and adults obtained high mean scores (in the 60s and 70s), except those who participated in Miyake et al.'s (2001) study who obtained a mean score of 49%. On the other hand, older adults who participated in Geary et al.'s (1996) study obtained the lowest mean scores, i.e. 38% and 36% for USA and Chinese participants respectively.

These results suggest that adults and university students were better able to cope with demands of this test, than high school students and older adults. This in turn suggests that adults and university students were better able to mentally rotate two-dimensional objects on plane of the paper, than high school students and older adults.

Cube Comparisons Test (S-2): Appendix G(vi) indicates that older adults obtained the lowest mean scores, i.e. 10% and 12% (Geary et al., 1996). On the other hand, high school students who participated in Sanders (2004) and Barnea and Dori's (1999) studies obtained mean scores in the 20s, while high school students in Abdel-Rahim et al.'s (1990) study obtained a much higher mean score (38% and 40% boys and girls respectively). A sample consisting of young and old people obtained a mean score of 36% (Smalley et al., 1989). The tables further show that university students and adults obtained higher mean scores, i.e. in the 30s (Allen et al., 1996 [South Carolinian participants]; Geary et al., 1996 [younger Chinese adults]), in the 40s (Geary et al., 1996 [younger American adults]; Geary & Widaman, 1987; Kozhevnikov & Hegarty, 2001; Kozhevnikov, Hegarty & Mayer, 2002) and in the 50s (Allen et al., 1996 [Georgian participants]; Burton & Fogarty, 2003).

These results show that young adults and university students were better able to cope with demands of the Cube Comparisons Test, than high school students and older adults. Furthermore, the results show that participants obtained lower scores in this test (with the highest mean score in the 50s) than in the Card Rotations Test (with the highest mean scores in the 60s and 70s). Low performance in this test suggests that the participants encountered more difficulties when undertaking mental rotations involving three-dimensional objects, than when rotating two-dimensional objects.

Form Board Test (VZ-1): Egyptian high school students who participated in Abdel-Rahim et al.'s (1990) study obtained mean scores of 26% and 30% (males and females respectively). On the other hand, South African high school students who participated in Sanders's (2004) study obtained mean scores of 42% and 38% in experimental and comparison groups respectively (Appendix G(vi) shows that these participants obtained better scores after an intervention). Adults and university students who participated in Burton and Fogarty's (2003) study obtained a mean score of 43%. However, Kozhevnikov et al. (2002) reported a lower mean score (9%). There is no clear pattern in these results, about performance of high school and university students.

This discussion shows that no study in the literature reviewed reported a mean score of 50% and above. This suggests that participants in these studies struggled to meet demands of this test. That

is, the participants encountered difficulties in performing a series of mental operations on two-dimensional objects on the plane of the paper, a skill measured by this test.

Paper Folding Test (VZ-2): Like the previous tests, adults and university students performed better than high school students on this test. Israeli high school students who participated in Barnea and Dori's (1999) study obtained a mean score of 25% in this test (the participants obtained a better score in a post-test). On the other hand, Egyptian high school students who participated in Abdel-Rahim et al.'s (1990) study obtained mean scores of 35% and 30% (males and females respectively). South African high school students who participated in Sanders' (2004) study obtained a mean score of 40% (these learners obtained a better score after an intervention).

Adults and university students obtained better mean scores in this test: 50% (Burton & Fogarty, 2003, and female participants in Mayer and Massa, 2003), 55% (Miyake et al., 2001; Peters et al., 1995), 60% (Kozhevnikov & Hegarty, 2001; Kozhevnikov et al., 2002; Wickett et al., 2000) and 70% (males participants in Mayer & Massa, 2003).

These results show that university students were better able to perform a series of mental operations in space.

Surface Development Test (VZ-3): Egyptian high school students who participated in Abdel-Rahim et al.'s (1990) study obtained the lowest mean scores in this test, i.e. 17% and 13% by males and females respectively. South African high school students who participated in Sanders's (2004) study obtained better scores, i.e. 40% and 43% in experimental and comparison groups respectively (the experimental group obtained a better mean score after an intervention). Australian adults and university students who participated in Burton and Fogarty's (2003) study obtained a mean score of 50% in this test. On the other hand, Georgian university students obtained a mean score of 67% while South Carolinian university students obtained a mean score of 48% (Allen et al., 1996). These results suggest that adults and university students were better able to mentally manipulate three-dimensional images in space.

It has to be noted that several researchers have conducted interventions with the aim of improving learners' spatial ability skills (e.g. Braukmann & Pedras, 1993; Cohen, 1983; Lord, 1985). Their exercises included (i) usage of two-dimensional representations, e.g. asking participants to imagine what a two-dimensional structure would look like after rotation or when viewed from different perspectives, and then showing them a step by step procedure illustrating this rotation; (ii) usage of three-dimensional objects, e.g. asking participants to imagine what three-dimensional objects would look like after rotation, and then asking them to rotate the objects or to move around the objects to see how they would appear from different perspectives; (iii) usage of computer simulations illustrating rotating objects or viewing them from different perspectives. Although contrasting results have been found, there is evidence that these activities can improve learners' spatial ability skills.

Summary: The results discussed above show that school and university students and adults struggle to mentally manipulate objects in space. The results further show that the participants encountered more problems when manipulating three-dimensional objects in space.

Critique of the psychometric approach

The psychometric approach assumes that all participants responding to a spatial ability test undertake the same mental process presumed from requirements of each test. Thus, differences in performance of each test imply difference in mastery of the presumed skill. That is, ability to mentally detach a figure from background is assumed to determine performance on tests measuring Spatial Perception, ability to rotate a figure is assumed to determine performance in tests measuring Spatial Orientation, while ability to undertake presumed mental transformations (prescribed for each test) is assumed to determine performance in tests measuring Spatial Visualization. Critiques argue that this line of thinking pays no attention to cognitive processes undertaken by participants when answering the tests (e.g. Burin, Delgado & Prieto, 2000; Pellegrino, Alderton & Shute, 1984).

The Information Processing Approach

Having realized weaknesses of *The Psychometric Approach*, researchers investigated mental processes undertaken by people answering spatial ability tests. A lot of this research focused on mental rotation (Mumaw & Pellegrino, 1984 and Pellegrino & Kail, 1982 noted this point). As a result, the next discussion focuses mainly on mental rotation.

Response-Time Method

Shepard and Metzler (1971) conducted the first study investigating mental processes undertaken by people answering mental rotation tests. Others such as Cooper (1975), Cooper and Podgorny (1976), Just and Carpenter (1976), and Kail, Pellegrino and Carter (1980) conducted further research in this field. All these researchers used pairs of stimuli arranged so that there was some angular disparity between orientations of the stimuli. As an example, Figure 2.1 shows two pairs of stimuli with angular disparities of 0° and 180° .

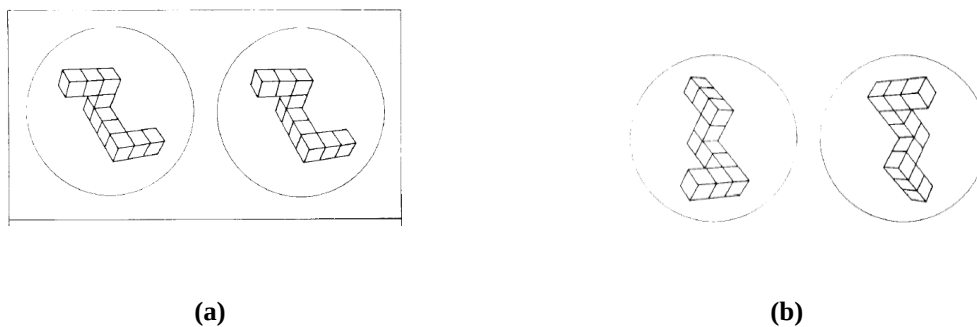


Figure 2.1 Stimuli with angular disparities of (a) 0° and (b) 180° (Just & Carpenter, 1976:443)

The stimuli could be identical or different (the latter being mirror images or perturbed).

- *Identical stimuli*: These stimuli were similar in shape and form, and therefore could be rotated into each other (see an example in Figure 2.2).

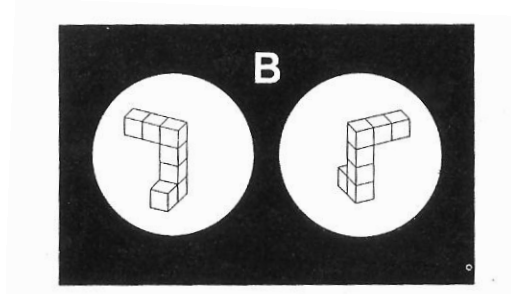


Figure 2.2 Example of identical stimuli (Shepard & Cooper, 1982:52)

- *Mirror-image stimuli*: The stimuli were identical in shape and form, but could not be rotated into each other because one was a mirror image of the other (see an example in Figure 2.3).



Figure 2.3 Example of mirror-image stimuli (Shepard & Cooper, 1982:313)

- *Perturbed stimuli*: These stimuli had some physical differences, and therefore could not be rotated into each other (see an example in Figure 2.4).



Figure 2.4 Examples of perturbed stimuli (after Shepard & Cooper, 1982:146)

The researchers asked participants to judge whether each pair consisted of identical or different stimuli. The researchers measured time taken to make the comparison (henceforth referred to as response time), and plotted this time against angular disparity between stimuli. Figure 2.5 illustrates a typical graph obtained by these researchers.

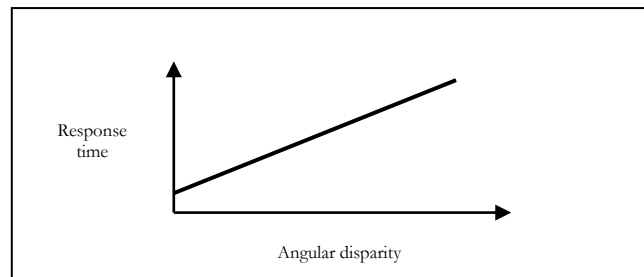


Figure 2.5 Typical graph obtained when plotting response time against angular disparity

The graph shows that response time increased linearly with angular disparity between stimuli. This suggests that participants took shorter time to compare stimuli with smaller angular disparity, and longer time to compare stimuli with larger angular disparity. Researchers used these results to conclude that participants compared stimuli by mentally rotating one shape into the other.

Some researchers realized that this response time measured time needed to undertake several processes, e.g. to encode the stimuli, to perform mental rotations, and to compare the stimuli (e.g. Cooper & Shepard, 1973). These researchers devised experiments to measure separate response times for encoding, mental rotation and comparison. They found that time required for each of the three processes increased with angular disparity between the stimuli. However, the largest increase was observed on the mental rotation component (e.g. Shepard & Klun, cited by Cooper & Shepard, 1973). Researchers considered this as evidence that participants mentally rotated images when solving these tasks.

Eye-Fixation Method

Just and Carpenter (1976) used eye fixation method to investigate mental processes undertaken by people answering spatial ability tests. Participants were fitted with eye-movement tracking devices which allowed the researchers to determine the amount of time spent looking at each component of the stimuli. Just and Carpenter used patterns of eye movements to conclude that the participants searched for components of stimuli that could be rotated to each other, mentally rotated one of the stimuli, and then compared the stimuli. Thus, Just and Carpenter provided another piece of evidence suggesting that people mentally rotate stimuli when solving a mental rotation task. Furthermore, Just and Carpenter's study provided additional evidence suggesting that people undertake three processes when solving a spatial task: encoding (searching), mental transformation, and comparison.

Critique of the information processing approach

Researchers working in the information processing approach acknowledge that individual differences in spatial ability could result from efficiency (or lack thereof) in undertaking any of the three mental processes (i.e. encoding, transformation and comparison). Egan (1979) proposes that

sources of encoding difficulty could be different from sources of transformation (e.g. mental rotation) difficulty, which could be different from sources of comparison difficulty. He argues that any of the three processes could affect performance in the spatial tests. Mumaw, Pellegrino, Kail and Carter (1984), who measured time needed to compare pairs of stimuli, concluded that (i) speed in performance of the three processes resulted in superior performance on a test, (ii) weakness in one of the three processes resulted in intermediate performance, while (iii) weakness in two or all three processes resulted in poor performance.

The information processing approach assumes that people answering spatial ability tests undertake the three mental processes in the same order. This approach fails to acknowledge that participants might employ different strategies when answering a spatial ability test. The next line of research focused on mental strategies employed when answering these tests.

The Strategic Approach

A lot of research investigating strategies focused on mental rotation (Burin et al., 2000 noted this fact). As a result, the following discussion focuses mainly on mental rotation, but draws from other spatial tasks whenever information is available.

Types of strategies used

Literature reports three types of strategies used by people answering mental rotation tests: object rotation, frame rotation, and analytic strategies.

- ***Object rotation:*** Literature reports two types of object rotation: holistic rotation which involves mental rotation of complete figures (as prescribed in manuals of tests), and partial rotation which involves mental rotation of components of figures.
- ***Frame rotation:*** People imagine changing reference frames relative to a figure, rather than mentally rotating the figure. That is, people imagine looking at a figure from different perspectives, rather than mentally rotating the figure as prescribed in manuals of tests.
- ***Analytic strategies:*** People do not undertake mental rotation, but rather use non-spatial strategies, e.g. looking at features of a figure such as relative position of lines and angles.

Appendix G(vii) illustrates studies which investigated strategies used to solve mental rotation tasks. The appendix shows that researchers analyzed three types of data when investigating processes undertaken to solve mental rotation tasks:

- ***Response-time data:*** Researchers measured time needed to compare stimuli (as discussed in Section 2.2.1, p 31).

- *Eye-fixation data:* Participants were fitted with eye-movement tracking devices. These devices allowed researchers to determine the pattern in which participants looked at each component of the stimuli (as discussed in page 33)
- *Introspective reports:* Participants were asked to describe strategies they used when answering mental rotation tests.

The appendix further shows that object rotation and analytic strategies were inferred from analysis of all types of data, while frame rotation was inferred from response time and introspective reports.

Differences in Strategies Used

The following discussion focuses mainly on mental rotation because a lot of research on mental strategies used tasks involving mental rotation. However, I draw evidence from other spatial tasks whenever possible.

Mental rotation: Twenty four of the 25 papers illustrated in Appendix G(vii) reported object rotation. Eighteen of these papers reported holistic rotation, eight reported partial rotation, while three reported rotation without specifying whether it was object or partial rotation. In addition to object rotation, five papers reported frame rotation. Four of these papers used response-time as the data source while one used introspective reports as the source of data.

Finally, Appendix G(vii) shows that seven papers reported the use of analytic strategies to solve the mental rotation task.

Some papers reported more than one strategy. Fifteen reported object rotation only while one paper reported frames rotation only. Nine papers reported more than one strategy each: two reported object and frame rotations, five reported object rotation and analytic strategies, while two papers reported all the three strategies. Thus more than one strategy is inferred from the same participants (implying that the participants use more than one strategy when solving these tasks).

Other spatial tasks: People use different strategies when answering other spatial ability tests. For example, Burin et al. (2000) administered a Form-Board type of a test to 152 participants, and asked the participants to report strategies they used when answering the test. Burin et al. considered responses given by 32% of the participants as holistic and considered responses given by the remaining 68% as analytic. In another study, Snow (1978, 1980) administered a paper folding test to participants, and measured eye movements as the participants answered the test. In addition, he asked the participants to report strategies they used when answering the test. His results indicated that high spatial-ability participants tended to mentally fold the paper, punch holes, and unfold the paper before scanning response alternatives. On the contrary, low spatial-ability participants tended to look back and forth at the folding process and response alternatives, usually eliminating alternatives before responding.

In yet another study, Schultz (1991) administered several spatial tests to 32 participants, asking the participants to describe strategies they used to answer the tests. Table 2.6 illustrates strategies reported for three tests: Hidden Patterns Test, Card Rotations Test and 3-D Rotations Test (a form of Cube Comparisons Test).

Table 2.6 Strategies used to solve spatial tasks (Schultz, 1991)

Tests	Number of participants (in %) using each strategy		
	Move object	Move self	Analytic
Hidden Patterns Test	22	28	50
Card Rotations Test	65	0	35
3-D Rotations Test	59	0	41

The table shows that the participants reported using three strategies when answering the Hidden Patterns Test (move object, move self and analytic strategies). The table further shows that the participants reported using only two strategies when answering mental rotation tests (move object and analytic strategies). It appears that the participants used different strategies when answering Card Rotations and 3-D Rotations tests. Schultz (1991) argues that a test measures what it purports to measure only to participants who employ a prescribed strategy.

Strategy Change

Research shows that people change strategies when answering spatial ability tests. For example, Lohman and Kyllonen (1983) and Kyllonen, Lohman and Woltz (1984b) administered a Form-Board type of a test to participants, and measured time taken by the participants to encode stimuli, perform mental transformations, and compare the stimuli. Their results indicated that the participants used both holistic and partial approaches in each of the three mental processes. The results further indicated that the participants changed from one strategy to another in each of these processes, depending on demands of the test. Lohman and Kyllonen (1983) suspected that the participants learned more effective strategies while responding to the tasks.

In another study, Kyllonen, Lohman and Snow (1984a) administered a Paper Folding Test to 58 high school students and investigated strategies used by the students when answering the test. All participants reported changing strategies while answering the test. The participants reported using analytic strategies to find answers for simpler items, saying that there was no need to imagine the folding, punching and unfolding processes when dealing with these items. The participants said that it became necessary to imagine the folding, punching and unfolding processes as items became difficult. Kyllonen et al. (1984a) concluded that item characteristics and experience in the task influenced strategies used to complete the tasks.

In yet another study, Schultz (1991) administered several spatial ability tests to 24 participants at two different sittings (10 weeks apart). The participants answered a randomly selected half of items

from each test in the first sitting, and answered the remaining half in the second sitting. The participants completed a Solution Strategy Questionnaire after each sitting. This questionnaire asked the participants to indicate the strategies they used when answering test items. Table 2.7 illustrates the number of participants who reported to have used one strategy across sittings in each test.

Table 2.7 Number of participants who used the same strategy across sittings (Schultz, 1991)

Psychometric Test	Most popular strategy (across sittings)	% of participants endorsing the strategy
3-D Rotation Test	Move object	63%
Card Rotations Test	Move object	67%

The table shows that 63% of the participants reported to have moved the object when answering the 3-D Test (a Cube Comparisons Test) while 67% reported to have used this strategy when answering the Card Rotations Test. These figures suggest that 37% and 33% of the participants changed strategies when answering the 3-D and Card Rotations tests respectively.

Table 2.8 illustrates the extent to which the participants changed strategies when answering two other tasks: the DAT (a form of Surface Development Test) and the Form Board Test.

Table 2.8 Number of participants who changed strategies (Schultz, 1991)

Psychometric test	% of participants who changed strategy	Strategy change	
		From	To
Space Relations (DAT)	50%	Holistic	Partial
	37.5%	Partial	Holistic
	12.5%	Partial	Guessing
Form Board	60%	Holistic	Partial
	40%	Partial	Holistic

The table shows that the participants generally changed from using a holistic strategy to using partial strategies and vice versa. However, 12.5% of the participants changed from using partial strategies to guessing responses when answering the DAT test.

In another study, Barratt (1953) administered a battery of spatial ability tests to 84 participants, and asked the participants to describe how they answered items in the tests. Table 2.9 illustrates responses he obtained from a DAT test. The table shows that in many instances, the participants folded and/or unfolded a shape to determine the answer. It appears that few participants used analytic strategies on simpler items, but more used these strategies as items increased in difficulty. Overall, the table shows that different participants used different strategies, and further shows that the participants changed strategies within one test.

Table 2.9 Strategies used when answering the DAT test (Barratt, 1953)

Strategy	Number of participants	
	Simpler items	Difficult items
Participants who spontaneously folded the pattern to note relationship of parts.	57	12
Participants who looked first at response figures (solid objects) and then looked at the pattern. Many reported unfolding one of the response figures to see if it was the same as the pattern.	17	20
Participants who did not fold or unfold stimulus pattern or response figures at all, but looked for other cues such as angle intersection.	7	44
Participants who could not work the problems, and hence guessed	1	8

Implication of spatial scores in this study

The preceding discussion helps readers to understand controversies surrounding interpretation of scores obtained from spatial ability tests. Designers of tests advise respondents to undertake specific mental processes when answering the tests. However, the *Information Processing Approach* indicates that some respondents undertake several processes when answering the tests, while the *Strategies Approach* shows that some respondents use different strategies when answering the tests, and sometimes change strategies in the course of a given test. Research on mental strategies raises questions about validity of interpretations of spatial ability test scores.

- If participants use strategies not prescribed in instructions of a test, then the test does not measure what it purports to measure.
- If participants change strategies in the course of a test, then the test does not measure one skill for such individuals.
- If different participants use different strategies when answering one test, then the test measures different skills on different individuals.

Lohman and Kyllonen (1983) argue that interpreting test scores presumes knowledge of how participants answered the test. They further argue that strategy change makes it difficult to know whether a test measured one skill in each participant, and whether the test measured the same skill across the participants. Accordingly, one can know what a test measured only by knowing how participants solved items in the test.

The foregoing discussion brings to light a possibility that for some learners who participated in the current study, the six spatial ability tests might have measured skills not intended by designers of the tests, and might have measured different skills on different individuals. When discussing results obtained in each test, acknowledge that some participants might have used processes and strategies different to those recommended by designers of the tests.

It has to be borne in mind that performance in spatial ability tests gives information about learners' ability to cope with tasks requiring mental manipulation of objects in space, but little information about learners' overall academic ability. Overall academic ability depends on spatial ability together with other abilities. Ekstrom and her associates (1976) argue that overall academic ability depends on factors such as *spatial ability* (discussed in depth in this chapter), *associative fluency* defined as 'the ability to produce rapidly words which share a given area of meaning or some other semantic property' (Ekstrom et al., 1976:41), *logical reasoning* defined as 'the ability to reason from premise to conclusion, or to evaluate the correctness of a conclusion' (Ibid:141), *general reasoning*, defined as 'the ability to select and organize relevant information for the solution of a problem' (Ibid:133), *memory span* defined as 'the ability to recall a number of distinct elements for immediate reproduction' (Ibid:101), and many other factors.

The complex relationship between spatial ability and overall academic achievement is demonstrated by performance of one of the learners interviewed in the current study (pseudo-named Motena). She obtained very low scores in the six spatial ability tests and consequently struggled to interpret aspects of diagrams requiring usage of spatial ability skills. However, she happened to be one of the high academic achievers in the school (she had a badge indicating this). It appears that she was capable in other skills (than spatial ability) needed for scholastic success. The fact that only spatial ability was measured in the current study means that results cannot allow me to comment about learners overall academic ability.

Summary

I have discussed three approaches used when studying spatial ability: (i) the *Psychometric Approach* which enabled researchers to define spatial ability and its components, and to design tests measuring each of these components, (ii) the *Information Processing Approach* which investigated mental processes undertaken by people answering spatial ability tests, and (iii) the *Strategic Approach* which investigated mental strategies used by people answering spatial ability tests.

The discussion shows that people carry out several processes when answering spatial ability tests. Furthermore, the discussion shows that some people change strategies when answering the tests, often using strategies not prescribed in manuals of test (suggesting that a test can measure several skills on one individual). In addition, the discussion shows that sometimes people use different strategies when answering spatial ability tests (suggesting that a test can measure different skills across individuals).

It is difficult to investigate strategies used on each item so as to enable evaluation of strategies used across items, and evaluation of strategies used across participants (especially when several tests are administered to a large sample of participants). Without knowledge of strategies used by the learners, it becomes difficult to know the number of learners for whom tests measure skills intended by test designers. I acknowledge this fact when interpreting and using spatial ability scores in Chapters 5, 7 and 8.

2.2.2 Models and modelling

This chapter has a brief discussion of models because diagrams analyzed in the study illustrate a model of the Earth-Moon-Sun system.

Definition of a model

A model is a representation of an object, phenomenon, idea, event, process, or system (Gilbert & Priest, 1997; Gobert & Buckley, 2000; Tregidgo & Ratcliffe, 2000). Models enable aspects of objects or phenomena to be visible or accessible (Crawford & Cornell, 2004; Gilbert & Boulter, 1998; Gobert & Buckley, 2000). For example, models are constructed when an object or phenomenon under study is too small or too large to be accurately perceived, too fast to be studied accurately, too distant in space & time, or too complex to be studied in detail.

Types of models

The following definitions show relationships between mental models and analogical models used in school (e.g. in the form of physical models or diagrams).

- **Mental model:** A mental model is “an internal representation of an object, state of affairs, or a sequence of events or processes, of how the world is, and of physiological and everyday social actions” (Gilbert & Priest, 1997:751). Justi and Gilbert (2000:994) argue that mental models cannot be accessed directly, but can only be “inferred from the major modes of human communication: gesture, speech and writing”. Gobert and Buckley (2000) argue that learners’ mental models can be inferred from analysis of reasoning provided by the learners.
- **Expressed model:** An expressed model is an “external representation of ... one’s mental models ... expressed through action, speech, written description, and other material depictions” (Gobert & Buckley, 2000:892). Thus, a mental model can be expressed using physical objects, oral descriptions, mathematical conventions or diagrams (Gilbert, Boulter & Rutherford, 1998a).
- **Consensus model:** A consensus model is an “expressed model that has been subjected to testing by the academic community associated with a given subject” (Gilbert & Priest, 1997:751), and has gained social acceptance among members of that community (Coll, France & Taylor, 2005; Gilbert *et al.*, 1998a; Gobert & Buckley, 2000; Justi & Gilbert 2000).
- **Analogical model:** This is a simplified or exaggerated representation of a consensus model (Coll *et al.*, 2005; Harrison & Treagust, 2000). There exist similarities and differences between consensus and analogical models (caused by simplification and/or exaggeration).

Theorists in the field of modelling argue that learning can be enhanced if learners map only similarities between consensus and analogical models (e.g. Gilbert *et al.*, 1998b; Hardwicke, 1995).

These theorists further argue that learning can be distracted if learners consider analogical models as exact replicas of consensus models, and therefore map all aspects of analogical and consensus models. Gilbert et al. (1988b) propose that similarities and differences between consensus and analogical models be spelled out in order to enhance effectiveness of analogical models.

The Earth-Moon-Sun system model

This thesis considers the Earth-Moon-Sun system conceptualized by scientists as a **consensus model** agreed upon by members of the scientific community. On the other hand, the thesis considers diagrams illustrating this system as **analogical models** intended to illustrate the system as conceptualized by scientists. There exist similarities and differences between diagrams and the Earth-Moon-Sun system conceptualized by scientists. The theory of models (discussed above) proposes that such differences be spelled out to enhance effectiveness of the diagrams. I have taken these issues into consideration when discussing results obtained in this study.

2.2.3 Diagram Design and Interpretation

Several scholars have conducted research involving diagrams. Most of this research investigated ways of using diagrams to help learners understand textual information (e.g. Hannus & Hyona, 1999; Mathai & Ramadas, 2009; Winn & Solomon, 1993), impact of background knowledge on interpretation of diagrams (e.g. Kindfield, 1993/1994; Kozma, 2003; Lowe, 1988), impact of animations on understanding science concepts (e.g. Hoffler & Leutnar, 2007; Lewalter, 2003), and impact of cognitive load on interpretation of diagrams (e.g. Sweller et al., 1990).

Diagram experts posit that properties of both the diagrams and the viewer determine an amount of information obtainable from diagrams (e.g. Cheng, Lowe & Scaife, 2001; Lowe, 1989, 1995). However, relatively less research has been conducted to investigate the nature of diagrams found in school textbooks, and to further investigate learners' ability to interpret these diagrams (e.g. Ametller & Pinto, 2002; Colin et al., 2002; Khanyane, 2002). As a result, most researchers make claims about effectiveness of diagrams without understanding what the diagrams mean to learners.

This section deals with issues associated with design and interpretation of diagrams i.e. the importance of diagrams in school textbooks, issues relating to diagram design, issues relating to scientific diagrams, issues relating to interpretation of diagrams, and issues specific to diagrams illustrating phases of the Moon.

Importance of Diagrams in School Textbooks

Several researchers believe that the presence of diagrams in textbooks enhances learning and understanding of information (e.g. Mayer & Anderson, 1991; 1992). Some authors argue that diagrams help people learning about unfamiliar, unobservable and/or abstract concepts (Braden, 1994; Fredette, 1994; Gropper, 1965). These authors further argue that diagrams clearly illustrate

spatial relationships between objects, and quickly convey information that requires many words to explain. Larkin and Simon (1987) argue that diagrams can be a better representation not necessarily because they contain more information, but because they can enable viewers to quickly and easily obtain information.

Diagrams are usually used to think about ideas and to communicate ideas (Lowe, 1988; Seels, 1994). Lowe (1988) argues that learners use diagrams mainly to think about ideas. When used to think about ideas, diagrams can serve any of the following roles (Duchastel, 1983):

- **Motivational role:** Diagrams can help to draw learners' attention, to motivate them, and to help them enjoy content.
- **Retentional role:** Diagrams can help learners to remember information.
- **Explanatory role:** Diagrams can help learners to understand information.

For each of the roles discussed above, diagrams can be independent or they can support textual information. A diagram is **independent** if it conveys the entire message intended by the illustrator. Such diagrams consist of graphics only (e.g. weather maps), or graphics combined with words (Lowe, 1986). Words support graphics by providing clues for interpreting diagrams e.g. to label components or to explain what happens in diagrams (Braden, 1994; Lowe, 1986).

When textual information carries the main message intended by authors, diagrams can either complement or supplement textual information (Braden, 1994; Fredette, 1994). A diagram **complements** text if it presents information already supplied in the text, but does so in a visual format. Such diagrams reinforce and clarify information provided in the text (Fredette, 1994). On the other hand, a diagram **supplements** text if it provides additional information not provided in the text, which is needed to understand concepts (Fredette, 1994).

Diagram Design

The first part of this section describes elements used when designing diagrams, while the second part describes principles recommended for design of diagrams that can effectively convey intended messages.

Design Elements

A diagram consists of symbols and inscriptions, collectively referred to as **marks** (Kosslyn, 1989). Symbols include circles, spheres, lines, arrows, etc. They are made up of configuration of design elements such as lines, shape/form, colour, texture, light/shade, volume, and space (Fleming, 1967; Goldstein, 1976; Rockman, 2000; Thompson, 1994). The configuration of design elements gives information about figure, background, direction of movement, relative sizes, relative positions, density of marks, proximity of marks, and similarity of objects (Rockman, 2000).

Inscriptions are made up of alphabetical and numerical symbols, i.e. letters and numbers (Fleming, 1967). They are either descriptive or explanatory in nature. Descriptive inscriptions are usually non-sentences, e.g. headings and labels. Headings articulate what a diagram is about, while labels articulate what parts of a diagram represent (Fleming, 1967). Explanative inscriptions are usually sentences that explain what happens in diagrams (Henderson, 1999). Inscriptions can be found within or adjacent to a diagram (Fleming, 1967; Henderson, 1999).

Design Principles

Design principles are guidelines recommended for using marks to convey messages intended by diagrams illustrators (Thompson, 1994). Literature describes several principles applicable to design of different types of illustrations such as diagrams, graphs, and charts (e.g. Goldstein, 1976; Kosslyn, 1989; Kress & van Leeuwen, 1996; Rockman, 2000; Thompson, 1994). Only one type of these illustrations has been used in this study, i.e. diagrams. As a result, the following discussion deals with design principles applicable to diagrams only. Kosslyn (1989) classifies design principles into syntactic, semantic and pragmatic categories. Syntactic principles focus on perception of diagrammatic information, semantic principles focus on interpretation of this information, while pragmatic principles focus on suitability of diagrams to intended audiences.

Syntactic Principles: Table 2.10 discusses syntactic principles found in literature. The Table shows that syntactic principles suggest ways of designing diagrams so that (i) marks can be easily detectable and organized into perceptual units, (ii) important aspects of diagrams can easily attract viewers' eyes, and (iii) diagrammatic information does not overload working memory. These principles focus on processes that occur in **sensory memory**. Scientists accept that light from objects enters the perceiver's eyes and forms sensory images interpreted by the brain. Baddeley (1998) argues that sensory memory, which lasts only for a fraction of a second, plays an important role early in the interpretation of this information. Treisman (1986) claims that this early interpretation consists of two stages: the pre-attentive stage followed by the feature integration stage. The pre-attentive stage depends on input stimulus, and is responsible for identification of features of objects (e.g. colour, size, contrast, tilt, and curvature). The feature integration stage is responsible for recombination of these features. This includes separating a figure from background, maintaining the same shape, size and colour when a figure is viewed from different perspectives and from varying distances, and understanding static and motion cues found in a figure (Kosslyn & Rosenberg, 2004; Reisberg, 2001). Prior knowledge and expectations help individuals to conjoin these features (Treisman, 1986). Reisberg (2001) argues that this explains why individuals differ in their ability to interpret diagrams.

Table 2.10 Syntactic design principles applicable to diagrams

Principle	Explanation	Source
Perceptual apprehension; legibility	Diagrams should be drawn so that marks are easily perceived, to enable viewers to see the visual message conveyed by each mark.	Kosslyn (1989), Thompson (1994)
Perceptual organization	The design of diagrams should enable viewers to perceive associated marks as linked	Goldstein (1976), Kosslyn (1989), Thompson (1994), Rockman (2000)
Processing priorities, emphasis, salience	Parts of a diagram that carry the main message should have more visual weight so that they can easily attract the eye.	Goldstein (1976), Kosslyn (1989) Thompson (1994), Rockman (2000)
Processing limitations	A diagram should contain no more than 4 to 7 perceptual groups. Although up to seven can be seen at a single glance, only up to four can be held in the mind at once.	Kosslyn (1989)

Semantic Principles: Baddeley (1998) asserts that from the sensory memory, information is manipulated in the **working memory**. Baddeley (1996) argues that working memory helps perceivers to interpret information obtained from the sensory memory, and to coordinate this with information stored in long-term memory. Semantic principles suggest ways of designing diagrams so that viewers can easily interpret information illustrated in the diagrams (see Table 2.11).

Table 2.11 Semantic design principles applicable to diagrams

Principle	Explanation	Source
Representativeness	Marks should be used so that the intended meaning of each mark corresponds to spontaneous interpretation of the mark.	Kosslyn (1989)
Congruence	<i>Surface compatibility:</i> Appearance of lines and regions should be compatible with their meaning.	Kosslyn (1989), Rockman (2000)
	<i>Ordering:</i> Pairs of words should be ordered in accordance with natural usage.	Kosslyn (1989)
Schema availability	Intended reader must have knowledge needed to understand a diagram.	Kosslyn (1989)
Clarity, concept availability	A diagram must make use of concepts familiar to viewers.	Thompson (1994)
Between level mapping	Each mark should have only one meaning in the diagram.	Kosslyn (1989)
Simplicity	Each visual should deal with a single concept, and provide information needed by audience to understand the concept.	Thompson (1994)
Harmony	Parts of a diagram should relate and complement each other.	Thompson (1994)

These principles recommend that marks be chosen to appropriately represent intended entities so that viewers can interpret each mark as intended by illustrators. In addition, the principles recommend that marks be chosen so that each has only one meaning in a diagram to avoid

ambiguities in meanings associated with the marks. Furthermore, the principles recommend that each diagram be designed so that components give a unified message. These principles are intended to help viewers easily interpret information illustrated in diagrams.

Pragmatic principles: These principles suggest ways of designing diagrams to ensure suitability of diagrams to the context of intended audiences (see Table 2.12).

Table 2.12 Pragmatic Design principles applicable to diagrams

Principles	Explanation	Source
Purpose compatibility	Diagrams should provide appropriate amount of information needed for the intended purpose.	Kosslyn (1989)
Contextual compatibility	A diagram must comply with context of intended audiences (e.g. using terminology used on other parts of the context).	Kosslyn (1989)

The principles recommend that illustrators state the purpose of each diagram to enable viewers to look for relevant information in each diagram. The principles further recommend that diagram designers use a context familiar to intended viewers (e.g. presenting information from top to bottom and from left to right for learners using the western culture of reading). This would enable viewers to easily obtain information presented in diagrams. If these principles are followed, diagrams would be suitable to the context of intended viewers.

Conventions used in Scientific Diagrams

Diagrams in science textbooks have different purposes, and use different conventions to convey information (Henderson, 1999). As a result, interpretation of these diagrams requires viewers to use different skills and strategies. The following are some of the conventions used in scientific diagrams:

- A symbol can be used to represent an entity, e.g. symbols used to represent objects circuit diagrams. Accurate interpretation of diagrams requires viewers to know the meaning of each symbol.
- A symbol can appear more than once in a diagram, representing different entities. For example, arrows can be used to label components of a diagram, and to indicate movement of entities in the diagram (Henderson, 1999; Schollum, 1983).
- A symbol can appear more than once in a diagram, representing an entity changing position. For example, diagrams illustrating seasonal change usually show the Earth in different positions around the Sun.
- Exaggeration can be used to enhance understanding of intended messages. For example, relative distances between objects can be distorted in order to clarify relationships. In addition, some information is omitted to focus learners' attention to intended messages. For example,

devices holding apparatus are sometimes omitted in diagrams illustrating scientific experiments (Henderson, 1999).

This discussion shows that diagram interpretation requires learners to correctly interpret conventions used in the diagrams. Section 6.6 (pp 153-154) discusses conventions used in diagrams illustrating phases of the Moon, while Chapters 7 and 8 investigate learners' interpretation of these conventions.

Problems associated with design of diagrams

The following discussion identifies problems at syntactic, semantic and pragmatic levels.

Syntactic problems

Syntactic principles propose that diagrams be designed in a way that can enable viewers to perceive all marks in a diagram, and to perceive associated marks as linked (see page 43). The following syntactic problems have been found in literature reviewed for this study.

Non conspicuous captions: Syntactic principles require captions to stand out from text and other labels in a diagram. However, Khanyane (2002) found that captions of components of a diagram illustrating formation and breaking down of ozone molecules were written in a font similar to that used in text. Furthermore, she found that the caption of a diagram illustrating a food web was written in a font similar to that used for labels in the diagram. She concluded that the captions did not stand out from the rest of other textual information in these diagrams.

Confusing layout of marks: Syntactic principles require design of diagrams to enable viewers to see associated marks as linked. However, Khanyane (2002) found that captions of components of a diagram illustrating formation and breaking down of ozone molecules were placed midway between the components. Khanyane concluded that viewers might be confused as to whether a caption refers to the figure above or below.

Complexity of diagrams: du Plessis et al. (2003) investigated learners' interpretation of two illustrations found in school textbooks, one illustrating the cardiac circle and the other illustrating thermal regulation. The diagram illustrating the cardiac circle had two figures of the heart and several arrows indicating blood entering and leaving the heart. These arrows formed more than four perceptual groups. The flowchart illustrating thermal regulation had several concepts (and arrows between the concepts). This diagram, too, had more than four perceptual groups. du Plessis et al. (2003) considered both diagrams to be complicated. Thus processing information from these diagrams might overload working memory.

Semantic problems

Semantic principles recommend that diagrams be designed in a way that enables viewers to obtain all information intended by illustrators. The following semantic problems were found in literature reviewed for this study.

Inconsistency of symbols: Khanyane (2002) found that some oxygen atoms were larger in one part of a diagram, and smaller in another part of the diagram illustrating formation and breakdown of ozone. This illustration erroneously implies that oxygen atoms have different sizes (but this is not the case).

Confusing information: Some diagrams present information in a confusing manner. Stylianidou et al. (2002) found this problem in a diagram illustrating energy changes. The top half of this diagram showed sunlight warming sea water, causing the water to evaporate and condense to form rain. The bottom part showed generation of electricity using rain water collected in a dam. At a first glance, the diagram confusingly appeared to illustrate the water cycle. A further look erroneously suggests that the top part illustrates changes in water while the bottom part illustrates changes in energy.

Pragmatic problems

Pragmatic principles recommend that diagrams be designed in a way that suits the context of intended viewers. The following pragmatic problems were found in literature.

Insufficient information: Some diagrams give less information than required to understand messages intended by illustrators. Stylianidou et al. (2002) found this problem on a diagram intended to illustrate energy. The diagram illustrated three modes of transport arranged spatially: space transport at the top, sea transport in the middle, and land transport at the bottom. The diagram had a heading 'Energy', but no other information about energy. Thus, illustrators did not clarify a link between the diagram and energy. Stylianidou et al. argued that the diagram appeared to illustrate transport rather than energy.

Diagrams without captions: Khanyane (2002) found three illustrations which had no captions. The first was a diagram illustrating views of different stakeholders about indigenous forests, the second illustrated deforestation while the third illustrated formation and breakdown of ozone. The third diagram had no caption, but components of the diagram had captions.

The preceding discussion shows that some science diagrams used in schools violate design principles recommended in literature. It is against this knowledge that the current study investigated weaknesses in design of diagrams illustrating phases of the Moon.

Diagram interpretation (visual)

When interpreting diagrams, people need to process both verbal and nonverbal information provided in the diagrams. Paivio's dual coding theory explains how people mentally process this

information. Paivio (1971) assumes that cognition consists of activity of two systems; the verbal system specialized for processing and representation (storage) of verbal information and the nonverbal system specialized for processing and representation of nonverbal information. The two systems are assumed to be functionally independent. That is, either system can be active without the other or both can be active in parallel (Paivio, 1986).

Paivio (1986) proposes that activation of verbal and nonverbal representations occurs at representational, referential and associative levels.

- **Representational processing:** Verbal stimuli activate representations stored in the verbal system while nonverbal stimuli activate representations stored in the nonverbal system. These activations enable viewers to read verbal stimuli and to form mental images of nonverbal stimuli.
- **Referential processing:** Verbal stimuli activate nonverbal representations of the same referent (e.g. reading a name enables viewers to form a mental image of the named object). Also, nonverbal stimuli activate verbal representations of the same referent (e.g. looking at an object enables viewers to recall the name of the object).
- **Associative processing:** Verbal and/or nonverbal representations of one referent activate verbal and/or nonverbal representations of another referent. That is, a name and/or a mental image of one entity trigger a mental image and/or a name of another entity.

Paivio (1986) argues that variables in the stimulus situation and individual differences determine the activation of verbal and nonverbal representations. Attributes of stimuli include the nature of items to be processed (e.g. concrete or abstract), and the context in which the items are processed (e.g. instructions to image the situation or to carry a verbal task). On the other hand, individual differences include preferences for thinking in words or using images, and a variety of verbal and spatial abilities.

Schönborn and Anderson (2009) discuss three factors affecting students' ability to interpret diagrams: (a) diagram design, (b) learners' conceptual understanding of information illustrated in diagrams, and (c) learners' reasoning ability e.g. visual literacy skills (to be defined shortly). Literature indicates that, indeed, these three factors affect learners' interpretation of diagrams.

Impact of poor diagram design

Although diagrams can be helpful, poor design hinders their effectiveness. The following discussion shows that students struggle to interpret poorly designed diagrams.

Ambiguity of symbols used in diagrams: Research shows that arrows help learners to interpret movement in diagrams (e.g. Heiser & Tversky, 2006; Schollum, 1983). However, learners struggle to interpret diagrams when the meaning of arrows is not clear in the diagrams. For instance, Khanyane (2002) interviewed 10 learners about the meaning of arrows in a diagram illustrating sections of a plant, and interviewed 10 learners about the meaning of arrows in a flow diagram

illustrating a food web (she did not indicate whether the same learners participated in both aspects of her interview). Five learners gave partially correct explanations of what the arrows represented in a diagram illustrating sections of a plant. The sixth learner gave a partially correct answer after being probed while four gave incorrect answers even after being probed. However, nine learners gave satisfactory explanations of what arrows meant in the diagram illustrating food web. This suggests that learners had no problem of interpreting arrows, but had problems with the manner in which arrows were used in the diagram illustrating sections of a plant.

Diagrams with insufficient information: Ametller and Pinto (2002) asked 25 high school students to interpret a diagram illustrating energy changes taking place when a catapult propels a piece of chalk. None of these students mentioned energy conservation when interpreting the diagram (energy conservation was implied but not mentioned in the diagram). Thus, lack of information on the diagram resulted in poor interpretation of the diagram.

In another study, Mathai and Ramadas (2009) asked students to interpret a ‘function diagram of digestion’. The diagram had information explaining what happens to food substances as they enter the mouth and leave the anus, but little information about processes occurring between the mouth and the anus. The majority of students had problems of understanding what happens between the mouth and the anus. It appears that the students had a problem of interpretation because not enough information was provided in the diagram.

Impact of poor conceptual knowledge

Research shows that background knowledge on concepts illustrated in diagrams affects learners’ ability to interpret diagrams. The following discussion shows that poor background knowledge hinders learners understanding of information illustrated in diagrams.

Colin et al. (2002) asked 32 high school students to interpret a diagram illustrating an image formed on a screen by a converging lens. Fifteen of the students had learned about optics. Fourteen of the 15 students said that if the screen was moved back, the image would stay on the screen, but be blurred and bigger (in fact the image appears to be blurred because of being in front of the screen). None of the 17 students who were not taught physics mentioned sharpness or blurredness of the shape resulting from moving the screen. These learners believed that the image would move with the screen. These responses indicate that poor understanding can result in misinterpretation of the diagram.

In another study, Khanyane (2002) investigated 10 learner’s interpretation of ‘balls’ and ‘sticks’ in a ball-and-stick model of an ozone molecule. Six learners correctly interpreted the balls as representing **oxygen atoms**. Two learners said that the balls represented **oxygen molecules**. One learner said that the balls represented **ozone molecule** while the last learner said that the balls represented **hydrogen**. Only four learners stated that the ‘sticks’ represented bonds. The remaining six learners gave wrong interpretations. Thus, some learners encountered interpretation problems because they did not know what the ‘balls’ and ‘sticks’ represented in an ozone molecule.

A further observation from literature is that participants with good background knowledge in a domain illustrated in diagrams (experts) usually understand the message better than participants with poor background knowledge the domain (Kindfield, 1993/1994). Lowe (1995) argues that knowledge stored in long term memory guides experts. This knowledge, which results from extensive experience with the relevant domain and the type of diagram, includes the nature of information conveyed by diagrams, the manner in which diagrams convey this information, and particular ways of processing this information (Henderson, 1999).

Impact of poor visual literacy skills

Diagram interpretation requires viewers to use visual literacy skills. Visual literacy has two components: ability to use visuals to communicate information, and ability to interpret information presented visually (Seels, 1994). The following discussion shows that sometimes poor visual literacy skills result in misinterpretation of diagrams.

Failure in perceptual organization: du Plessis et al. (2003) found that 50% of students had some difficulty of combining elements in a diagram illustrating thermoregulation (du Plessis et al. did not state the number of students who participated in interviews). Furthermore, 20% of the participants showed evidence of poor search patterns by not grouping appropriate information into elements in a diagram illustrating thermoregulation.

Not reading captions: Ametller and Pinto (2002) and Khanyane (2002) found that some learners do not voluntarily read captions of diagrams. Most of these learners misinterpreted diagrams because of not reading the captions. The majority of learners who participated in Ametller and Pinto's (2002) study gave correct interpretations after reading the captions.

Failure to interpret depth cues: Liddell (1997) investigated 346 South African children's interpretation of information illustrated in pictures. Some of the children had difficulty in understanding what the illustrations showed. Liddell found that 72% of the misinterpretations resulted from inability to interpret depth, shading, and perspective. In another study, Nicholson and Seddon (1977) investigated links between diagram interpretation and the number of depth cues found in diagrams. One hundred and five high school students' participated in the study. Nicholson and Seddon (1977) found that the ability to interpret diagrams increased as the number of depth cues increased. However, the results showed that more than half of the participants had difficulty in understanding information presented in these diagrams.

In yet another study, Seddon and Eniaiyaju (1986) administered cues tests to 200 high school students. The tests investigated learners' interpretation of depth cues found in ball-and-stick models of molecules. Only 6% of the participants performed satisfactorily on all cues tests. These results show that the majority of students encountered problems of interpreting depth cues.

Linking diagrams with irrelevant text: Sometimes misinterpretations result from linking diagrams with irrelevant text. For example, Khanyane (2002) asked 10 learners to interpret a diagram illustrating formation and breakdown of ozone. Two learners said that the diagram illustrated 'ozone scare'. Khanyane concluded that the learners read 'ozone scare' from neighbouring text

(‘ozone scare’ was a heading of this text). Five learners said that the diagram illustrated ‘ozone layer’. Khanyane suspected that these learners read this from neighbouring text.

The foregoing discussion shows that some learners lack visual literacy skills needed to interpret diagrams, and therefore fail to understand information illustrated in the diagrams.

Diagram interpretation (spatial)

Research shows that many science diagrams require learners to mentally manipulate diagrammatic information in space. Research further shows that many learners struggle to do this. For example, Constable, Campbell and Brown (1988), Russell-Gebbett (1984) and Sanders (2002) found that many students could not understand biological sections. Most of these students lacked spatial ability skills needed to understand the cross-sections, e.g. forming mental images of objects being cut, and imagining shapes and relative positions of objects after being cut. In another study, Kali and Orion (1996) found that many students lacked spatial ability skills needed to understand diagrams illustrating geological sections, e.g. imagining how a landform would look when cut, and what the surfaces would look like when viewed from different perspectives. In yet another study, Seddon, Tuckey and their associates found that learners lacked spatial ability skills needed to understand information presented in ball-and-stick models of molecular structures (Seddon, Adeola, El Farra and Oyediji, 1984; Seddon & Eniaijeju, 1986; Tuckey, Selvaratnam and Bradley, 1991). Understanding this information requires learners to correctly interpret depth cues used in the diagrams, and to imagine looking at molecular structures from different perspectives.

To fully understand phases of the Moon, learners need to imagine perceiving the Earth-Moon-Sun system from different perspectives, determining the illuminated fractions visible from Earth (see details in Section 4.3, pp 84-88). However, findings of Colin et al. (2002) suggest that learners might struggle to perform these mental tasks. Colin et al. presented 34 high school students with a diagram illustrating the Sun’s rays approaching the planet Jupiter (illustrated in Figure 2.6). Two regions (AB and CD) were marked on the diagram. The region AB was illuminated by the Sun’s rays, but was on the side of Jupiter not visible to viewers on Earth. The region CD was visible to viewers on Earth, but could not be seen because of being in darkness. Colin et al. asked the students to explain why regions AB and CD could not be seen from Earth. Only four of the 34 students correctly explained why Earth viewers could not see AB and CD. The remaining 30 gave incorrect explanations. These results suggest that some high school learners struggle to explain why certain regions of an illuminated planet cannot be seen from Earth. This in turn suggests that students could struggle to understand information presented in diagrams illustrating phases of the Moon.

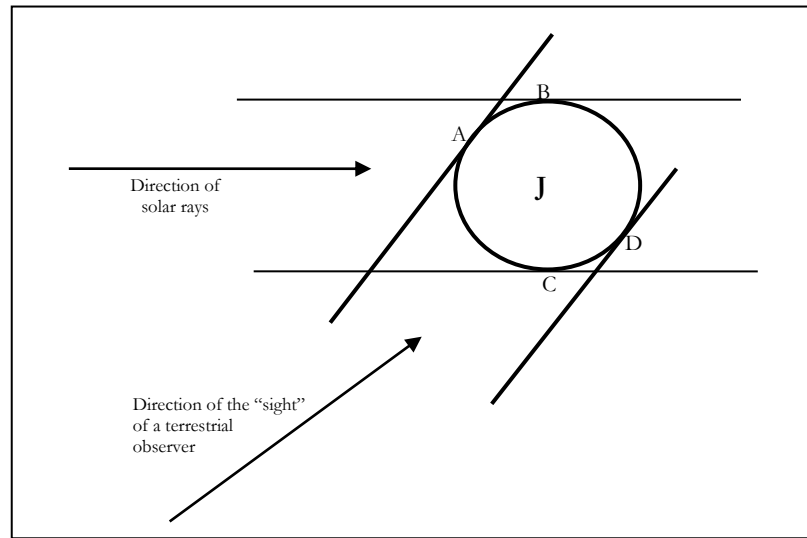


Figure 2.6 Illustration of the Sun's rays approaching the planet Jupiter (after Colin et al. 2002)

Diagrams illustrating Phases of the Moon

The discussion in Section 2.1.1 (p 11) shows that the bulk of research dealing with phases of the Moon has focused on misconceptions about the cause of these phases, and on interventions intended to help learners understand the cause of moon phases. In addition, I have shown in Section 1.3 (pp 4-5) that very little research has focused on the nature of diagrams found in school textbooks, and to further investigate learners' ability to interpret these diagrams. I have found even fewer papers which have dealt with issues associated with diagrams illustrating phases of the Moon.

A typical diagram illustrating phases of the Moon shows the Earth, the Moon in its orbital path around the Earth, phases of the Moon, and the Sun's rays illuminating the Earth and the Moon (see Section 4.3, pp 84-88 for details). These diagrams have both the static and dynamic features. That is, the Earth and the Sun appear to be static in these diagrams, while the Moon appears to change positions in its orbital path around the Earth, and to change shape as it orbits the Earth. Review of literature shows that some researchers have found problems in textbook diagrams illustrating phases of the Moon. For example, Martinez-Pena and Gil-Quilez (2001) found that some diagrams illustrating phases of the Moon did not show the Moon as seen from space (Section 4.3 explains why this information is important). Furthermore, Martinez-Pena and Gil-Quilez found that the Sun and/or the Earth were missing in some diagrams. No explanations were provided as to why this information was missing in the diagrams.

Further research shows that relative sizes and distances between the Earth, the Sun and the Moon are not maintained in diagrams illustrating phases of the Moon (see Dove, 2002; Engeström, 1991; Subramaniam & Padalkar, 2009). As a result, the Moon appears to be much bigger and much closer to the Earth than reality. Engeström (1991) argues that this representation fails to indicate that the

probability of the Earth's shadow falling on the Moon is very small. Furthermore, Engeström (1991) and Subramaniam and Padalkar (2009) speculate that this representation might enhance a view that the Earth's shadow causes phases of the Moon. Furthermore, researchers found that these diagrams illustrate the Moon's orbit along the plane of the ecliptic (e.g. Dove, 2002; Engeström, 1991; Martinez-Pena & Gil-Quilez, 2001; Trundle et al., 2002). These researchers propose that this representation could enhance a common misconception in which people associate phases of the Moon's with the Earth's shadow.

Further analysis of the diagrams shows that artists use bright colours to represent part of the Moon visible from Earth, and dark colours to represent part of the Moon not visible from Earth. However, studies by Trundle and her associates (Bell & Trundle, 2008; Trundle et al., 2010) and Wilhelm, Sherrod & Walters (2008) show that some people use the bright and dark colours in a way contradicting meanings given by diagram illustrators. Bell and Trundle (2008) asked 50 pre-service teachers to draw shapes of the Moon they expected to see when making daily Moon observations. Two of the participants shaded visible part of the Moon and left the unseen part of the Moon as white. Thus, these participants used black colour to represent visible part of the Moon (contrary to the convention used in diagrams). In another study, Wilhelm et al. (2008) asked 24 pre-service teachers to complete a Moon chart while making daily Moon observation over a five-week period. Seven of these teachers switched their method of shading, from shading visible part of the Moon to shading part of the Moon not visible from Earth. Thus, they changed the meaning of shaded and non-shaded parts of the Moon. In yet another study, Trundle et al. (2010) asked 20 Grade 8 learners to complete a Moon chart while making daily Moon observations. Trundle et al. advised the learners to shade shapes representing visible part of the Moon, and leave the unseen part of the Moon as white. These results indicate that some people consider the shaded part as representing visible part of the Moon while diagram illustrators consider the white part as one being visible from Earth. Without explanation of what each colour represents, different viewers might ascribe different meanings to dark and light colours.

In addition to textbook diagrams, research has been conducted to investigate problems on diagrams illustrating phases of the Moon in children's story books (Trundle et al., 2008). Trundle et al. found 772 illustrations in 80 story books. These researchers found that one fifth of these illustrations were scientifically incorrect, and argued that the illustrations could enhance misconceptions. The majority of these 'non-scientific' shapes were of crescent (32%) and gibbous (24%) phases. Trundle et al. (2008) conducted a detailed analysis of diagrams found in two of the 80 story books. The analysis showed that the diagrams illustrated the sequence of moon phases as seen from the southern hemisphere, despite the fact that intended viewers lived in the northern hemisphere. This could confuse users of diagrams.

The concept of moon's phases requires learners to simultaneously process information given by three objects in order to determine shape of the Moon as seen from Earth. Thus, this concept is interactive (i.e. it requires several elements to be processed simultaneously). Malbery, Bain and Halford (1986) and Sweller and Chandler (1994) found that people experience difficulties when processing highly interactive information. Sweller (1993) and Sweller and Chandler (1994) argue that interpretation of highly interactive material remains a problem even if diagrams are well

constructed. This implies that learners might struggle to interpret diagrams illustrating astronomy concepts, even if these diagrams are well designed.

Summary

This section has discussed (a) reasons for which diagrams are used in school textbooks, (b) principles recommended for design of diagrams that can easily convey intended messages, (c) conventions used in scientific diagrams, and (d) problems encountered by students interpreting scientific diagrams. The discussion shows that several diagrams violate design principles recommended in literature. Thus, usage of these diagrams might hinder learning of information illustrated in the diagrams. The discussion further shows that sometimes learners struggle to interpret conventions used in these diagrams, and to mentally manipulate diagrammatic information in space. I have used this information when discussing results obtained in this study (see Chapters 6, 7 and 8).

2.3 Chapter summary

This chapter has presented literature related to phases of the Moon and theories used to design the study and to interpret the results. I discussed the spatial ability theory, which is important because interpretation of diagrams illustrating phases of the Moon requires people to manipulate the Earth, the Sun and the Moon in space. Then I discussed the theory of models because the diagrams used in this study illustrate a model of the Earth-Moon-Sun system. I ended the chapter by discussing issues relating to diagrams, e.g. importance of diagrams, design of diagrams, and interpretation of diagrams. The next chapter presents methods used to collect data in the study.

Chapter 3 Methodology

The previous chapters have discussed literature relating to the problem which motivated the study, and the theoretical framework used to design the study and interpret results. This chapter presents literature relating to methods used in the study, and further discusses the general design of the study. Figure 3.1 summarises the design of the study, showing how the study progressed from the review of literature, to the design of data gathering tools, collection and analysis of data, and arrival of conclusions. Section 3.1 discusses the paradigm in which the study was situated. Section 3.2 discusses sampling methods used in the study. Sections 3.3, 3.4, 3.5 and 3.6 discuss methods used to collect data in the study, indicating how rigour was ensured in each case. Subsequent chapters discuss data analysis, findings and conclusions made from the data.

3.1 Research Paradigm

A paradigm is defined as a network of assumptions, thoughts, beliefs and values about the nature of reality and how people get to understand reality (Chalmers, 1994; Gage, 1967; Ponterotto, 2005). Research paradigms influence methods and procedures used to design and conduct research (Gage, 1967; Punch, 2005; Usher, 1996). There exist three research paradigms: quantitative, qualitative, and pragmatic paradigms.

3.1.1 Quantitative paradigm

Proponents of this paradigm believe in one objective reality which exists separate from beliefs of individuals (Ponterotto, 2005). They believe that this reality can be identified and measured (Ponterotto, 2005). In their research, they standardise procedures to minimize impact of values, hopes, expectations, and feelings in the research process (Foddy, 1993; Guba & Lincoln, 1988). This enables them to study phenomena objectively (without bias). They prefer forced-choice questions (e.g. multiple-choice and fill-in questions) which can be easily administered to large samples of participants, and whose data can be processed easily and objectively (Foddy, 1993). The large amount of data enables these researchers to generalize findings to populations from which samples were taken.

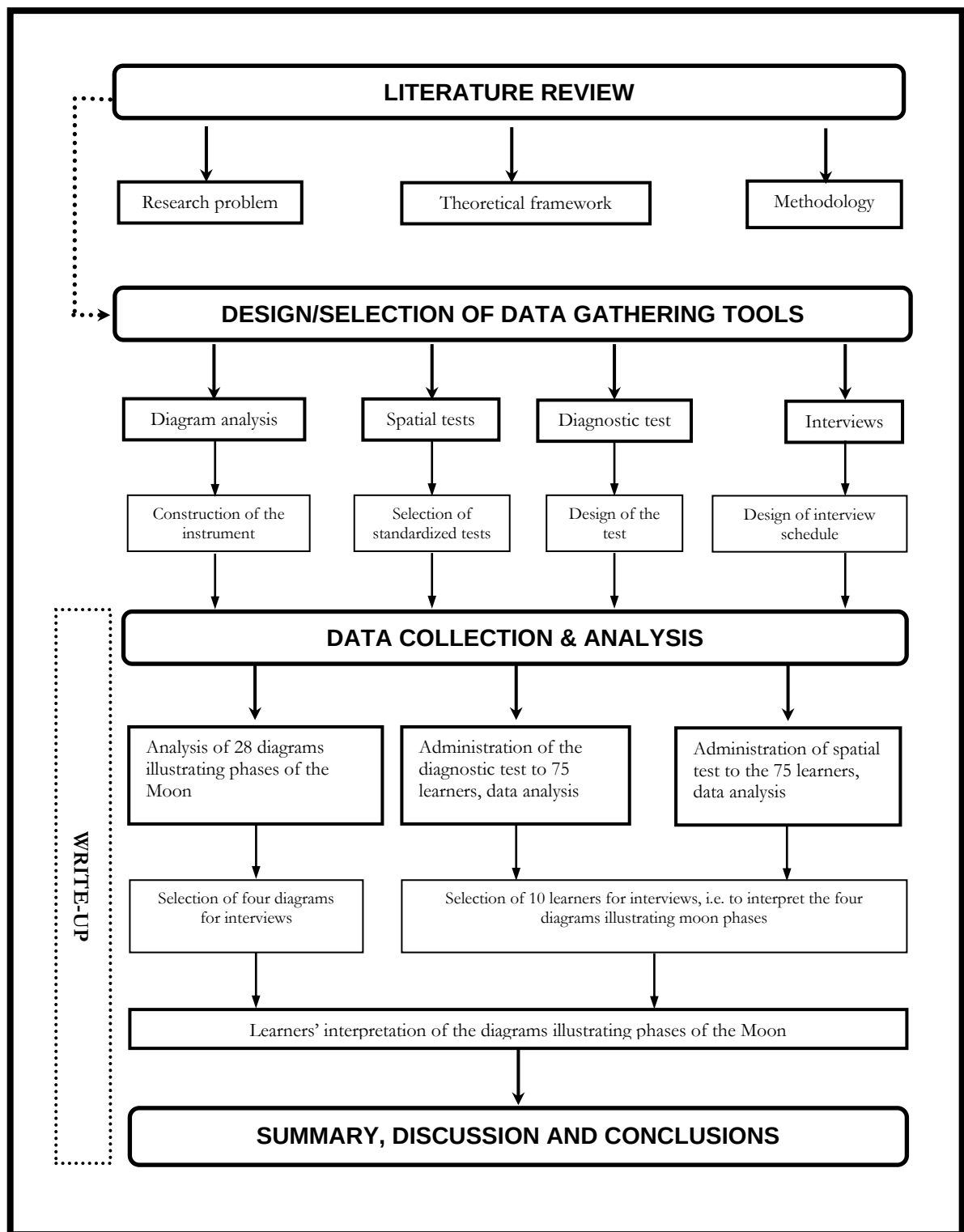


Figure 3.1 A diagram summarising design of the study

3.1.2 Qualitative paradigm

Proponents of this paradigm believe in multiple, equally valid realities constructed in the minds of individuals (Ponterotto, 2005). According to believers of this paradigm, factors such as culture, gender, values, hopes, expectations, and feelings determine how humans get to know about reality. Thus, the values and beliefs of researchers cannot be separated from the research process. They study phenomena in their natural settings, usually spending extended periods of time with participants in order to gain holistic understanding of phenomena being studied (Anderson, 1998; Punch, 2005). They prefer open-ended questions which provide rich data that enhances understanding of the phenomena (Foddy, 1993; Fraenkel & Wallen, 1990).

3.1.3 Pragmatic paradigm

Proponents of this paradigm hold no epistemological beliefs about reality and how to study reality. They design research in a way that best provides answers to research questions, and this enables them to use methods usually associated with either qualitative or quantitative paradigms, or to integrate the methods in order to answer research questions (Johnson & Onwuegbuzie, 2004; Punch, 2005; Reeves & Hedberg, 2003).

Some researchers argue against usage of qualitative and quantitative methods in one study, claiming that the methods are based on different philosophical assumptions (e.g. Sale, Lohfeld & Brazil 2002). However, others such as Creswell (2005) argue for mixing the methods that are needed to address the problem being investigated. Punch (2005) discusses different reasons for integrating qualitative and quantitative methods.

- *Qualitative research can facilitate quantitative research.* This occurs when researchers need quantitative data, but conduct qualitative research to understand characteristics of intended participants, and then use findings to design quantitative research. Results enable researchers to generalize findings to populations from which samples were taken.
- *Quantitative research can facilitate qualitative research.* This occurs when researchers need qualitative data, but conduct quantitative research to understand characteristics of intended participants, and then use findings to design qualitative research. Results enable researchers to get deep understanding of phenomena being studied.
- *Qualitative and quantitative methods can be integrated to understand phenomena being studied.* This occurs when researchers need both qualitative and quantitative data, and design research to get these types of data. Results enable researchers to get deeper understanding of the phenomena being studied, and to generalize findings to populations from which the samples were taken.

Several authors warn that using methods associated with both qualitative and quantitative approaches in one study causes several challenges. First, a researcher has to learn about both approaches in order to use and mix the methods appropriately (Creswell, 2005; Johnson & Onwuegbuzie, 2004). Also, the researcher has a challenge of deciding which methods to use first, and when to integrate findings obtained from using the methods (Ivankova, Creswell & Stick, 2006). Additionally, a

single researcher might encounter difficulties of collecting both qualitative and quantitative data, especially if these data are collected at the same time (Creswell, 2005; Ivankova et al., 2006; Johnson & Onwuegbuzie, 2004). Furthermore, it might be difficult for the researcher to obtain resources needed to collect and analyse both types of data. Thus, mixing the methods might be more expensive than using methods associated with only one approach (Ivankova et al., 2006; Johnson & Onwuegbuzie, 2004).

3.1.4 Research Paradigm employed in the study

This study was based on no epistemological beliefs about reality and how this reality should be studied. That is, research questions determined methods and strategies used to collect data in the study. Table 3.1 illustrates data gathering tools which provided data to answer each of the research questions in the study (see the Research Questions in Section 1.5, p 6).

Table 3.1 Data gathering tools used in the study

Research question	Data gathering instrument/strategy	Type of data
1	Spatial ability tests	Quantitative
2	Diagnostic test	Quantitative
3	Diagram analysis instrument	Qualitative
4	Interview	Qualitative
5	Interviews	Qualitative

The table shows that the tools provided both quantitative and qualitative data. The quantitative data obtained through the use of diagnostic and spatial ability tests informed selection of learners who participated in interviews. Thus quantitative study facilitated qualitative study.

Usage of methods associated with both qualitative and quantitative approaches did not result in challenges for data collection and analysis in the current study. First, I worked hard to understand both approaches in order to use the methods appropriately. Furthermore, my research questions suggested the order in which data had to be collected. Thus, I did not collect qualitative and quantitative data at the same time, and also, I encountered no difficulties of deciding which methods to use first. Finally, I obtained materials needed to process and analyze all the data obtained in the study.

3.2 Sampling

Educational researchers collect data from people, events and objects in order to understand characteristics associated with these entities (Ary, Jacobs & Razavieh, 1990; McMillan &

Schumacher, 1993). It is sometimes difficult to obtain data from the entire population (i.e. all entities relevant to a study) because of pragmatic, financial and time constraints, and, as a result, researchers may use samples to infer characteristics of populations (van Dalen, 1973; Ary et al., 1990; Cohen & Manion, 1995). Sample refers to a smaller group of entities from which data is collected, selected from the entire group called the population (McMillan & Schumacher, 1993).

Researchers usually select samples using one of the two main sampling approaches: probability and non-probability sampling (Ary et al., 1990; Cohen & Manion, 1995). **Probability sampling** is an approach in which all entities relevant to a study have equal and/or known probability of being selected. This method is ideal for researchers who want to generalize their findings, because the participants selected through the use of this approach are considered to be representative of their population (Hopkins, 1976; Ary et al., 1990; McMillan & Schumacher, 1993). However, probability sampling cannot always be utilized in educational research because existing conditions may not allow all participants to be available for research (Hopkins, 1976; Ary et al., 1990). Educational researchers, therefore, often utilize **non-probability sampling**; an approach in which researchers use (or choose from) participants who are readily available for a study. McMillan and Schumacher (1993) point out that this approach has two major limitations: (i) the sample is not necessarily representative of the population, and (ii) samples are likely to be biased if people volunteer to participate in the research. Despite these two limitations, non-probability sampling has been utilized in this study because the aim of the study was to understand characteristics of participants, not to generalise findings to the population from which the sample was selected.

Two forms of non-probability sampling were used in this study; convenience sampling and purposive sampling. **Convenience sampling** involves selection of participants that are accessible for a study, depending on availability of time and resources (van Dalen, 1973). I used this method to obtain diagrams analysed in the study. That is, I made an effort to get as many textbooks as possible which had diagrams illustrating phases of the Moon, and analysed diagrams found in these books. Thus, I analysed diagrams from books that were available for the study.

Purposive sampling involves selection of participants that are likely to provide data needed for a study (Cohen & Manion, 1995). I used this method to obtain learners who answered the diagnostic and spatial ability tests, to select learners who participated in the interviews, and to select diagrams used in the interviews. The use of this approach had a number of advantages as discussed below:

- *Learners who answered diagnostic and spatial ability test:* I administered the tests to learners studying in an English medium school located in town. I hoped that these learners would be better able to communicate in English than learners in schools located out of town.
- *Learners who participated in interviews:* I used results from spatial ability tests to select learners who interpreted diagrams illustrating phases of the Moon. Five of these learners had obtained high spatial ability scores while the other five had obtained low spatial ability scores. Results enabled me to establish links between diagrams interpretation and learners' spatial ability skills.

- *Diagrams used during interviews:* I selected four diagrams with the fewest design problems to be used during interviews. It was important for these diagrams to have as few design problems as possible, to minimize misinterpretations that might result from poor design of diagrams.

3.3 Rigour

Rigour in research refers to validity (truthfulness) and reliability (consistency) of inferences researchers make on the basis of data they collect (Fraenkel and Wallen, 1990; Salkind, 2009).

3.3.1 Validity

Researchers need to pay attention to validity of data they collect, and validity of inferences they make on the basis of the data (Fraenkel & Wallen, 1990; Punch, 2005).

Validity of data

This is a measure of the extent to which “data represents the phenomenon for which it stands” (Punch, 2005:252). It “depends on the amount and type of evidence there is to support the interpretations researchers wish to make” (Fraenkel & Wallen, 1990:128). Different methods are used to validate quantitative and qualitative data.

Validating quantitative data: When validating quantitative data, researchers have to define content to be assessed, and then construct test items that adequately cover the content (Punch, 2005; Rosenthal & Rosnow, 2008). The content knowledge and test items have to be given to experts to check content validity, i.e. the extent to which the test fairly covers the required content (Punch, 2005; Rosenthal & Rosnow, 2008). Fraenkel and Wallen (1990) suggest that the experts should also check clarity of instructions, quality of printing, and language used in the test. Section 3.4.1 explains validation of tests used in this study (first paragraph on page 65, and second paragraph on page 69).

Validating qualitative data: Punch (2005) gives two pieces of advice that can enhance validity of qualitative data. First, he advises researchers to use check coding. This is a process in which another researcher checks coding and processing of data. Secondly, he advises researchers to provide an audit trail through the analysis, i.e. to show “how the data were analyzed to arrive at conclusions” (Punch 2005:289). Sections 3.5.2 (last paragraph on page 73) and 3.6.4 (last paragraph on page 80) explain how check coding was used when processing data obtained from

diagrams and interviews respectively. Chapters 6, 7 and 8 give detailed explanations of how data was used to arrive at conclusions.

Validity of inferences

This aspect of rigour has two components, internal validity and external validity.

Internal validity: This is “the extent of controlling extraneous variables” (McMillan & Schumacher, 1993:172), and “the extent to which the relationships between the variables are correctly interpreted (so that) the findings faithfully represent and reflect the reality which has been studied” (Punch, 2005:254). Table 3.2 lists some threats to internal validity, i.e. variables that might have to be controlled. These include history, subject attrition, maturation, researcher and participant effects.

Table 3.2 Threats to internal validity

Threats	Explanation
History	Source of error resulting from uncontrolled events/incidents (e.g. power failure) that happen during the conduct of research (McMillan & Schumacher, 1993; Rosenthal & Rosnow, 2008).
Subject attrition	The effect in which participants drop in the course of a study, especially the studies extending over a long period of time (McMillan & Schumacher, 1993).
Maturation	Changes that occur to participants, e.g. being hungry, tired, discouraged; or growing older, wiser, stronger, or more experienced (McMillan & Schumacher, 1993; Rosenthal & Rosnow, 2008).
Researcher effects	Bias caused by presence of a researcher, e.g. dress code, age and educational level. These can affect the way participants respond (McMillan & Schumacher, 1993).
Participant effects	Participants may behave in a particular manner because of being subjects of an investigation. These changes are initiated by participants themselves, not the experimenter (McMillan & Schumacher, 1993).

Table 3.6 (page 72) explains the steps I took to minimize these threats for diagnostic and spatial ability tests, while Table 3.15 (page 79) explains how I minimized these threats for the interviews.

External validity: Quantitative researchers use this term when referring to the extent to which research findings can be generalized to populations from which samples were taken (McMillan & Schumacher, 1993; Punch, 2005). As has been mentioned above, the purpose of this study was to extend understanding not to generalize findings.

The term *transferability* is considered by qualitative researchers whose aim is to extend understanding (McMillan & Schumacher, 1993; Punch, 2005). Transferability requires researchers to give detailed descriptions of the sample, the context of the study, and the theories used to design the study and interpret results. This enables readers to fully understand conditions under which

research has been conducted (McMillan & Schumacher, 1993). This, in turn, enables the readers to evaluate the extent to which research findings can be used in other settings (Henning 2004; McMillan & Schumacher, 1993; Punch, 2005) and to use these findings when designing further research (McMillan & Schumacher, 1993). I have given detailed description of the research in this thesis, to enable readers to get an in-depth understanding of the methods used in the study, and to evaluate the extent to which my findings can be used in other settings.

3.3.2 Reliability

Quantitative researchers use the term ‘reliability’ when referring to consistency of administering instruments and scoring data obtained from the use of the instruments (Fraenkel & Wallen, 1990; Punch, 2005; Salkind, 2009). On the other hand, qualitative researchers use this term when referring to consistency of the researcher’s interactive style, data recording and analysis methods, and interpretation of meanings obtained from data (McMillan & Schumacher, 1993). Table 3.3 illustrates ways of increasing reliability in research (discussed by McMillan & Schumacher, 1993; Punch, 2005; Salkind, 2009; Stemler, 2004).

Table 3.3 Ways of increasing reliability in a study

Quantitative research	Qualitative research
Researchers should • Eliminate unclear questions because participants might respond to these items in different ways at different times. • Standardize test instructions and conditions under which the test is taken (e.g. temperature, time of day etc.). • Minimize impact of external events (e.g. sporting activities). • Maintain consistent scoring procedures. • Check interrater reliability.	• Researchers enhance reliability in their design by clearly explaining the context in which the study is based, methods used to select participants, and data collection and analysis strategies. • They reduce threats to reliability in data collection by mechanically recording data and using verbatim accounts.

The table shows that quantitative researchers eliminate unclear questions, standardise test instructions, and maintain consistency in scoring, taking interrater reliabilities into consideration. The aim of these researchers is to enhance truthfulness of interpretations made from the results. They believe that truthfulness can be ascertained if independent raters produce the same result.

The table further shows that qualitative researchers enhance reliability giving details about context of the study, selection of participants, and the processes of data collection and analysis. These researchers do not strive for truth because they believe that reality is constructed by individual based on experiences, beliefs, expectations, etc.

All these issues were taken into consideration during the conduct of this research. That is

- Validation and piloting of the diagnostic test eliminated unclear questions from the test.

- Designers of spatial ability tests provide standard instructions for administration and scoring of these tests. In the same way, I drew up standard instructions that were given to learners who answered the diagnostic test (see the diagnostic test in Appendix B).
- I administered the tests during school days when there were no external events such as sporting activities.
- I scored all the tests, hence maximizing consistency in the scoring procedure.
- I provide details of methods followed when processing data obtained from diagrams and interviews.
- The interviews were video recorded, and the data was transcribed verbatim. A second researcher checked transcription of the tapes, and consistency of coding the data.

3.4 Spatial and Diagnostic Tests

In this section, I describe how I selected spatial ability tests and designed the diagnostic test used in the study. In addition, I describe methods that I used to collect data in the study.

3.4.1 Selection/design of tests

The first part of this section deals with selection of spatial ability tests from the ETS kit. The second part deals with design of the diagnostic test for the study.

Spatial ability tests

I selected six spatial ability tests from the *Kit of Factor-Referenced Cognitive Tests* developed by Ekstrom *et al.* (1976) at the Education Testing Service (ETS). Table 3.4 illustrates component of spatial ability measured by each test. I used the Hidden Patterns Test (CF-2) because it measures people's ability to mentally detach a figure from distracting background. This skill is needed when interpreting diagrams illustrating phases of the Moon. That is, diagram viewers need to focus at the Moon in one position while ignoring the Moon in other positions which might act as distracting background. In addition to the CF-2 test, I used the Card Rotations (S-1) and Cube Comparisons (S-2) Tests because they measure people's ability to mentally rotate objects in space, a skill needed to understand why earth viewers see phases of the Moon (e.g. the turning of the Earth on its axis and Moon's orbit around the Earth). The S-1 test is simpler, measuring peoples' ability to mentally rotate two-dimensional objects on plane of the paper. Results of this test give information about people's ability to undertake mental rotations. The S-2 test, on the other hand, measures people's ability to mentally rotate three-dimensional objects in space (similar to understanding phases of the Moon, which requires mental manipulation of three-dimensional objects in space). Thus, the S-2 test is more demanding and more relevant than the S-1 test. Learners who have spatial ability skills needed to mentally rotate objects in space would get high scores on both tests, while learners who

lack these skills would get low scores in both tests. However, learners who are good in mental rotation, but struggle to rotate three-dimensional objects in space would obtain high scores on the S-1 test and low scores on the S-2 test. Thus, information obtained from the two tests helps us to understand the exact problems that learners encounter when mentally rotating objects in space.

Table 3.4 Spatial ability tests used in the study¹

Component of spatial ability	Tests from ETS Kit	
	Name	Code
Spatial Perception	Hidden Patterns Test	CF-2
Spatial Orientation	Card Rotations Test	S-1
	Cube Comparisons Test	S-2
Spatial Visualization	Form Board Test	VZ-1
	Paper Folding Test	VZ-2
	Surface Development Test	VZ-3

Finally I used the Form Board Test (VZ-1), the Paper Folding Test (S-2) and the Surface Development Test (VZ-3) which all measure people's ability to perform a series of mental transformations. The VZ-1 test measures people's ability to execute these transformations on the plane of the paper. Results obtained from this test measure people's ability to mentally manipulate several objects at the same time. The VZ-2 test is more challenging, measuring people's ability to mentally manipulate a paper in three-dimensional space. This test gives more information than the VZ-1 test, i.e. not only about people's ability to execute a series of mental transformations, but to execute the transformations in three-dimensional space. The VZ-3 test measures people's ability to mentally construct three-dimensional shapes from two-dimensional drawings. Results obtained from this test give information that can help us to understand the extent to which participants can mentally perceive the Earth, the Sun and the Moon as three-dimensional objects from drawings illustrating the Earth-Sun-Moon system.

Learners who have spatial ability skills needed to execute a series of mental manipulations in space would get high scores on the three tests while learners who lack these skills would get low score on these tests. On the other hand, learners who have skills needed to execute a series of mental manipulations in space, but struggle to manipulate 3-D objects in space would get high scores on the VZ-1 test and low scores on the VZ-2 and VZ-3 tests. Furthermore, learners who have skills needed to mentally manipulate 2-and 3-D objects in space but struggle to construct 3-D shapes from 2-D drawings would get high scores on the VZ-1 and VZ-2 tests but obtain low scores on the VZ-3 test. Thus, usage of the three tests helps us to understand the exact problems that learners encounter when endeavouring to undertake a series of mental manipulation in space.

¹ The table is a modification of ideas suggested by Salthouse, Babcock, Mitchelle and Skovronek (1990)

I selected tests from the ETS kit for four reasons: (i) the tests were appropriate for learners who participated in the study, i.e. designers indicate that the tests are suitable for persons who have reached Grade 9 and older, but can be administered to younger participants if researchers read out instructions (ii) thorough research was done when the tests were developed, (iii) reliability coefficients show the tests to be very reliable (0.7 and above for S-2 and VZ-2, 0.8 and above for CF-2, S-1 and VZ-1, and above 0.9 for VZ-3), and (iv) comparison can be made with other studies because the tests are widely used. When discussing the results, I pay attention to similarities and differences between skills measured by the tests, and skills needed to understand phases of the Moon.

The diagnostic test

Diagnostic tests are usually pencil-and-paper techniques used to identify existing knowledge and competencies, and to identify areas of strength and weakness (Fraser, 1991). Diagnostic tests have the following advantages (similar to advantages of questionnaires discussed by Cohen & Manion, 1995; Fraenkel & Wallen, 1990; McMillan & Schumacher, 1993; Oppenheim, 1966 and Sax, 1968) which are applicable to the study: (a) they are a relatively cheap way to gather research data because they do not necessarily require a researcher to travel to individual respondents, (b) they do not need to be administered by trained staff, (c) data can be obtained from large samples in a short time, (d) processing and analyzing the data can be simpler and quicker than is the case for interviews.

Design of the diagnostic test: The first step in the design of the test was to specify content knowledge to be evaluated through the test. It should be remembered that the curriculum requires (i) Foundation Phase learners to know that spatial objects such as the Sun, the stars, the Moon and the planets can be studied to establish **pattern of their movements** and **their relative positions**, (ii) Intermediate Phase learners to know that the **apparent shape of the moon changes in a predictable pattern**, and to further know that the **motion of the Moon relative to the Earth and the Sun** can be used to explain these changes, and (iii) Senior Phase learners to know that most spatial objects are in **regular and predictable motion**, and to further know that the motions of the Earth and the Moon explain phenomena such as phases of the Moon.

Section 4.3 (84-88) gives details about the content knowledge evaluated by the diagnostic test. The knowledge statements discuss issues associated with (i) **the regular and predictable motion of the Earth** such as the Earth's rotation and its orbit around the Sun, (ii) the **regular and predictable motion of the Moon** such as duration of Moon's orbit around the Earth, the rising and setting times of the Moon during each phase, the reasons why the Moon rises later each day, and time lapse between phases of the Moon, and (iii) **regular and predictable appearance of the Moon**, the shape of the Moon seen from earth during each phase, and reasons why the Moon appears to face opposite directions as seen from different hemispheres.

I used the knowledge statements to design the diagnostic test (see the test in Appendix B). The test consisted of 11 questions.

- **Questions 1 – 7:** These were multiple-choice questions testing learners' background knowledge on concepts associated with phases of the Moon. All these questions could be answered using knowledge taught in schools (from Intermediate Phase to Senior Phase as required by the curriculum). In addition, learners with good understanding of the Earth-Moon-Sun system, and those who have stayed in environments that enable view of the sky at night (e.g. where there is no electricity) could get correct answers for most of these questions.
 - Question 1 investigated learners' understanding of the duration of a complete cycle of moon phases (related to ***regular and predictable motion of the Moon***). This question investigated factual knowledge that learners have to be told.
 - Question 2 investigated learners' understanding of the rising and setting times of the Moon (related to ***regular and predictable motion of the Moon***). This question can be answered using factual knowledge that learners have to be told. In addition, learners who understand the Earth-Moon-Sun system could get a correct response for this question.
 - Question 3 investigated learners' understanding of time lapse between phases of the Moon (related to ***regular and predictable motion of the Moon, and predictable pattern of the Moon's phases***). Like the previous question, learners who have a good understanding of the Earth-Moon-Sun system could get a correct answer for this question. In addition, learners who regularly see the Moon in the sky could get a correct answer for this question.
 - Question 4 investigated learners' understanding of the delay in rising times of the Moon from day to day (related to ***regular and predictable motion of the Moon***). Learners who have everyday experience with the Moon (e.g. who regularly see the Moon) could get a correct answer for this question, even if the topic had not been taught in schools.
 - Question 5 investigated learners' understanding of the cause of moon's phases (related to the fact that the ***motion of the Moon relative to the Earth and the Sun can be used to explain changes in apparent shape of the Moon***).
 - Question 6 investigated learners' ability to link phases of the Moon, position of the Moon in the sky, and time of day (related to ***relative positions of the Earth, the Sun and the Moon, and phases of the Moon***). Learners who have a good understanding of the Earth-Moon-Sun system, and/or those who regularly see the Moon in the sky could get a correct answer for this question.
 - Question 7 investigated learner's understanding of the fact that all viewers on earth see the same phase of the Moon in a particular day, irrespective of locations of viewers on earth (related to ***regular motion of the Earth, and phases of the Moon***).
- **Questions 8 – 11:** These questions tested learners' ability to mentally manipulate spatial information presented in diagrams.
 - Question 8 illustrated a viewer (P) on earth and an astronaut (A) on the Moon. The Moon appeared to be crescent-shaped as seen from the Earth (see Figure 3.2).

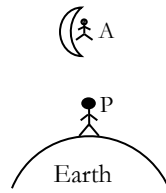


Figure 3.2 A diagram from Question 8

The question asked learners to determine the phase of the Earth that would be seen by the astronaut. To answer the question, learners needed to determine a configuration of the components of the Earth-Moon-Sun system for which earth viewers would see the crescent moon illustrated in the diagram, and to imagine looking at the Earth from the Moon in this position (related to *relative positions of the Earth, the Sun and the Moon, and phases of the Moon*).

- Question 9 tested skills necessary to determine phases of the Moon from diagrams, using a diagram that was likely to be familiar to the learners. The question illustrated the Earth, the Moon in eight positions around the Earth, and the Sun's rays shining on the Earth and the Moon (see Figure 3.3)

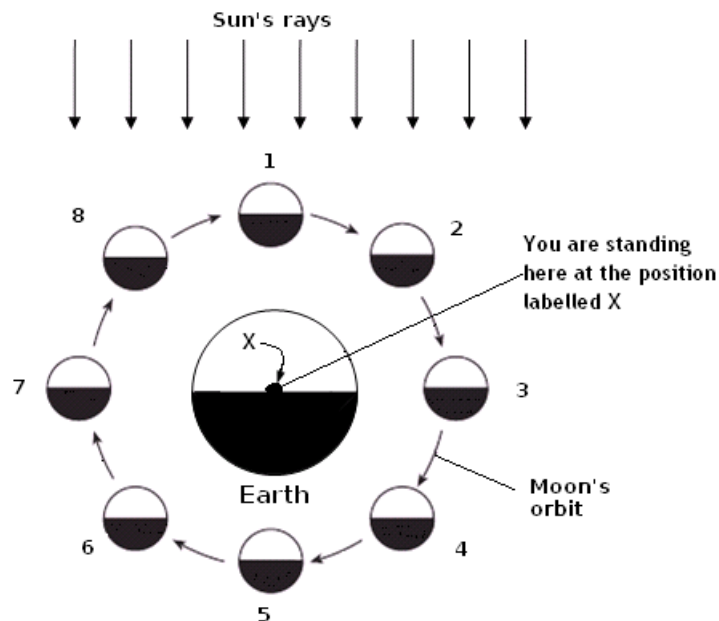


Figure 3.3 A diagram from Question 9

The question asked learners to determine phases of the Moon in positions 1, 4, 5, 7 and 8 as seen from the earth shape. Learners who had used this diagram before would be in better position to answer the question, than learners who had never used the diagram. In addition,

learners with high spatial ability skills could outperform learners with low spatial ability because the question required respondents to manipulate objects in space.

- Question 10 illustrated the Planet Mars, its two moons, and the Sun's rays approaching the planet and its moons (see Figure 3.4).

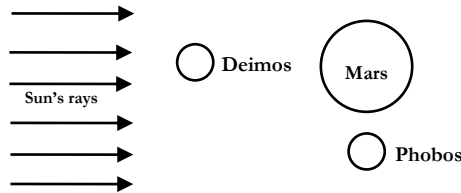


Figure 3.4 A diagram from Question 10

The question asked learners to determine the phase of Phobos as seen from Deimos. This questions required learners to use diagrams to determine the shape of one spatial object as seen from another, a skill needed to interpret diagrams illustrating phases of the Moon. Failure to get the correct answer to this question suggested that learners would likely struggle to interpret diagrams illustrating phases of the Moon.

- Question 11 tested learners' ability to perform simultaneous rotation and revolution of spherical objects. The question illustrated the Planet Mercury in its orbital path around the Sun. A crater (C) was illustrated on the surface of Mercury (see Figure 3.5).

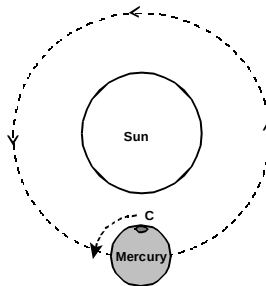


Figure 3.5 A diagram from Question 11

The question asked learners to draw the planet and its crater after a given duration of time (in days), thus investigating learners' ability to perform simultaneous rotations and revolutions needed to understand phases of the Moon. Failure to get a correct answer indicated that learners would likely struggle to understand concepts requiring simultaneous rotation and revolution of spherical objects.

Format of the test: The test consisted of five pages, a cover page and the questions in four pages (see Appendix B). The cover page had the following sections: (a) a space for learners to write their

names, (b) a question asking learners to indicate whether they had been taught about phases of the Moon, and the grade level in which they learned about the topic, (c) information explaining importance of the study, (d) the instructions explaining how to answer the questions. The four-page test was printed on both sides of an A3 sheet, which was then folded to make a booklet.

Each question had a confidence scale asking learners to indicate how certain they were about correctness of their responses. In addition, Questions 8-11 each had a visualization scale asking learners to indicate how easy it was for them to visualize what the diagrams illustrated. The diagnostic test consisted of spaces for learners to indicate specific problems encountered while responding to the test.

Validation of the test: The test was content-validated by two experts: an astronomer doing some work with school learners on astronomy education, and an experienced science education researcher who had interest in astronomy education. I asked the experts to check (a) clarity of instructions, (b) scientific accuracy of content in the test, (c) appropriateness of terminology used in the test (d) appropriateness of multiple-choice distractors, (e) whether the test fairly covered intended content, and (f) any other issues they could find interesting. Responses from these experts resulted in modification of instructions, simplification of language, and modification of some items. For instance, the astronomer suggested modification of the diagram in Question 10. In this diagram, the two moons were almost equidistant from the planet. The astronomer indicated that if this were the case, the moons would collide as they orbit the planet.

3.4.2 The pilot study

Research methodologists recommend that research instruments be piloted before being used to collect data in a study (e.g. Oppenheim, 1966; Sax, 1968). Pilot studies enable researchers to check ambiguities in wording, so that ambiguous words can be re-worded to clarify meanings (Behr, 1973; Bell, 1987; Oppenheim, 1966). Furthermore, pilot studies enable researchers to determine the time needed to complete a test, and to check if a test gives the type of data expected (Bell, 1987; Sax, 1968).

I piloted the diagnostic and spatial ability tests to investigate (a) appropriateness of language used in the diagnostic test, (b) clarity of instructions in this test, (c) and time needed to answer the test, (d) time required to administer spatial ability tests, to explain instructions to the learners, and to collect each spatial ability test before administering the next. I conducted the pilot study in a nearby English-medium school located in town. I hoped that learners in the school would be better able to communicate in English language than learners in schools located out of town.

A group of 31 Grade 9 learners gathered in a school hall to answer the tests. The learners were told about the purposes of the study. After this introduction, the learners were given the diagnostic test, and were instructed to complete information required on the cover page of the test (e.g. to state whether they had learned about phases of the Moon, and to indicate the grade level in which they learned about the topic). Thereafter, two items on the cover page were used to instruct learners on how to complete the diagnostic test and to indicate confidence and visualization levels. After this,

the learners were asked to answer the diagnostic test. Sax (1968) recommends that respondents of a pilot study be asked to report difficulties encountered when answering a test. Following this advice, the respondents were asked to state the problems they encountered while answering the test (the diagnostic test had spaces for this).

The diagnostic test was then collected, and the learners were given the Hidden Patterns Test (CF-2). The learners were familiarized with instructions and requirements printed on the cover page of this test. Furthermore, the learners used items on the cover page to practice answering the test. After this, the learners answered the CF-2 test for the duration specified on the cover page. The CF-2 test was then collected and the learners were administered the Card Rotations Test (S-1). As was the case with the CF-2 test, the learners were familiarized with requirements of the S-1 test before answering the test. Then, the Cube Comparisons Test (S-2) was administered, and the same procedure was followed. Care was taken to ensure that no question papers remained with learners, i.e. all the question papers, used and unused, were collected.

Bell (1987) and Sax (1968) recommend that methods of data analysis be tried out after a pilot study to investigate if items yield the type of information required. When processing data obtained from the diagnostic test, I entered learners' responses onto a spreadsheet indicating names of learners, grade level in which they claimed to have learned about phases of the Moon, a response selected for each question (Questions 1-10), and columns indicating correctness of responses for Question 11. Also, I entered learners' confidence levels and visualization abilities onto the spreadsheet. A second researcher checked accuracy of entering marks into the spreadsheet. The test was scored out of 18 as illustrated in Table 3.5.

Table 3.5 Criteria used to score the diagnostic test²

Question number	Marks	Notes
1-7	1 each	Learners select a correct answer for each question
8	1	Although learners were encouraged to make diagrams, the diagrams were not compulsory. As a result, I awarded no marks for the diagrams.
9	5	The question had five items. Each item was awarded a mark
10	1	No marks were awarded to diagrams (for the same reason as in Question 8).
11	4	1 mark was awarded for each of the two Mercury positions. Also, one mark for each of the Crater's positions.
Total	18	

Each spatial test was marked as recommended in the manual. That is, I counted correct and wrong responses for each test, and used formulae recommended to correct for guessed responses. I entered learners' marks onto a spreadsheet, and asked a second researcher to check correctness of marking and entering the marks into the spreadsheet.

² Marks were awarded for all the correct responses, even if learners indicated that they were uncertain or had guessed the answers.

Oppenheim (1966) argues that re-piloting has to be done if questions have been re-worded because these might have introduced new difficulties. Although learners had obtained low scores in the test, their comments indicated that none had encountered problems with instructions and language used in the diagnostic test. As a result, I made no modifications on the diagnostic test.

3.4.3 Main study

Bell (1987) and Oppenheim (1966) recommend that participants of a pilot study be as similar to the research sample as possible. For this reason, I administered the tests to a group of 65 Grade 9 learners in the school that provided learners for the pilot study. It was unlikely that this would affect validity of findings because (i) no question papers had been left in possession of the pilot-study learners, and (ii) none of the learners knew that the tests would be administered to learners who did not participate in the pilot study.

I administered the tests to the 65-learner group a week after the pilot study. The tests were placed inside a folded A3 sheet to minimize time spent administering each test to the learners. The tests were arranged in this order from the top: the diagnostic test, the Hidden Patterns Test (CF-2), the Card Rotations Test (S-1), and the Cube Comparisons Test (S-2). Two instructions were written in bold on the A3 folder, advising learners not to open the folder until to do so, and not to change the order of tests in the folder. The instructions of each test were read to the learners (as was the case with the pilot group). After answering the first test, learners took the next test from the folder until all the tests had been answered.

Two days later, I administered the following spatial tests to the 65-learner group: the Form Board Test (VZ-1), the Paper Folding Test (VZ-2), and the Surface Development Test (VZ-3). The tests were placed in an A3 folder, and again learners were advised not to open the folder until they were told to do so, and not to rearrange tests in the folder. The instructions for each test were followed during administration, and each test was collected before learners answered the next test.

The fact that no modifications had been made on the diagnostic test, and the fact that the main study was conducted in the school that was used to pilot the diagnostic test, meant that data obtained from the pilot study could be used together with the data obtained from the larger group. As a result, the three spatial ability tests (VZ-1, VZ-2 and VZ-3) were administered to the 31-learner group which had participated in the pilot study. This administration was done a week after the tests had been administered to the 65-learner group.

Table 3.6 illustrates steps taken to enhance internal validity of inferences that would be made from the data. Data from the tests was processed in the same way as the data obtained during the pilot study. That is, the tests were marked and entered onto a spreadsheet. A second researcher checked accuracy of marking and entering marks onto the spreadsheet. Analysis of data showed that only 75 learners had completed all the tests. This number formed the total sample in the study. The results obtained from these learners were used to select learners for the interviews (see Chapters 4 and 5 for details).

Table 3.6 Minimizing threats to internal validity on diagnostic and spatial ability tests

Threats	Impact of threats in the study
History	No uncontrolled events occurred during the conduct of the study.
Subject attrition	Some participants missed some tests as the tests were administered in a total of four sessions. However, the sample obtained was large enough to enable me to find 10 learners who would participate in interviews.
Maturation	All the tests were administered at the same time of day, that is, after learners' short break. This consistency was aimed to increase reliability of data obtained from the participants. In addition, each testing session lasted for about an hour, to minimize a possibility of participants becoming tired or losing interest.
Experimenter and subjects effects	The learners were told that information obtained from the tests would help improve the teaching and learning of science, not for their assessment. It was hoped that this would ease learners' (possible) excitement and nervousness.

3.5 Diagram Analysis

This part of the study employed content analysis, defined as the evaluation of written and/or visual data in documents, *e.g.* in newspapers, diaries, budgets, lesson plans, and textbooks (Anderson, 1998; Fraenkel & Wallen, 1990; van Dalen, 1973). I used content analysis to evaluate accuracy of information presented in diagrams illustrating phases of the Moon, and the extent to which the diagrams complied with visual design principles.

3.5.1 Obtaining the books

Several publishers were informed about the purpose of the study. These publishers provided textbooks designed for learners in Grades 4 to 12, both in the *Social Sciences* and *Natural Sciences* learning areas. More books were obtained from nearby bookshops. In total, 52 books were found to have information dealing with astronomical concepts (day and night, seasons, phases of the Moon and eclipses). However, only 27 of these books had diagrams illustrating phases of the Moon. Four of these books (from one publisher) had the same diagram. As a result, only one of these diagrams was analyzed in the study. This reduced the number of books from 27 to 24, and resulted in 28 diagrams (four books each used two diagrams to illustrate phases of the Moon, as shown in Appendix C).

I examined diagrams, text, and activities intended to help learners understand concepts associated with phases of the Moon in the 24 books. A second researcher checked accuracy of this analysis. In addition, I conducted a detailed analysis of diagrams presented in each book. First, I numbered the books from 1 to 24 depending on complexity of the diagrams. I considered simpler diagrams to be those illustrating phases of the Moon only, and considered complex diagrams to be those

illustrating the Sun, the Earth, the Moon's orbit, and phases of the Moon. Table 3.7 illustrates criteria used to number the books.

Table 3.7 Criteria used to number the 24 books

Criterion	Number of books	Book Numbers
Diagrams showing phases of the Moon only ³	10	1 to 10
Diagrams showing the Earth, the Moon in its orbital path around the Earth, and phases of the Moon	1	11
Diagrams showing the Sun (or Sun's rays), the Earth, and the Moon in its orbital path around the Earth.	2	12 & 13
Diagrams showing the Sun, the Earth, the Moon in its orbital path around the Earth, and phases of the Moon ⁴ .	11	14 to 24

Table 3.8 illustrates components of each diagram, and grade level for which each book was intended. A second researcher checked accuracy of information presented in Tables 3.7 and 3.8.

Table 3.8 shows that Books 14, 15, 21 and 22 each used two diagrams to illustrate the concept of moon's phases. In each book, one of the diagrams illustrated the Sun, the Earth and the Moon in its orbital path around the Earth, while the other diagram illustrated phases of the Moon. I used letters (a) and (b) to differentiate between the two diagrams; the letter (a) indicates the diagram which appeared first in the book (e.g. Diagram 14a indicates the first diagram in Book 14).

3.5.2 Design of diagram-analysis instrument

Thompson (1994) argues that design principles are not fixed rules, but can be altered depending on context and circumstances. I used all the principles that appeared to be applicable to diagrams when designing the analysis instrument. A second researcher checked the instrument, and suggested some modifications on the instrument. Then, I used the instrument to analyse the first diagram. The second researcher checked application of the principles to the diagram, made suggestions about how to apply the principles, and further suggested modifications to the instrument. For example, it became clear in the course of the analysis that some problems found in diagrams could not be easily solved by diagrams designers (e.g. it would be difficult to illustrate the Moon's orbit as tilted at 5° to the Earth's orbit). This prompted me to redefine a violation as an error that could have been avoided by artists of diagrams. The second researcher checked analysis of each diagram, and suggested modifications to the instrument to cater for all issues emerging from the analysis. Thus, the instrument was improved after analysis of each diagram, so that the instrument was finalised after all the diagrams had been analysed.

³ These books were ordered according to the number of Moon phases illustrated and labelled.

⁴ The books were ordered according to the number of Moon phases, the number of Moon positions and the number labels.

Table 3.8 Components of diagrams in the 24 books

Book	Grade	Sun	Earth	Lunar positions								Lunar phases							
				A	B	C	D	E	F	G	H	A	B	C	D	E	F	G	H
1	4											✓	✓			✓			✓
2	5											✓		✓		✓		✓	
3	6												✓	✓		✓		✓	
4	8											14 unlabelled shapes							
5	7											✓	✓	✓	✓	✓	✓	✓	✓
6	5											✓	✓	✓	✓	✓	✓	✓	✓
7	6											✓	✓	✓		✓		✓	✓
8	5											✓	✓	✓	✓	✓	✓	✓	✓
9	8											11 shapes							
10	8											✓	✓	✓	✓	✓	✓	✓	✓
11	4		✓	✓		✓		✓		✓		✓		✓		✓		✓	
12	5	✓	✓									✓	✓	✓	✓	✓	✓	✓	✓
13	7	✓	✓									✓	✓	✓	✓	✓	✓	✓	✓
14	4	✓	✓	✓		✓		✓		✓		✓	✓	✓	✓	✓	✓	✓	✓
15	6	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
16	5	✓	✓	✓		✓		✓		✓		✓		✓		✓		✓	
17	4	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓		✓	
18	6	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
19	4	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
20	6	✓	✓	✓		✓		✓		✓		✓	✓	✓	✓	✓	✓	✓	✓
21	7	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
22	7	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
23	7			12 shapes								12 shapes							
24	8	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Key

A	New Moon	B	Waxing Crescent	C	First Quarter	D	Waxing Gibbous
E	Full Moon	F	Waning Gibbous	G	Last Quarter	H	Waning Crescent

When modifying the instrument, I excluded some principles which appeared to be irrelevant to diagrams analyzed in this study. Table 3.9 explains why I considered each principle to be irrelevant to this study.

Table 3.9 Reasons for excluding some design principles from this study

Principles			Reason for exclusion
Syntactic	Processing priorities	Parts of a diagram that carry the main message should have more visual weight so that they can easily attract the eye.	No components of the diagrams should stand out from the rest.
Semantic	Schema availability	Intended reader must have knowledge needed to understand the diagram.	The diagrams are designed for learning purposes. Thus, they can use concepts unfamiliar to learners.

Some semantic principles appeared to be relevant, but needed some modification to fit context of the study. Table 3.10 explains the reasons for modifying each principle.

Table 3.10 Reasons for modifying some semantic design principles

Principle		Reason for modification
Representativeness	Intended meaning of a mark should correspond to the spontaneous interpretation of the mark.	These principles appear to focus on non-ambiguity of marks. The principles have been modified to make one principle: NON-AMBIGUITY
Between level mapping	Each mark should have only one meaning	
Congruence	<i>Surface compatibility:</i> The appearance of lines and regions should be compatible with their meaning.	The principle appears to be suitable for graphs and charts. To comply with diagrams, it has been modified to be SCIENTIFIC ACCURACY
	<i>Ordering:</i> Pairs of words should be ordered in accordance with natural usage.	

Appendix D shows a complete set of the design principles used to analyze the diagrams.

3.6 Interviews

Interviews involve direct communication between interviewers and respondents (Anderson, 1998; McMillan & Schumacher, 1993). Interviewers ask questions and record responses from respondents (Anderson, 1998). Table 3.11 illustrates advantages and disadvantages of interviews (discussed by Cohen & Manion, 1995; Fraenkel & Wallen, 1990; McMillan & Schumacher, 1993; Oppenheim, 1966; Sax, 1968).

In this study, I conducted interviews to deeply investigate meanings that learners ascribe to diagrams illustrating phases of the Moon. The interviews enabled me to clarify questions to the learners, and to probe responses given by the learners. In addition, the interviews enabled me to build and maintain rapport with the participants. For example, one learner who appeared to be nervous in the beginning of the interview opened up and became at ease as the interview progressed. Furthermore, interviews enabled me to investigate the extent to which models could

help the learners to clarify their ideas about diagrams illustrating phases of the Moon. Thus, I used interviews because of the rich data they provided, despite the disadvantages discussed in Table 3.11.

Table 3.11 Advantages and disadvantages of interviews

Advantages	Disadvantages
- Interviewers can clarify questions because of their interaction with respondents, and this improves the validity of responses obtained. - The interaction enables interviewers to probe responses given by respondents, and also enables respondents to clarify their responses. This allows interviewers to better understand answers given by the respondents. - Interviewers can build and maintain rapport with respondents to keep them motivated. - Interviews make it easier for second language speakers (who struggle to write in a foreign language) and less literate subjects to clarify their ideas. - Interviewers can observe non-verbal responses (<i>e.g.</i> demonstrated answers and time taken to respond). Non-verbal responses give additional information which cannot be obtained from the use of questionnaires.	- Travelling to respondents and usage of data recording technology make interviews relatively more expensive than questionnaires. - It is generally time-consuming to conduct interviews and to analyze interview data. - Respondents may be uncomfortable and unwilling to report their own feelings in a face-to-face interview. - The process of learning to conduct satisfactory/good interviews is long and difficult. Inexperienced and poorly trained interviewers may, for example, ask leading questions and misinterpret responses given by the respondents, which may lead to data of questionable validity.

The interviews were conducted 12 months after learners had completed the diagnostic and spatial tests. This is because of a lot of work that was required in (i) processing data obtained from the diagnostic test and six spatial ability tests, (ii) careful selection of learners for participation in interviews, and (iii) construction of the interview schedule. The learners had not learned about phases of the Moon since completing the diagnostic test. Thus, their subject matter knowledge in this field remained unchanged. Nevertheless, some of the learners considered to be ideal for interviewing were no longer in the school. However, the large sample of learners enabled me to find ten learners who were suitable to participate in interviews (see Section 5.5, p 131 for details).

3.6.1 The interview schedule

Fielding (1993) and Punch (2005) discuss three types of interviews: structured, semi-structured, and unstructured interviews.

- **Structured interviews:** Researchers prepare interview questions and possible probes in advance. Interviewers ask questions in the same order, using the same wording to all respondents. The interviewers may record responses by ticking a check-mark of pre-determined responses.
- **Semi-structured interviews:** Researchers prepare interview questions and possible probes in advance, but only as a guide. Interviewers are free to modify questions (*e.g.* to paraphrase the

questions) depending on circumstances. The open-ended nature of questions and responses may require interviewers to use recording devices (e.g. video and tape recorders).

- **Unstructured interviews:** Interviewers know themes on which to ask questions, but they ask questions in a way that best suits the situation. That is, no questions are prepared in advance. Recording devices are a necessity because of the open-ended nature of these interviews.

When undertaking this study, it was important for me to prepare questions and probes before conducting the interviews. In addition, I believed that the questions had to be adapted to suite existing conditions. As a result, the interviews conducted in this study were semi-structured in nature. I designed the interview schedule to investigate learners' interpretation of diagrams illustrating phases of the Moon. The semi-structured nature of these interviews enabled me to clarify questions to the respondents, and to probe responses given by the learners.

3.6.2 Preparation for the interviews

The interview was designed so that learners would give verbal responses, make some drawings, and use models when interpreting the diagrams. Vosniadou and her colleagues warn that presentation of models can bias learners' responses towards scientifically acceptable ideas which learners may have been exposed to, even if learners did not understand these ideas (Vosniadou, Skopeliti & Iskopentaki, 2004, 2005). To avoid this possible bias, I presented models towards the end of the interview when learners had responded to the majority of questions. The following objects were designed to be used as models during the interviews:

- Eight shapes representing phases of the Moon were cut out from Diagram 21b, which illustrates phases of the Moon as seen from the northern hemisphere. Table 3.12 shows the eight shapes, henceforth referred to as cut-out moon shapes.

Table 3.12 Shapes of the Moon cut from Diagram 21b

New Moon	Waxing Crescent	First Quarter	Waxing Gibbous	Full Moon	Waning Gibbous	Last Quarter	Waning Crescent
							

- A white polystyrene ball of about 4 cm diameter was obtained. Half of the ball was coloured black while the other half remained white.
- A circular paper of about 4 cm diameter was cut out from a white A4 sheet. Half of the paper was coloured black while the other half remained white.

The semi-structured nature of the interview and the fact that diagrams and models were used required the interview to be video taped. A postgraduate student agreed to be the camera person for

the entire session of interviews. He practiced using the camera before the actual interview sessions to be familiar with manipulating components of the camera.

3.6.3 Piloting the interviews

The school provided an office to be used as a venue for the interviews. The school administration indicated that the door of the office had to remain open throughout the course of the interview (and hence a need to monitor noise from outside). The first learner entered the interview room, and the interview proceeded as planned in the interview schedule. After this interview, the camera person commented on the nature of the interview and pointed out issues to be improved on. The second learner then entered the interview room, and the same procedure was followed.

I transcribed video tapes of the two learners. The camera person assisted with the transcription where the quality of sound was poor (e.g. because of noise from outside). I analyzed the results to evaluate the extent to which the analytical framework could be used in the data. I made a table with columns indicating learners' statements, what the statements meant about learners' interpretation of the diagram, and hints learners used to make this interpretation. I got the camera person to comment about accuracy and consistency of this coding. He generally agreed with the coding but made some minor suggestions. For example, one of the two learners appeared to be uncertain as to what the moon shapes and the curved arrows represented in Diagram 24. This learner said that the arrows indicated movement from Full Moon to New Moon, but insisted that the Moon does not move. The camera person suggested that both responses be recorded to indicate that the learners gave both a correct and a wrong response (and I adopted this when coding data obtained in the main study).

Table 3.13 describes some problems encountered during the interviews, and some steps taken to solve these problems.

Table 3.13 Problems encountered while piloting the interview schedule

Problem	Solution
The quality of visuals was somewhat poor because of light shining on the table through the window.	The school provided curtains to solve this problem.
There were a lot of materials on the table that was used for interviews	The owner of the table agreed to remove her materials from the table.

The interview sessions lasted 25 minutes and 26 minutes respectively for the two learners. This gave idea about the number of tapes that would be required during the main study.

Learners appeared to have no problems with the interview as structured. As a result, no modifications were made on the interview schedule. Thus the interview schedule was used in the main study.

3.6.4 The main study

The interview proceeded as indicated in the interview schedule. Table 3.14 illustrates the order in which the learners participated in the interviews (Section 5.5, p 131 describes how spatial ability scores were used to select these learners).

Table 3.14 Learners who participated in the interviews

Order of interview	Pseudonym	Interview date
1	Lehana	17 September
2	Masilo	17 September
3	Selomo	17 September
4	Makalo	17 September
5	Lisebo	17 September
6	Seboka	17 September
7	Fumane	19 September
8	'Mamosa	19 September
9	Karabo	08 October
10	Motena	08 October

Table 3.15 illustrates possible threats to internal validity of data obtained from the interview.

Table 3.15 Possible threats to internal validity of data obtained from interviews

Threats	Explanation
History	An intercom system was used to indicate time for exchange of classes, and to make announcements. This affected the flow of interviews. In addition, the alarm of the intercom system affected the quality of the audio being recorded.
	There was too much noise from the outside during exchange of classes, particularly because the interview venue had to be open at all times. The interview was stopped for a few minutes to allow noise to subside.
Subject attrition	Some learners considered to be ideal for interviewing were no longer in the school, while others had not consented to being interviewed. Thus, some of the best learners could not participate in the interviews.
Maturation	Each interview was designed to be short enough so that the participants would not get tired or lose interest.
	Learners had not learned about phases of the Moon since they completed the diagnostic test. Thus, their subject matter knowledge in this field remained unchanged. This however, could not be the case if learners interacted with this knowledge outside the classroom.

Processing data obtained during the interviews

Fielding (1993) indicates that researchers can either write everything said by respondents (i.e. verbatim transcription) or write only facts considered to be important (i.e. selective transcription). He argues that verbatim transcription provides rich data which allows researchers to see patterns that could be missed if selective transcription was used. He acknowledges that verbatim transcription is time consuming, and suggests that the number of transcriptions should determine whether to transcribe verbatim or selectively. He recommends verbatim transcriptions for smaller samples (e.g. less than 20). Although there are services that help to transcribe data, he advises researchers to do the transcription whenever possible. He argues that this helps researchers to be familiar with the data, and to see patterns during transcriptions.

Following on this advice, I transcribed all the video tapes (this helped to maintain consistency, which could enhance reliability of data). I used verbatim transcription for verbal responses, and used words to explain non-verbal responses (e.g. manipulation of models). The camera person helped during the transcription, particularly in instances where the quality of sound was very poor.

I noted the following issues about learners' responses:

- The learners made verbal statements when interpreting the diagrams. However, they sometimes used gestures and hand movements to supplement verbal responses, e.g. indicating the direction of the sun's rays or the Moon's orbit.
- Sometime learners used inappropriate terminology when interpreting the diagrams, e.g. referring to the Earth as the world, referring to phases of the Moon as types of moon, and using inappropriate terminology when referring to individual phases of the Moon (e.g. calling them quarters of the Moon). Despite language difficulties observed in these responses, it was easy to understand responses given by the learners (and to understand what they saw when looking at the diagrams).
- Some learners changed responses in the course of the interview. Sometimes learners changed responses in a way suggesting that the first response was slippery of the tongue. I recorded the second response that appeared to demonstrate learners' ideas about what the diagrams illustrate. At other times, however, learners gave responses with justification, but changed when asked further questions about the response. I recorded both responses in such cases.

When analysing the data, I made a table with columns indicating learners' statements, what the statements meant about learners' interpretation of the diagram, and hints learners used to make this interpretation. I got the camera person (who had experience of teaching this topic) to comment about accuracy and consistency of coding responses from two of the ten learners. His responses helped me to finalise the coding of responses obtained during interviews. For example, he insisted that I indicate instances where learners gave correct responses despite using inappropriate terminology (e.g. referring to phases of the Moon as types of Moon). I did not calculate interrater reliability because of the nature of the study. That is, the study was conducted by one researcher who used the same criteria to process and analysed data obtained from interviews. Interrater reliability is deemed necessary in research where multiple raters process data independently and

then compare their results to evaluate consensus and consistency of coding the data (see for example Stemler, 2004).

3.7 Ethical Issues

The following ethical issues were followed in the study.

- Application was made to the Educational Testing Service (ETS) for license to use tests from the *Kit of Factor-Referenced Cognitive Tests* developed by Ekstrom *et al.* (1976) at the institution. Appendix F shows the license granted by the ETS for usage of the tests in the current study.

The agreement between the researcher and the ETS was that the tests would be administered by December 2007. I complied with this condition by administering the tests in July 2007. Another agreement was that the tests would not be included in the research report. I have complied with this condition as well. That is, I have attached cover pages of the tests in Appendix A but not the actual tests.

- Data for the study was obtained from a school under the jurisdiction of Gauteng Department of Education (GDE). Application was made to the GDE asking for clearance to collect data in the school. Appendix F shows a clearance letter granted to the researcher by the Gauteng Department of Education.
- Application was made to the University Human Ethics Research Committee (HERC) for clearance to conduct research involving human participants. The application form was accompanied by consent forms which have been used in the study. Appendix F present the clearance letter obtained from the university's HERC and the consent forms.

3.8 Reflection on the methods

I administered the diagnostic and spatial tests to two groups of learners in two sessions for each group. Some learners participated in only one of these sessions. As a result, I discarded incomplete data obtained from these learners. Some of these learners had obtained very high scores in the few tests that they answered. It is possible that incomplete data made me discard learners who would be suitable to participate in interviews. It would have been advisable to administer the tests in fewer sessions. However, time constraints did not allow me to administer all the seven tests in one session for each group of learners. Also, it was not practical to administer all the tests in one sitting (the learners would be tired before answering some of the tests).

Another methodological issue is that I conducted interviews a year after the learners had answered the tests. As a result, some of the learners suited to participate in the interviews were no longer in the school. It would have been advisable to conduct interviews when learners were still in the same classes, as all would be available for interviews. A further problem associated with conducting interviews after such a long time is that, although learners did not formally learn about phases of the Moon during this time, they might have encountered this knowledge outside class. Such knowledge would affect validity of results obtained in the study. However, learners' responses during interviews indicated that if they encountered this knowledge, the knowledge did not enhance their understanding of concepts associated with phases of the Moon.

I have indicated earlier in the chapter that I used non-probability sampling in the study (Section 3.2, p 59). I further indicated that this method has some limitations, e.g. (i) samples are not necessarily representative of populations, and (ii) samples might be biased when people volunteer to participate in research. These limitations had no impact on the study because the aim of the study was to understand characteristics of participants, not to generalise findings to the population from which the sample was taken.

3.9 Summary

This chapter has discussed the research paradigm on which the study was based, issues associated with rigour, selection/design and administration of data gathering tools (spatial and diagnostic tests, the diagram analysis instrument, and the interview schedule), and methods used when processing data obtained from administration of these instruments. The next chapter presents results obtained from administration of spatial ability tests.

Chapter 4 Diagnostic test

4.1 Introduction

This chapter presents results obtained from analysis of the diagnostic test. Section 4.2 presents learners' claims regarding learning about phases of the Moon. Section 4.3 presents propositional knowledge statements used to design the diagnostic test. Sections 4.4 and 4.5 present item-by-item analysis of responses to questions in the diagnostic test, indicating the extent to which learners appeared to understand concepts and skills tested in each question. Section 4.6 presents an answer to the second research question. Section 4.7 discusses the extent to which ten learners selected to participate in interviews understood concepts associated with phases of the Moon.

4.2 Learners claims regarding learning about phases of the Moon

The cover page of the diagnostic test had a question asking the learners to indicate whether they had learned about phases of the Moon, and to indicate the grade level in which they learned about the topic. This section presents responses given by the 75 learners who participated in this study.

Twenty two learners indicated that they had learned about the topic in primary school. The curriculum requires Intermediate Phase learners to know the sequence of moon phases and to understand that the motion of the Moon relative to the Earth and the Sun causes these phases. The curriculum further requires Senior Phase learners to know that motions of the Earth and the Moon explain several concepts including phases of the Moon. It has to be borne in mind that the Intermediate Phase and the first Grade of the Senior Phase (Grade 7) are in primary school. This shows that the topic can be taught only in primary school, covering content prescribed for both Intermediate and Senior Phases (since the curriculum does not stipulate the grade level in which the topic has to be taught). It is not surprising, therefore, that some learners might learn about the topic in primary school and never again in high school.

Forty six learners indicated that they had never learned about phases of the Moon. This is worrying because the topic is supposed to be taught both in the Intermediate and senior phases, and is found in books designed for use in Grades 4 to 8. If the Grade 9 learners had never learned about phases of the Moon, then teachers of both the Intermediate and Senior phases skipped phases of the Moon when teaching about 'The Planet Earth and Beyond'.

Three learners could not remember whether they had learners about phases of the Moon, while four indicated that they had learned about phases of the Moon in Grades 8 and 9 (in the school where data was collected). It is very unlikely that only four of 75 learners could have been taught the topic

in the school. As a result, I conclude that that the learners were never taught about this topic in this school (Grades 8 and 9). If the learners had never learned about phases of the Moon in primary school (as their claims suggest), then we should expect their content knowledge would be low in this topic.

4.3 Propositional knowledge statements

The following section presents propositional knowledge statements associated with the Earth, the Sun and the Moon.

4.3.1 The Earth-Moon-Sun system

The Sun is at the centre of the solar system, surrounded by planets and their satellites. The Sun radiates light and other forms of energy in all directions. A small fraction of the Sun's rays shines on the planets and their satellites. These rays appear to be parallel by the time they reach the planets (because the planets are so small as compared to the Sun, and because the rays will have travelled long distances).

The Earth, being one of the planets, orbits the Sun once in $365\frac{1}{4}$ days. In addition, the Earth spins on its axis once in 24 hours. The Sun and the Moon appear to rise in the east and set in the west as a result of this spin. The Moon changes position relative to the Earth, the Sun and the stars in the course of a month. That is, if we imagine the Moon located in a certain position relative to the Earth and the Sun, and among the stars; the Moon takes 27.3 days to orbit the Earth and get back to the same position relative to the stars (the duration known as the sidereal month). However the Moon needs to take a longer journey to get back to its original position relative the Earth and the Sun because the Earth changes position relative to the Sun in the course of a month. The period of the Moon's orbit around the Earth to get back to the same position relative to the Earth and Sun, known as the synodic month, takes 29.5 days. The Moon rises about 50-to-60 minutes later as a result of its orbit around the Earth.

The Moon's orbital path around the Earth is tilted at 5° to the ecliptic (the plane of the Earth's orbital path around the Sun). That is, if the Earth-Sun system is drawn on a horizontal plane so that the Earth orbits the Sun in this plane, the plane of the Moon's orbital path around the Earth has to be drawn at 5° from the horizontal plane. This implies that the Moon is not precisely in line with the Earth-Sun system. This, in turn, suggests that the Earth only rarely casts a shadow on the Moon (which explains why eclipses occur only rarely).

The direction of the Moon's orbit depends on the location of viewers on the Earth. For viewers in the southern hemisphere, the Moon appears to orbit the Earth in a clockwise direction (see Figure 4.1).

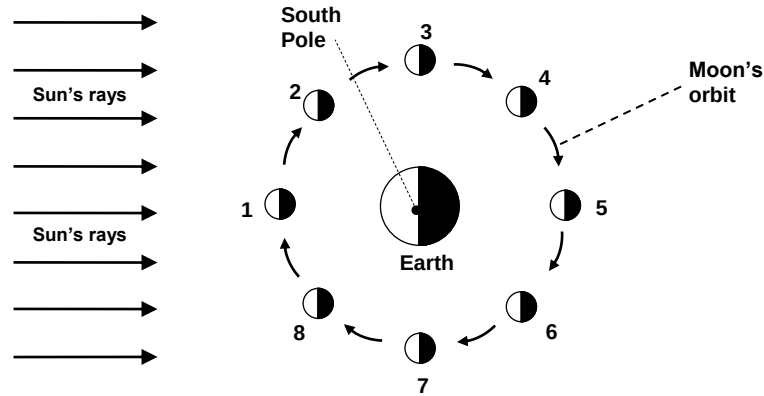


Figure 4.1 Direction of the Moon's orbit as seen from the southern hemisphere

For viewers in the northern hemisphere, the Moon appears to orbit the Earth in a counter clockwise direction (see Figure 4.2).

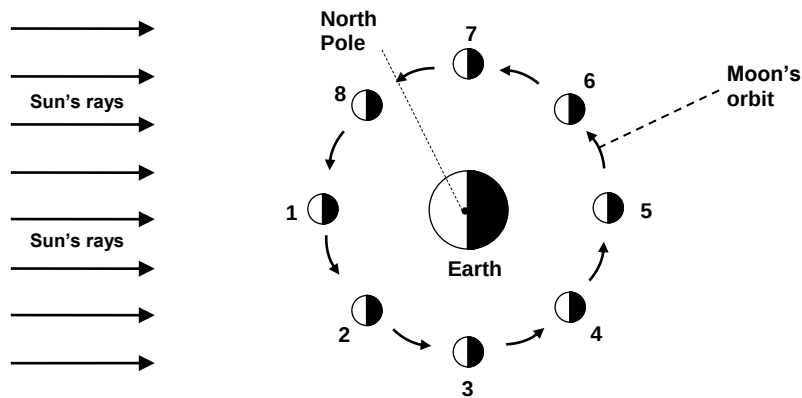


Figure 4.2 Direction of the Moon's orbit as viewed from the northern hemisphere

The Moon's orbital path around the Earth appears to be almost circular when seen from one of the poles (as illustrated in Figures 4.1 and 4.2). However, this orbital path appears to be an oval if viewed at some angle from the poles.

4.3.2 Phases of the Moon

Figures 4.1 and 4.2 show that the Sun illuminates half of the Moon's surface at any given point and time. The Moon can be seen from Earth if part of its illuminated surface reflects sunlight towards the Earth.

Figure 4.3 illustrates the Moon in 8 positions on its orbital path around the Earth, and shows corresponding phases of the Moon. Figure 4.3a illustrates phases of the Moon as seen from the southern hemisphere while Figure 4.3b illustrates these phases as seen from the northern hemisphere.

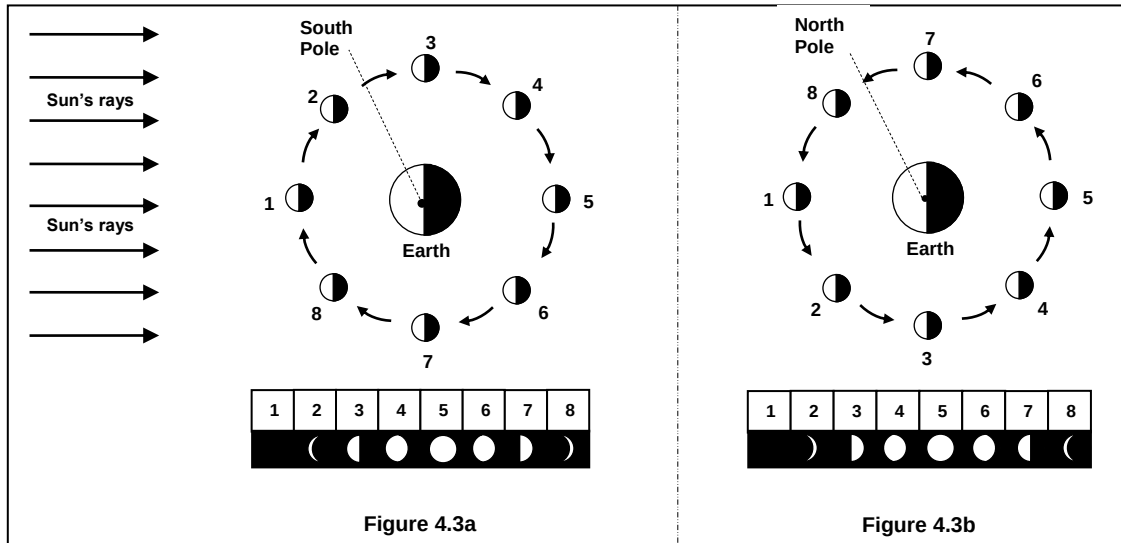


Figure 4.3 Moon phases as seen from (a) the southern hemisphere and (b) the northern hemisphere

The following discussion describes phases of the Moon as seen from Earth when the Moon is in each of the eight positions in its orbital path around the Earth.

- **New Moon:** This phase occurs when the Moon is in Position 1. The illuminated surface of the Moon faces away from the Earth and therefore reflects sunlight away from the Earth. As a result, the Moon is not visible from the Earth during this phase. This phase marks the beginning of the lunar cycle (hence the name *New Moon*).
- **Waxing Crescent:** This phase occurs when the Moon is between Positions 1 and 3, and it lasts for about 7 days and 9 hours. During this phase, less than half of the illuminated surface of the Moon faces Earth and therefore reflects sunlight towards the Earth. As a result, the Moon appears to be crescent-shaped as seen from the Earth. The crescent appears to be on the left-hand side of the Moon (facing the right-hand side) as seen from the southern hemisphere (see Figure 4.3a). On the other hand, the crescent appears to be on the right-hand side of the Moon (facing the left-hand side) as seen from the northern hemisphere (see Figure 4.3b).
- **First Quarter:** This phase occurs when the Moon is in Position 3. Half of the illuminated surface of the Moon faces the Earth and therefore reflects sunlight towards the Earth. As a result, viewers on Earth see half of the Moon. This half appears to be on the left-hand side of the Moon (facing the right-hand side) when seen from the southern hemisphere. However, the half appears to be on the right-hand side of the Moon (facing the left-hand side) when seen from

the northern hemisphere. The phase is called *First Quarter* because the Moon has travelled the first quarter of its orbital path.

- **Waxing Gibbous:** This phase occurs when the Moon is between Positions 3 and 5, and it lasts for about 7 days and 9 hours. During this phase, more than half of the illuminated surface of the Moon faces Earth and therefore reflects sunlight towards the Earth. The Moon appears to be gibbous-shaped as seen from the Earth. The gibbous shape appears to be on the left-hand side of the Moon (facing the right-hand side) as seen from the southern hemisphere, and to be on the right-hand side of the Moon (facing the left-hand side) as seen from the northern hemisphere.
- **Full Moon:** This phase occurs when the Moon is in Position 5. The entire surface of the Moon illuminated by the Sun's rays faces the Earth and therefore reflects sunlight towards the Earth. The Moon appears to be a complete circle as seen by viewers on Earth (hence the name *Full Moon*).
- **Waning Gibbous:** This phase occurs when the Moon is between Positions 5 and 7, and it lasts for about 7 days and 9 hours. During this phase, part of the illuminated surface of the Moon is now facing away from the Earth, and therefore reflects sunlight away from the Earth. Like in Position 4, the Moon appears to be gibbous-shaped as seen by viewers on Earth. However, the gibbous appears to be on the right-hand side of the Moon (facing the left-hand side) as seen from the southern hemisphere, and on the left-hand side of the Moon (facing the right-hand side) as seen from the northern hemisphere.
- **Last Quarter:** This phase occurs when the Moon is in Position 7. Half of the illuminated surface of the Moon faces away from Earth and therefore reflects sunlight away from the Earth. Viewers on Earth see only half of the Moon. This half appears to be on the right-hand side of the Moon (facing the left-hand side) as seen from the southern hemisphere and to be on the left-hand side of the Moon (facing the right-hand side) as seen from the northern hemisphere. The phase is called *Last Quarter* because the Moon has travelled three quarters of its orbital path (and has to travel one quarter to complete its orbit).
- **Waning Crescent:** This phase occurs when the Moon is between Positions 7 and 1, and it lasts for about 7 days and 9 hours. During this phase, less than half of the illuminated surface of the Moon faces the Earth and therefore reflects sunlight towards the Earth. Like in Position 2, the Moon appears to be crescent-shaped as seen from the Earth. However, the crescent appears to be on the right-hand side of the Moon (facing the left-hand side) as seen from the southern hemisphere and on the left-hand side of the Moon (facing the right-hand side) as seen from the northern hemisphere.

Figure 4.4 summarizes time lapse between phases of the Moon.

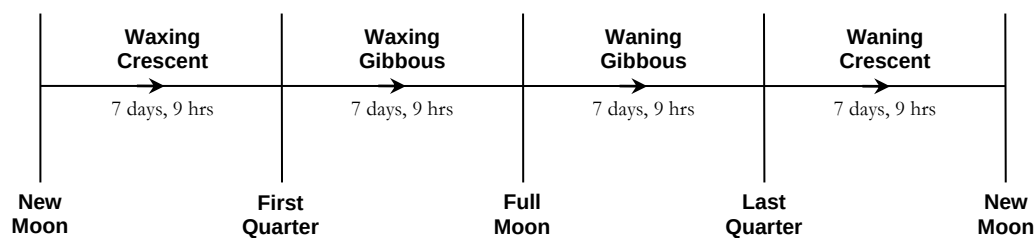


Figure 4.4 Time lapse between phases of the Moon

These propositional knowledge statements were used during the design of the diagnostic test presented in Appendix B.

4.4 Results obtained from the diagnostic test

Questions 1 to 10 consisted of multiple-choice items while Question 11 required learners to make drawings. Each question had a section requiring learners to indicate their certainty about the responses. In addition, Questions 8 to 11 (which had diagrams) had questions asking learners to indicate the extent to which they were able to visualize what the diagrams illustrated.

When presenting results, I discuss learners' responses and confidence levels for each question. In addition, I present learners' visualization abilities for Questions 8 to 11.

4.4.1 Question 1⁵

This question investigated learners' understanding of the duration of a complete cycle of moon phases. Understanding this duration would help learners to understand why phases of the Moon change in a 'predictable way' as required by the curriculum.

A complete cycle of phase of the Moon occurs once in ☐ 27.3 days ☐ 28.0 days ☐ 29.5 days* ☐ 30.0 days ☐ 31.0 days	How sure are you that your answer is correct? ☐ I am sure ☐ I think so ☐ I am guessing

⁵ In this and subsequent questions, the symbol * indicates a correct response

Table 4.1 illustrates learners' responses to Question 1, while Table 4.2 illustrates learners' confidence levels on responses given for this question.

Table 4.1 Learners' responses to Question 1

Distractors	Number of learners (N = 75)
27.3 days	4
28.0 days	20
29.5 days*	18
30.0 days	12
31.0 days	21

Table 4.2 Learners' confidence on responses given for Question 1

Confidence level	All learners (N = 75)	learners who selected the correct response (N = 18)
I am sure	9	2
I think so	46	8
I am guessing	20	8

Table 4.1 shows that only 18 learners selected the correct response in this question. Table 4.2 shows that only 2 of these learners claimed to be sure about their responses. These results suggest that only two learners knew the exact duration of the complete lunar cycle. This question tested factual knowledge that learners have to be told. The fact that learners were not taught about phases of the Moon helps to explain why the majority did not know the duration of the complete cycle of moon phases.

Performance of learners who participated in the current study is much lower than the performance of Israeli high school students who had never been taught about astronomy concepts, where 58% of 448 junior high school students (Trumper 2001a) and 70% of 378 senior high school students (Trumper, 2001b) selected the correct answer. However, there exist some differences between questions asked in the current study and Israeli studies. First, Trumper's question was about duration of the **Moon's orbit** around the Earth while the current question was about duration of the **cycle of lunar phases**. Secondly, Trumper asked students to select an alternative that best **estimated** the duration of the Moon's orbit around the Earth (the distractors were hour, day, week, month, and year). The majority of students selected 'month' as the best estimate. The current study, on the other hand, asked students to select an **exact** duration of a complete cycle of lunar phase from distractors that were very close to a month (27.3 days, 28 days, 29.5 days, 30 days, and 31 days). Poor performance in this question suggests that the question was more challenging than the question asked by Trumper. Lastly, Trumper did not ask participants to indicate their confidence on the responses for this question. As a result, we do not know the number of learners who guessed the correct answer.

4.4.2 Question 2

This question investigated learners' understanding of the rising and setting times of the Moon. The question investigated learners' understanding of the Moon's motion relative to the motion of the Earth as required by the curriculum.

When viewed from the Earth, the Moon appears to rise in the east and set in the west daily. This is because ☐ the Moon revolves (circles) around the Earth ☐ the Earth rotates (turns) on its axis* ☐ the Earth revolves (moves) around the Sun ☐ the Moon rotates (turns) on its axis ☐ the Moon revolves (circles) around the Sun	How sure are you that your answer is correct? ☐ I am sure ☐ I think so ☐ I am guessing

Table 4.3 illustrates learners' responses to this question while Table 4.4 illustrates learners' confidence levels on the responses given for this question.

Table 4.3 Learners' responses for Question 2

Distractors	Number of learners (N = 75)
the Moon revolves (circles) around the Earth	27
the Earth rotates (turns) on its axis*	21
the Earth revolves (moves) around the Sun	17
the Moon rotates (turns) on its axis	3
the Moon revolves (circles) around the Sun	7

Table 4.4 Learners' confidence on responses given for Question 2

Confidence level	All learners (N = 75)	Number of learners (out of 21 who selected the correct response)
I am sure	24	8
I think so	44	11
I am guessing	7	2

Table 4.3 shows that 21 learners selected the correct response for this question. Table 4.4 shows that only eight of these learners claimed to be certain about correctness of their responses. This question tested factual knowledge taught in schools. Poor performance in this question supports claims that the learners were not taught about phases of the Moon in this school.

Poor performance in this question corroborates results found by Plummer and her associates (2009a, 2009b, 2010, and 2011) and Ogan-Bekiroglu (2007) which show that some learners and pre-service teachers have misconceptions about the rising and setting of the Moon. For example, only 14% of 36 pre-service teachers who participated in Ogan-Bekiroglu's study knew that the Moon rises in the East and sets in the west. Six percent of these teachers said that the Moon rises in the west and sets in the east, while 36% said that the Moon does not rise and set. Although Ogan-Bekiroglu did not investigate reasons for rising and setting of the Moon, her study shows that some people have poor conceptual knowledge about facts associated with the rising and setting of the Moon.

Plummer's research also shows that some people have inaccurate ideas about moonrise and moonset. For example, some of the participants in her research gave responses suggesting that (i) the Moon does not move, but is fixed in one location in the sky, (ii) the Moon does not rise and set, but circles the sky, and (iii) the Moon rises and sets at the same location in the horizon.

4.4.3 Question 3

This question investigated learners' understanding of time lapse between phases of the Moon. This time lapse is part of the predictable nature of the Moon's phases which the curriculum requires learners to understand.

If the Moon is in the last quarter phase on the 7th of November, on what day (approximately) will the Moon be full? ☐ November 14 ☐ November 21 ☐ November 28* ☐ December 7 ☐ December 14	How sure are you that your answer is correct? ☐ I am sure ☐ I think so ☐ I am guessing

Table 4.5 illustrates learners' responses to Question 3 while Table 4.6 illustrates learners' confidence on responses given for this question.

Table 4.5 Learners' responses on Question 3

Distractors	Number of learner (N = 75)
November 14	18
November 21	9
November 28*	28
December 7	16
December 14	4

Table 4.6 Learners' confidence levels for Question 3

Confidence level	All learners (N = 75)	Number of learners (out of 28 who selected the correct response)
I am sure	13	6
I think so	41	17
I am guessing	21	5

Table 4.5 shows that 28 learners selected the correct response for this question. Table 4.6 indicates that only six of these learners claimed to be certain about correctness of their responses. These results suggest that only six learners knew the time lapse between Last Quarter and Full Moon phases. Like the previous questions, this question investigated learners' understanding of factual knowledge taught in school. However, learners who regularly observe the Moon could get a correct answer for this question. Poor performance suggests that the learners lacked daily experience of Moon phases.

This poor performance supports results found by Mulholland and Ginns (2008). Only 49% of 72 pre-service teachers who participated in their study gave correct duration of time lapse between New Moon and First Quarter. However, 21% gave correct duration of time lapse between New Moon and Last Quarter while 1% gave a correct duration of time lapse between Full Moon and Last Quarter. The results of Mulholland and Ginns show that even pre-service teachers lack understanding of time lapse between phases of the Moon. It is not surprising, therefore, that high school students who were never taught about the concept would get wrong answers for this question.

4.4.4 Question 4

This question investigated learners' understanding of the delay in rising times of the Moon from day to day. This question tests knowledge associated with motions of the Earth and the Moon, which the curriculum requires learners to understand. Learners who have everyday experience with the Moon (e.g. who regularly observe the Moon) could get a correct answer for this question, even if the topic had not been taught in schools.

If the Moon rises at 21h00 (9 o'clock) tonight, tomorrow night it will rise at about ☐ 19h00 (7 o'clock) ☐ 20h00 (8 o'clock) ☐ 21h00 (9 o'clock) ☐ 22h00 (10 o'clock)* ☐ 23h00 (11 o'clock)	How sure are you that your answer is correct? ☐ I am sure ☐ I think so ☐ I am guessing

Table 4.7 illustrates learners' responses to this question while Table 4.8 illustrates learners' confidence on responses given for this question. .

Table 4.7 Learners' responses to Question 4

Distractors	No. of learner (N =75)
19h00 (7 o'clock)	15
20h00 (8 o'clock)	21
21h00 (9 o'clock)	29
22h00 (10 'clock)*	8
23h00 (11 'clock)	2

Table 4.8 Learners' confidence on responses given for Question 4

Confidence level	All learners (N = 75)	Number of learners (out of 8 who selected the correct response)
I am sure	15	1
I think so	33	2
I am guessing	27	5

Table 4.7 shows that only eight learners selected the correct response for this question. Twenty nine learners select a response suggesting that the Moon rises at the same time in two consecutive days while thirty six learners selected responses indicating that the Moon rises earlier in the following day. These results suggest that the 65 learners did not know that the Moon rises later each day. Saying that the Moon rises at the same time and/or earlier in the second day suggests that the learners have never paid full attention to the Moon's movement in the sky (the Moon can easily be seen rising later in a subsequent day). These results support finding of Plummer (2009a, 2009b, 2010, and 2011) which show that some people lack knowledge of the Moon's motion in the sky.

Table 4.8 indicates that only one of the eight learners who selected the correct response claimed to be sure about correctness of this response. Poor performance in this question confirms that the learners had inadequate conceptual knowledge about facts associated with rising and setting of the

Moon (as was the case in Question 2). This knowledge can be obtained by observing the Moon in the sky. Poor performance suggests that the learners lacked experience of the Moon in the sky.

4.4.5 Question 5

This question investigated learners' understanding of the cause of moon's phases.

As seen from the Earth, the Moon seems to change shape during the month because of ☐ the turning of the Earth on its own axis ☐ the shadow of the Earth falling on the Moon ☐ the changing positions of the Earth, Sun and Moon* ☐ the turning of the Moon on its own axis ☐ the Earth moving around the Sun	How sure are you that your answer is correct? ☐ I am sure ☐ I think so ☐ I am guessing

Table 4.9 illustrates learners' responses to this question while Table 4.10 indicates learners' confidence on responses given for this question.

Table 4.9 Learners' responses to Question 5

Distractors	Number of learner (N = 75)
the turning of the Earth on its own axis	6
the shadow of the Earth falling on the Moon	26
the changing positions of the Earth, Sun and Moon*	23
the turning of the Moon on its own axis	6
the Earth moving around the Sun	14

Table 4.10 Learners' confidence on responses given for Question 5

Confidence level	All learners (N = 75)	Number of learners (out of 23 who selected the correct response)
I am sure	22	3
I think so	44	17
I am guessing	9	3

Table 4.9 shows that only 23 learners selected the correct response for this question. Table 4.10 shows that only three of these learners claimed to be confident about correctness of these responses. This suggests that only three learners knew the cause of moon phases.

Table 4.9 shows that the most common response, selected by 26 of the 75 learners, was that the shadow of the Earth causes phases of the Moon. This is similar to findings reported in literature, where the most common misconception reported about the cause of Moon phases is that the shadow of the Earth falls on the Moon to cause phases. Table 4.9 further shows that other alternatives, e.g. the one saying that the Sun turns on its axis to cause phases of the Moon, have been selected by fewer participants in this study, similar to low frequencies reported in literature (see Appendix G(i)).

4.4.6 Question 6

This question investigated learners' ability to link phases of the Moon, position of the Moon in the sky, and time of day. Learners who regularly observe the Moon in the sky could get a correct answer for this question.

If the Moon rises in the east as the Sun is setting in the west, then the phase of the Moon must be ☐ new Moon ☐ waxing crescent ☐ first quarter ☐ full Moon* ☐ waning gibbous	How sure are you that your answer is correct? ☐ I am sure ☐ I think so ☐ I am guessing

Table 4.11 illustrates learners' responses to this question while Table 4.12 illustrates learners' confidence on responses given for this question.

Table 4.11 Learners' responses to Question 6

Distractors	No. of learner (N = 75)
new Moon	20
waxing crescent	9
first quarter	29
full Moon*	14
waning gibbous	3

Table 4.12 Learners' confidence on responses given for Question 6

Confidence level	All learners (N = 75)	Number of learners (out of 14 who selected the correct response)
I am sure	7	2
I think so	39	6
I am guessing	29	6

Table 4.11 shows that only 14 learners selected the correct response while 61 learners selected wrong responses, suggesting that the majority of learners did not know that Full Moon rises at about sunset. Table 4.12 shows that only seven of the 14 learners who selected the correct answer indicated that they were certain about correctness of their responses. Learners could get a correct answer to this question by using knowledge obtained by observing the Moon in the sky. Poor performance in this question suggests that learners lacked daily experience of the Moon in the sky.

Results obtained in this question corroborate findings reported in literature, which show that some students have difficulty of understanding relationships between time of day and position of Full Moon in the sky. For example, only 6% of 32 middle school students who participated in Rider's (2002) study gave a correct response to a question asking for position of Full Moon in the sky when the Sun rises. The results also support findings which show that even university students and pre-service teachers lack understanding of relationships between phase of the Moon, time of day and position of the Moon in the sky (e.g. Mulholland & Ginns's, 2008; Ogan-Bekiroglu, 2007; Zelik et al., 1998).

4.4.7 Question 7

This question investigated learner's understanding of the fact that all viewers on Earth see the same phase of the Moon in a particular day, irrespective of locations of viewers on Earth. This question, too, investigated learners' understanding of the Earth-Moon-Sun system.

If we see the first quarter Moon tonight, which phase of the Moon will people on the other side of the Earth see when night arrives for them? ☐ a crescent Moon ☐ a first quarter Moon* ☐ a gibbous Moon ☐ a last quarter Moon ☐ a full Moon	How sure are you that your answer is correct? ☐ I am sure ☐ I think so ☐ I am guessing

Table 4.13 illustrates learners' responses to this question while Table 4.14 illustrates learners' confidence on responses given for this question.

Table 4.13 Learners' responses on Question 7

Distractors	No. of learners (N = 75)
a crescent Moon	9
a first quarter Moon*	9
a gibbous Moon	4
a last quarter Moon	40
a full Moon	13

Table 4.13 shows that only nine learners selected the correct response for this question. Table 4.14 shows that none of these learners claimed to be certain about correctness of their responses. These results suggest that none of the learners knew that viewers on different locations on Earth see the same phases of the Moon in one particular day.

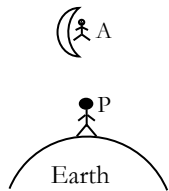
Table 4.14 Learners confidence on responses given for Question 7

Confidence level	All learners (N = 75)	Number of learners (out of 9 who selected the correct response)
I am sure	6	0
I think so	38	7
I am guessing	31	2

Research shows that some school students give wrong answers when asked questions similar to the one asked in this study. For example, only 10% of 32 middle school students who participated in Rider's (2002) study stated that if the Moon appears to be full as seen from New York, then the Moon would appear to be full as seen by viewers in California. Research further shows that some pre-service teachers give wrong answers when asked questions similar to one asked in this study. For example, only 51% of pre-service teachers who participated in Mulholland and Ginns's (2008) study correctly indicated that if the Moon appears to be full as seen from the USA, then the Moon would appear to be full as seen from Australia as well. However, a smaller number of participants (33%) in the same study correctly indicated that if the Moon appears to be in the First Quarter phase as seen from Johannesburg, then viewers in Australia would also see the Moon in the First Quarter phase. It appears, therefore, that some students and pre-service teachers have poor understanding of the fact that viewers on different locations on Earth see the same phase of the Moon in one day.

4.4.8 Question 8

This question illustrated a viewer (P) on Earth and an astronaut (A) on the Moon. The Moon appeared to be crescent-shaped as seen from earth.

The following diagram shows a person (P) standing on the Earth, looking at the crescent Moon. An astronaut (A) is standing on the Moon looking back towards the Earth. This question requires you to work out what phase of the Earth the astronaut will see. <i>The answer may not be as obvious as you think. To help you work out the answer, draw a diagram (in the space below) to show the positions of the Earth, the Sun and the Moon. Use your diagram to help you work out the answer.</i>	
	Draw your diagram here
What phase of the Earth will the astronaut (A) see? Circle the correct diagram/answer.  full Earth  gibbous Earth *  quarter Earth  crescent Earth  new Earth	
How sure are you that your answer is correct? ☐ I am sure ☐ I think so ☐ I am guessing	How difficult did you find it to imagine what was happening in the picture? ☐ It was easy ☐ I could imagine only after thinking hard ☐ I could not imagine what was happening

The question required learners to determine phase of the Earth that would be seen by the astronaut. The question tested learners' ability to imagine changing perspectives so as to see one celestial object from another. The question tested skills necessary to determine phases of the Moon from diagrams, using a context not likely to be used in school. The questions which test skills needed to understand astronomy concepts help us to understand why learners struggle to understand these concepts.

Table 4.15 illustrates learners' responses to this question while Table 4.16 illustrates learners' confidence on responses given for this question.

Table 4.15 Learners' responses to Question 8

Distractors	No. of learners (N = 75)
full Earth	12
gibbous Earth*	34
quarter Earth	10
crescent Earth	10
new Earth	7
No response	2

Table 4.16 Learners' competence levels on responses given for Question 8

Confidence level	All learners (N = 75)	Number of learners (out of 34 who selected the correct response)
I am sure	14	6
I think so	42	25
I am guessing	17	2
No response	2	1

Table 4.15 shows that 34 learners selected the correct response. Table 4.16 indicates that only six of these learners indicated that they were sure about correctness of their responses. It is worthy to note that none of the learners drew the Earth, the Sun and the Moon, which would help them workout the answer. As a result, the majority were not able to determine the correct answer. Table 4.17 illustrates learners' visualization ability in this question.

Table 4.17 Learners' visualization ability of the diagram illustrated in Question 8

Visualization ability	All learners (N = 75)	Number of learners (out of 34 who selected the correct response)
Easy	20	11
Hard	38	17
Impossible	15	4
No response	2	2

The table shows that only 20 learners indicated that it was easy for them to visualize what the diagram illustrated. This low number explains why the majority of learners selected wrong responses, and further explains why many were unsure about correctness of their responses.

Table 4.17 further shows that only eleven of the 34 learners who selected the correct response indicated that it was easy for them to visualize what the diagram illustrated. Analysis of learners'

responses indicates that only four of these eleven indicated that they were sure about their responses.

These results show lower performance than findings of Rochford and Sass (1988), where 67% of university students selected the correct answer for this question. However, Rochford and Sass did not ask the participants to indicate confidence levels. As a result, we do not know the exact number of learners who were sure about this response.

Poor performance obtained in this study somewhat mirrors results reported by Martinez-Pena and Gil-Quilez (2001) who asked 78 university students to make diagrams illustrating a situation where an astronaut can see the Moon in a Last Quarter phase when Earth viewers see Full Moon. Students' drawings show that many were not able to determine relative positions of the Earth, the Sun, the Moon and astronaut in space. However, Martinez-Pena and Gil-Quilez did not report frequencies (as discussed in Section 2.1, p 19). Results obtained in the current study, together with results obtained by Martinez-Pena and Gil-Quilez (2001) and Rochford and Sass (1988) show that high school and university students struggle to imagine viewing the Earth-Moon-Sun system from different perspectives. This might explain why these students struggle to understand astronomy concepts that require people to use this skill.

4.4.9 Question 9

This question tested skills necessary to determine phases of the Moon from diagrams, using context that was likely to be familiar to the learners. The question illustrated the Earth, the Moon in eight positions around the Earth, and the Sun's rays shining on the Earth and the Moon. The question asked learners to determine phases of the Moon in positions 1, 4, 5, 7 and 8 as seen from the Earth shape.

The diagram on the right shows sunlight shining on the Earth and the Moon. The Moon is shown in eight positions as it revolves around the Earth.

To help you to work out answers to the following questions, you might like to draw lines (on the diagram) showing what a viewer on Earth would see when the Moon is in each position.

The diagram illustrates the Earth-Moon-Sun system. At the top, 'Sun's rays' are represented by ten vertical arrows pointing downwards. In the center is a large circle labeled 'Earth', which is half-shaded black (the left half) and half-white (the right half). A point 'X' is marked on the Earth's surface, with an arrow pointing to it from the text 'You are standing here at the position labelled X'. Surrounding the Earth is a circular path labeled 'Moon's orbit'. Eight positions of the Moon are marked along this orbit, numbered 1 through 8. Each Moon is represented by a circle that is half-shaded black and half-white, with the shading corresponding to the Sun's rays. Position 1 is at the top, directly between the Sun and Earth. Position 2 is at the top-right, Position 3 is at the right, Position 4 is at the bottom-right, Position 5 is at the bottom, directly between Earth and Sun, Position 6 is at the bottom-left, Position 7 is at the left, and Position 8 is at the top-left. Arrows on the Moon's orbit indicate a counter-clockwise direction of revolution.

Imagine that you are standing at point X on Earth, looking at the Moon.							
If the Moon is in position 1, what would you see? Circle the correct diagram/answer.							
							

The question was followed by confidence level and visualization abilities as was the case with Question 8. Table 4.18 illustrates learners' responses to this question.

Table 4.18 Learners' responses to Question 9

Distractors	Number of learners who selected each distractor (N = 75)				
	Position 1	Position 4	Position 5	Position 7	Position 8
	12	0	24*	5	6
	22*	5	16	1	9
	3	11	8	8	17
	1	9	3	13	11*
	14	12	8	23	10
	6	17	4	17*	8
	12	10*	8	5	8
	3	10	4	2	4
No response	2	1	---	1	2

The symbol * indicates a correct response for each position of the Moon around the Earth. The table shows that out of 75 learners, 22, 10, 24, 17 and 11 learners selected correct answers for New Moon, Waxing Gibbous, Full Moon, Last Quarter and Waning Crescent respectively. These results indicate that few learners selected correct responses for each of the lunar phases. Furthermore, the results indicate that the lowest number of learners selected the correct responses for Positions 4 and 8 (representing crescent and gibbous phases). This suggests that determination of crescent and gibbous phases was more challenging than other phases. Table 4.19 illustrates learners' confidence level and visualization abilities for this question.

Table 4.19 Learners' confidence level and visualization abilities for Question 9

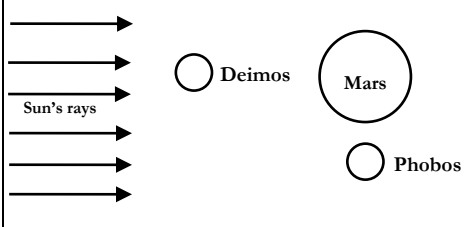
Confidence level	All learners (N = 75)	Visualization ability	All learners (N = 75)
I am sure	10	Easy	13
I think so	37	Hard	39
I am guessing	27	Impossible	22
No response	1	No response	1

This table shows that only 10 learners claimed to be sure about their responses. The table further indicates that only 13 learners stated that it was easy for them to imagine what the diagram illustrated. Learners' inability to visualize what the diagram illustrated corroborates results that I discuss in Chapter 5 of this thesis, which show that the learners had low spatial ability skills needed to understand astronomy concepts. The low number of learners who were able to visualize what the diagram illustrated explains why the majority selected wrong responses, and why the majority were uncertain about correctness of their responses.

Literature shows that some researchers administered tests which had questions asking participants to determine the appearance of the Moon from a given alignment of the Earth, the Sun and the Moon (e.g. Black, 2005; Mulholland and Ginns, 2008; Wilhelm, 2009b). However, none of these researchers reported the exact responses given by learners to these questions. Rather, they reported total marks obtained by learners in tests including these questions. As a result, there is no reference point to compare performance in this study with.

4.4.10 Question 10

This question tested skills necessary to understand phases of the Moon, using a context likely to be unfamiliar to the learners. The question illustrated the Planet Mars, its two moons, and the Sun's rays approaching the planet and its moons. The question asked learners to determine the phase of Phobos as seen from Deimos, thus applying the skills needed to answer Question 9.

Carefully examine the diagram on the right, which shows the positions of the Sun, Mars, and Mars's two moons (Phobos and Deimos). This question requires you to work out the phase of Phobos that a person on Deimos would see. <i>You might like to draw lines on the diagram to help you work out the answer to this question.</i>	
If you stood on Deimos and looked at Phobos, which 'phase of Phobos' would you see? Circle the correct answer.     	

How sure are you that your answer is correct? ☐ I am sure ☐ I think so ☐ I am guessing	How difficult did you find it to imagine what was happening in the picture? ☐ It was easy ☐ I could imagine only after hard thinking ☐ I could not imagine what was happening

Viewers on Deimos will see more than half (but not the entire) illuminated surface of Phobos. Thus, Phobos will appear to be gibbous-shaped. Table 4.20 illustrates learners' responses to this question while Table 4.21 illustrates learners' confidence on responses given for this question.

Table 4.20 Learners' responses to Question 10

Distractors	No. of learners (N = 75)
	15
	12
	28
	11
	9

Table 4.20 shows that 28 learners selected a correct response. Table 4.21 shows that only three of these learners indicated that they were sure about correctness of their responses. These results suggest that the majority of learners were not able to determine the appearance of Phobos from Demos.

Table 4.21 Learners' confidence levels on responses given for Question 10

Confidence level	All learners (N = 75)	Number of learners (out of 28 who selected the correct response)
I am sure	19	3
I think so	45	21
I am guessing	10	4
No response	1	---

Table 4.22 illustrates learners' visualization ability in this question.

Table 4.22 Learners' visualization ability on Question 10

Visualization ability	All learners	28 learners who selected the correct response
Easy	26	7
Hard	43	19
Impossible	5	2
None	1	---

The table shows that only 26 learners indicated that it was easy for them to visualize what the diagram illustrated. The table further shows that only seven of these learners selected a correct response. This question investigated learners' ability to execute skills needed to understand phases of the Moon. Poor performance in this question suggests that the learners struggled with these skills.

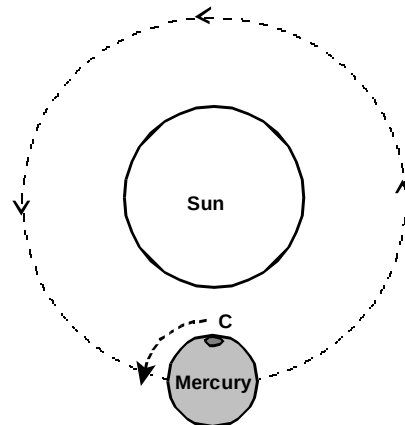
4.4.11 Question 11

The question illustrated the Planet Mercury in its orbital path around the Sun. A crater (C) was illustrated on the surface of Mercury. The question asked learners to draw the planet and its crater after a given duration of time (in days), thus investigating learners' ability to perform simultaneous rotations and revolutions needed to understand phases of the Moon.

Mercury turns on its own axis in about 60 days, and moves around the Sun in 88 days.

The diagram on the right shows the path of Mercury (imagine it moving on the surface of the page). The diagram shows a crater (labelled "C") on Mercury, directly facing the Sun.

If Mercury now continues to move around the sun from the position given, draw on the diagram a circle to show



- The approximate position of Mercury after 22 days, with the new position of crater C clearly marked. **Label your diagram (a).**
- The position of Mercury after 30 days, with the new position of crater C clearly marked. **Label your diagram (b).**

How sure are you that your answers are correct? ☐ I am sure ☐ I think so ☐ I am guessing	How difficult did you find it to imagine what was happening in the picture? ☐ It was easy ☐ I could imagine only after hard thinking ☐ I could not imagine what was happening

Learners were supposed to draw mercury and the crater in positions illustrated in the following diagram.

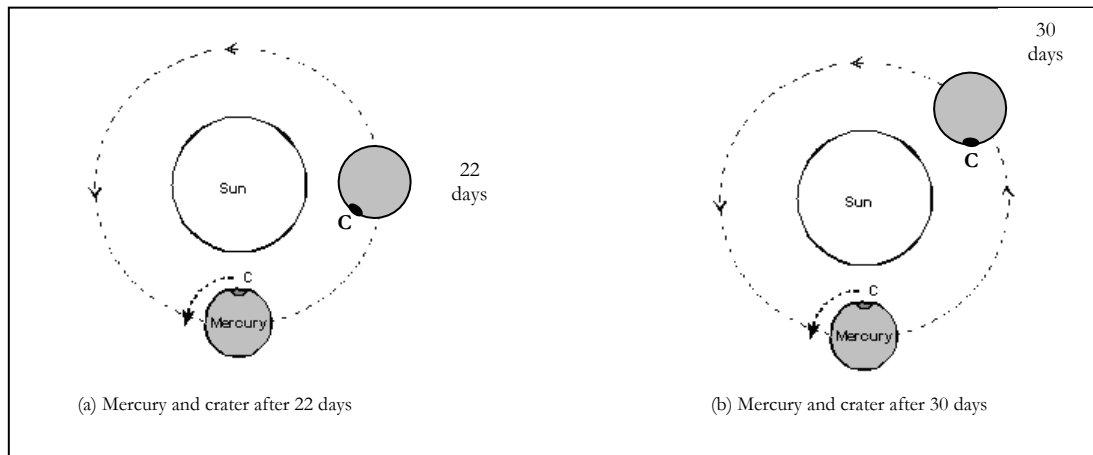


Table 4.23 illustrates learners' responses to this question.

Table 4.23 Learners' performance on Question 11

	22 days		30 days	
	Mercury	Crater	Mercury	Crater
Number of correct responses	29	8	25	10
Number of wrong responses	46	67	50	65

The following trends are observable from the table.

- *Positions of mercury:* 29 learners correctly determined the position of mercury after 22 days while 25 learners determined the position of mercury after 30 days. Analysis of responses shows that only 22 learners correctly determined the position of mercury in both occasions.
- *Positions of the crater:* Only eight learners correctly determined the position of the crater after 22 days while 10 learners correctly determined the position of the crater after 30 days. Analysis of responses shows that only three learners correctly determined the position of the crater in both occasions.

Further analysis of results shows that only one learner correctly determined the two positions of mercury and corresponding positions of the crater. These results suggest that learners encountered more difficulties in locating the positions of the crater than the positions of mercury. This, in turn, suggests that learners encountered more difficulty when mentally rotating the planet than mentally moving the planet around the Sun.

Table 4.24 illustrates learners' confidence levels and visualization abilities for this question.

Table 4.24 Learners' confidence and visualization abilities for Question 11

Confidence level	All learners (N = 75)	Visualization ability	All learners (N = 75)
I am sure	15	Easy	19
I think so	35	Hard	32
I am guessing	22	Impossible	22
No response	3	No response	2

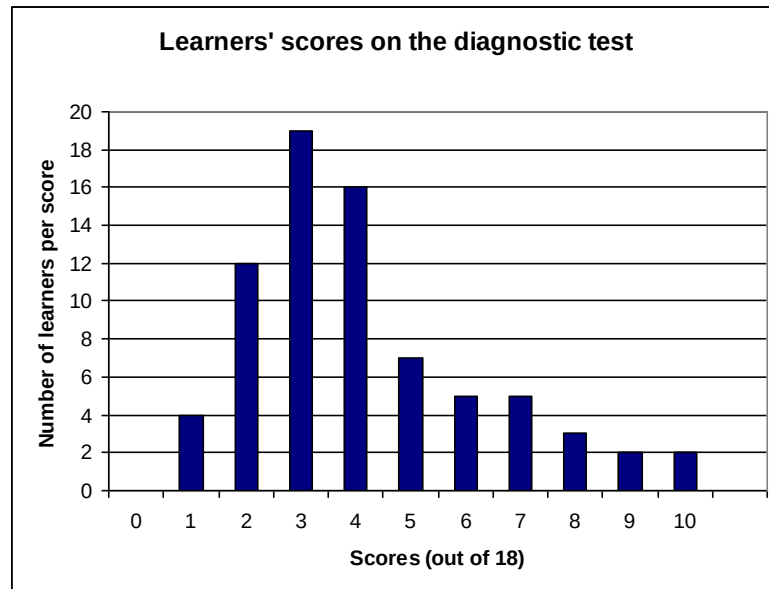
The table shows that 15 learners indicated that they were sure about correctness of their responses. The table further shows that 19 learners indicated that it was easy for them to visualize what the diagram illustrated. The fact that few learners easily visualized what the diagram illustrated explains why the majority failed to get correct answers in this question. These results suggest that almost all learners encountered difficulties when performing processes that require mental rotations.

This result corroborates findings that I discuss in Chapter 5, which show that the majority of learners performed poorly on tests measuring mental rotation (i.e. Spatial Orientation tests).

4.5 Summary of Learners' performance

Figure 4.5 illustrates learner's overall scores on the diagnostic test (uncertain and guessed responses have been included in the total scores). The following observations are made from the figure:

- **Central score of learners:** Both the mean and median scores have the value of 4 (22%). This shows that on average, the group obtained very low scores in this test. This in turn suggests that the group found the test to be difficult.
- **Variation of scores:** The highest score was 10 while the lowest score was 1, giving a range of 9 (50%). This value suggests a high variation between the highest and the lowest scores. The upper quartile was 5 while the lower quartile was 3, giving an inter-quartile range of 2 (11%). This value suggests that there was less variation of scores among 36 learners who obtained middle scores.



mean = 4, median = 4, mode = 3, range = 9, inter-quartile range = 2

Figure 4.5 Learners' scores on the diagnostic test

Questions 1 to 7 tested conceptual knowledge recommended by the curriculum. Learners' poor performance on these questions suggests that the learners lacked this knowledge. This corroborates learners' claims that they were not taught about these concepts. In addition to school based knowledge, Questions 3, 4, and 6 tested knowledge obtained by observing the Moon in the sky. Poor performance in these questions suggests that learners lacked this knowledge.

Research shows that carefully designed instructional interventions help learners to better understand concepts associated with phases of the Moon, e.g. Grade 4 learners in Trundle et al.'s (2007b) study. Low scores obtained in this study should not be interpreted as suggesting that the learners were not capable of understanding these concepts. Rather, the low scores might be explained by the fact that the learners had not formally learned about phases of the Moon. In the context of the current study, this low performance means that none of the learners would be advantaged by the background knowledge when interpreting diagrams.

Questions 8, 9, 10 and 11 tested learners' ability to execute skills needed to understand phases of the Moon, i.e. to perceive and manipulate celestial objects in space. Learners could get correct answers to these questions even if they were never taught about phases of the Moon. Poor performance in these questions suggests that learners encountered difficulties when mentally manipulating objects in space. This is not surprising, since Chapter 5 shows that the learners were very weak in these skills.

4.6 Answer to Research Question 1

The first research question has been phrased as follows:

What is the level of Grade 9 Natural Science learners' understanding of astronomy concepts associated with phases of the Moon?

Results obtained in this study show that the learners had very poor background knowledge on these concepts. Section 4.7 discusses the implications of this poor background knowledge on learners who participated in interviews.

4.7 Background knowledge of 10 learners selected to participate in interviews

Table 4.25 illustrates total scores obtained by 10 learners who participated in the interviews (Section 5.5, p 131 describes how I selected the learners). These totals exclude guessed answers (for Questions 1 to 10), thus getting rid of answers that could have been obtained by chance. Learners are arranged from top to bottom on the basis of spatial ability scores. That is, Learners 1-5 obtained low spatial ability scores while Learners 6 to 10 obtained high spatial ability scores.

Table 4.25 Learners' marks (excluding guessed responses on multiple-choice items)

Learners		QUESTION NUMBER																Total Score (out of 18)		
		1	2	3	4	5	6	7	8	9					10	11				
										Position 1	Position 4	Position 5	Position 7	Position 8		22 days			30 days	
																Mercury	Crater		Mercury	Crater
1	Lisebo		1						1								1		1	4
2	Lehana												1		1					2
3	Makalo		1					1	1					1	1					5
4	Motena								1						1					2
5	Karabo		1			1			1			1		1	1		1			7
6	Seboka								1	1		1	1	1	1	1				7
7	Fumane	1	1						1	1	1	1	1						1	8
8	Masilo			1						1		1			1			1		5
9	'Mamosa														1			1		2
10	Selomo									1		1	1	1		1		1	1	7

The table shows that all learners performed poorly on the first seven questions which tested conceptual knowledge about the Earth-Moon-Sun system. The table further shows that high spatial-ability learners performed better on Question 9 than low spatial-ability learners. As a result, high spatial-ability learners obtained better total scores than their low spatial-ability counterparts. Further analysis of the scores shows that the low spatial-ability learners obtained an average score of 4 while the high spatial ability learners obtained an average score of 6 out of 18. These mean scores suggests that all the 10 learners had poor background knowledge in these concepts. However, the high spatial-ability learners demonstrated a slightly better understanding of concepts associated with phases of the Moon than their low spatial-ability counterparts.

The discussion in Section 2.2.3 (p 49) shows that background knowledge on concepts illustrated in diagrams affects people's interpretation of the diagrams. The purpose of administering the diagnostic test was to investigate learners' background knowledge on phases of the Moon, so as to select learners in a way that would minimize impact of this knowledge on interpretation of diagrams. The fact that all learners had low background knowledge of these concepts suggests that none would be advantaged by background knowledge when interpreting diagrams.

4.8 Summary

This chapter has presented results obtained from the diagnostic test. The diagnostic test had questions investigating learners' understanding of concepts associated with phases of the Moon (Questions 1-7), and questions investigating learners' ability to mentally manipulate celestial objects in space (Questions 8-11). Learners obtained low scores in all the questions in this test. This suggests that the learners' had poor background knowledge on concept associated with phases of the Moon, and struggled to mentally manipulate celestial objects in space.

This chapter shows that all the 10 learners selected to participate in interviews had poor background knowledge on phases of the Moon. The next chapter presents results obtained from spatial ability tests.

Chapter 5 Spatial ability

5.1 Introduction

This study employed a mixed-methods approach in which quantitative research findings facilitated conduct of qualitative research (see Section 3.1.4, p 58). I administered six tests to investigate learners' spatial ability skills, and used findings to select learners who participated in interviews. This chapter presents scores obtained by learners on these tests. One test (Hidden Patterns Test) measured Spatial Perception; two tests (Card Rotations and Cube Comparisons Tests) measured Spatial Orientation, while three tests (Form Board, Paper Folding and Surface Development Tests) measured Spatial Visualization. Section 5.2 describes statistical constructs used to analyze data obtained from the spatial ability tests. Section 5.3 presents scores obtained by learners on these tests. Section 5.4 presents an answer to the second research question while Section 5.5 describes how spatial scores were used to select learners for participation in interviews.

5.2 Statistical constructs used in the chapter

The spatial ability tests generated quantitative data which required statistical analysis. Researchers use two statistical techniques to analyze quantitative data; descriptive statistics which allows researchers to describe characteristics of a sample, and inferential statistics which allows researchers to make inferences about characteristic of populations from which samples were selected (McMillan & Schumacher, 2001; van Lill & Grieve, 1990). The aim of this study was to describe characteristics of the sample, not to generalize findings to the population. As a result, the study employed descriptive statistics. The following sections describe theoretical constructs associated with descriptive statistics used in the study.

5.2.1 Types of data distribution

Most research deals with data consisting of more than one variable. When variables are plotted in a graph, data can make any of the following types of distribution.

Normal distribution: A distribution is normal if values cluster at the centre and spread uniformly towards edges (Fraenkel & Wallen, 1990). Figure 5.1 illustrates an example of a normal distribution.

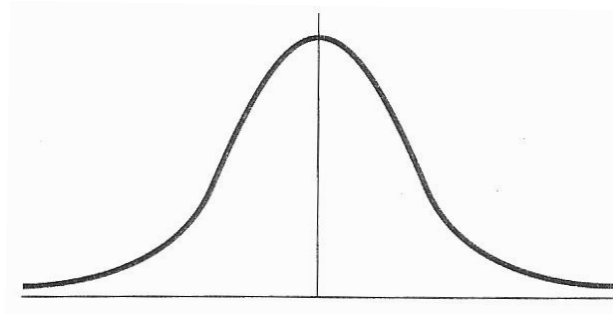


Figure 5.1 Example of a normal distribution

Skewed distribution: A distribution is skewed if values cluster towards one of the edges. A distribution is positively skewed if values cluster towards the left edge, as illustrated in Figure 5.2.

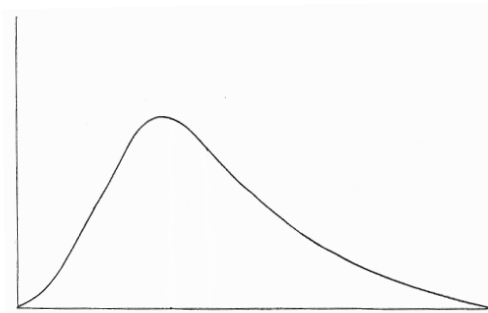


Figure 5.2 Example of a positively skewed distribution

On the other hand, a distribution is negatively skewed if values cluster towards the right edge, as illustrated in Figure 5.3.

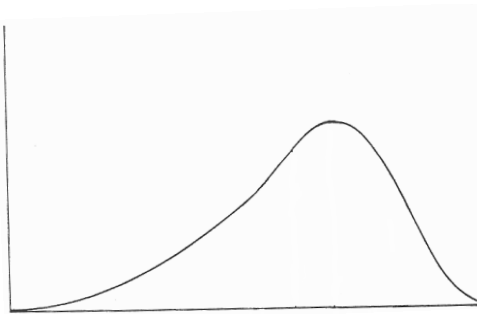


Figure 5.3 Example of a negatively skewed distribution

Sometimes distributions have outliers. McMillan and Schumacher (2001:167) define an outlier as a “point that falls far outside the main distribution of scores”; usually located beyond three standard deviations from the mean (I define standard deviation and mean in Sections 5.2.2 and 5.2.3, pp 111-114). If there are clear reasons for a score to be too far from others (e.g. errors in marking), researchers may correct or drop the score. However, there is no consensus about what to do with

outliers if there are no clear explanations for the extreme values (McMillan & Schumacher, 2001). I included outliers when calculating measures of central tendency and dispersion (discussed below).

5.2.2 Central tendency

van Lill and Grieve (1990:41) define central tendency as a “value which is central to a distribution which can be used to represent all the scores in a distribution”. Three measures of central tendency are used to describe data.

- **Mean:** This is the measurement of average values, obtained by summing all the values and dividing the sum by the number of values (Fraenkel & Wallen, 1990; Fraser, 1991).
- **Median:** This is the middle score in a distribution (Fraenkel & Wallen, 1990), which is equivalent to a score obtained by an average person (Haslam & McGarty, 2003).
- **Mode:** This is the most frequent score in a distribution (Fraenkel & Wallen, 1990; McMillan & Schumacher, 1993).

In a normal distribution, the three measures of central tendency assume the same value, located at the centre of the distribution (see Figure 5.4).

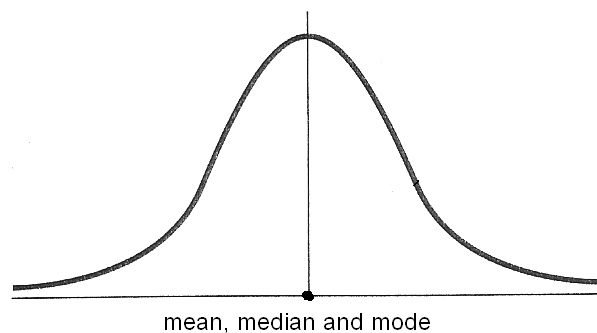


Figure 5.4 Measures of central tendency in a normal distribution

However, the three measures assume different values in skewed distributions. The mode is located at the peak, the median is located at the centre, and the mean is located towards the tail of the distribution (see Figure 5.5).

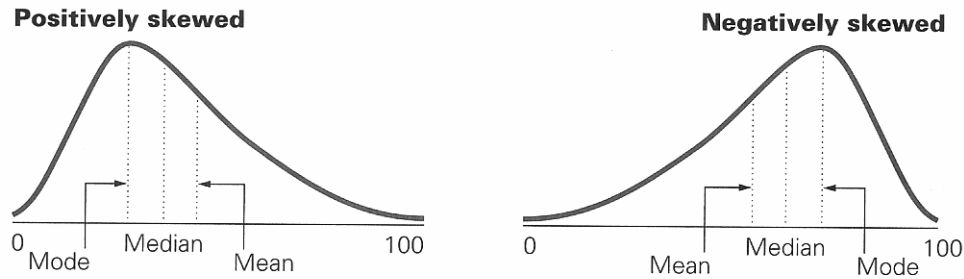


Figure 5.5 Measures of central tendency in skewed distributions (McMillan & Schumacher, 2001:161)

5.2.3 Variability/dispersion

Measures of dispersion help us understand the extent to which values in a data set differ from the central score (Haslam & McGarty, 2003; van Lill & Grieve, 1990). I discuss two types of dispersion, the first dealing with differences between high and low values in a distribution, and the second dealing with deviation of values from the mean.

- **Difference between high and low values:** This measure has two types, namely the *range* and the *inter-quartile range*. The range is calculated by subtracting the minimum value from the maximum value to find the difference between these values. Outliers can affect the range of a distribution because only two values are used to calculate this measure (McMillan & Schumacher, 2001; van Lill & Grieve, 1990). Thus, this measure can be misleading.

The inter-quartile range is used to overcome the impact of outliers. This measure gives information about the difference between values located at the lower and upper quartiles in a distribution (van Lill & Grieve, 1990). Quartiles are values located $\frac{1}{4}$ and $\frac{3}{4}$ away from the minimum value in a distribution. That is, quartiles are located at the 25th and 75th percentiles. Lower quartile is the value located at the 25th percentile while upper quartile is the value located the 75th percentile in a distribution.

Seventy five learners formed a sample for the current study. When the learners' scores are arranged in order from minimum to maximum, the lower quartile is the score obtained by the 19th learner, the upper quartile is a score obtained by the 55th learner, while the inter-quartile range is the difference between scores obtained by the 19th and the 55th learners. The inter-quartile range indicates the difference of scores between 36 learners who obtained middle scores.

- **Deviation of each score from the mean:** van Lill and Grieve (1990) discuss three types of this measure; deviation, variance and standard deviation.
 - *Deviation* is the difference between each score and the mean, obtained by subtracting mean from the scores. Deviation becomes positive for scores larger than the mean and negative for scores lower than the mean.
 - *Variance* is obtained by squaring deviation of each value, summing the squares of deviations, and dividing the sum by the number of values. The deviations are squared to get rid of the

negative sign obtained for values lower than the mean. As a consequence of squaring deviations, variance is expressed in square units of a quantity being measured.

- *Standard deviation* is obtained by taking square root of variance. Thus, standard deviation is expressed in the same units as the quantity being measured (Haslam & McGarty, 2003). Standard deviation indicates the distance (on average) of the scores from the mean (McMillan & Schumacher, 2001).

5.2.4 Application of statistical analysis in this study

When discussing learners' performance in each test, first I discuss general performance of learners in each of the tests. Table 5.1 illustrates criteria used to describe learners' competence in the skills measured by each test, and to evaluate easiness of executing skills measured by each test based on learners' scores.

Table 5.1 Criteria used to categorise learners' competence in skills measured by spatial ability tests⁶

Score (expressed in %)	Learners' competence in the skill	Easiness of executing skills measured by the test
≥ 80	Very high	Very easy
$60 \geq 79$	High	Easy
$40 \geq 59$	Intermediate	Moderate
$20 \geq 39$	Low	Difficult
$0 \geq 19$	Very low	Very difficult
< 0	Extremely low	Extremely difficult

The table shows that I classify competence into three main categories; high competence for learners scoring 60% and above, intermediate competence for learners scoring between 40% and 59%, and low competence for learners scoring 39% and below. I argue that execution of skills measured by the test was easy for learners obtaining high scores, to be moderate for learners obtaining intermediate scores, and that learners obtaining low scores encountered more difficulties when executing these skills.

After discussing general performance of the learners in each test, I illustrate test scores in a bar graph to note the type of distribution, and to identify scores that fall away from the rest (i.e. outliers). All results gave skewed distributions. In the discussion that follows, I discuss measures of central tendency and variance for each test. For central tendency, I discuss both the mean and the median. I discuss the mean because its calculation uses all values in a distribution, and discuss the

⁶ Negative scores were possible because the formulae recommended for calculating learners' scores used both correct and incorrect marks.

median because it is the value located the middle in skewed distributions. I discuss both the range and the standard deviation to give an idea about dispersion of learners' scores.

5.3 Learners' performance on the spatial ability tests

This section presents learners' performance on the six spatial ability tests administered in this study.

5.3.1 Spatial Perception (CF-2)

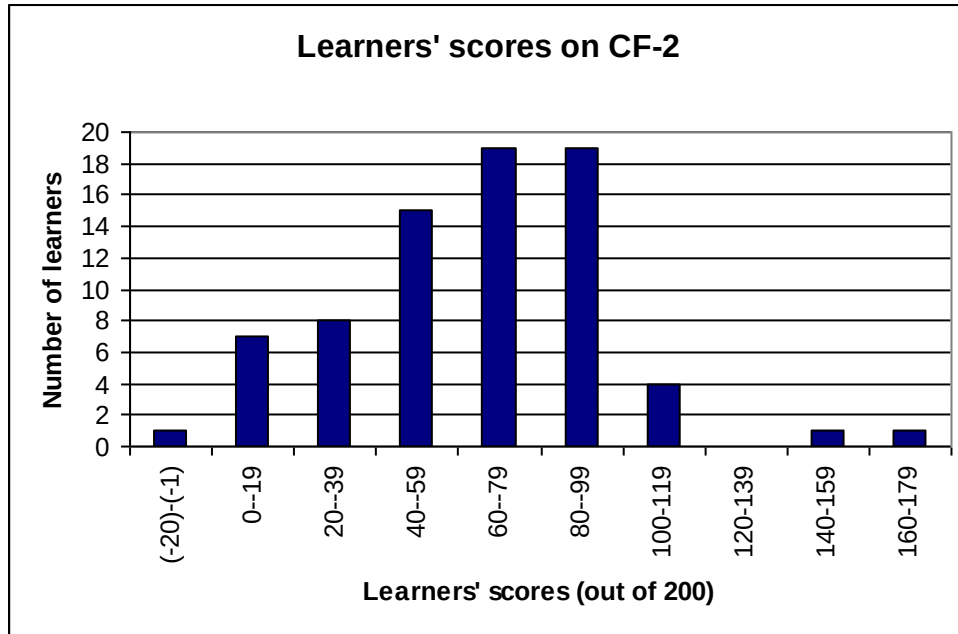
I used the Hidden Patterns Test (CF-2) to measure this skill. This test measured learners' ability to mentally detach a figure from a complex configuration. Table 5.2 illustrates learners' performance on this test.

Table 5.2 Learners' performance on the Hidden Patterns Test (CF-2)

Scores		Competence level	Number of learners obtaining the scores	
Raw score (out of 200)	Score expressed as %		Actual number of learners (out of 75)	Number expressed as %
≥ 159	≥ 80	Very high	1	1
$119 \geq 158$	$60 \geq 79$	High	1	1
$79 \geq 118$	$40 \geq 59$	Intermediate	23	31
$39 \geq 78$	$20 \geq 39$	Low	34	45
$0 \geq 38$	$0 \geq 19$	Very low	15	20
< 0	< 0	Extremely low	1	1

The table shows that only 2% of the learners obtained high scores (i.e. above 60%). Thirty one percent obtained intermediate scores while 66% obtained low scores. These results suggest that only 2% of the learners found it easy to mentally detach a figure from complex configuration. The results further suggest that 31% encountered moderate difficulty when executing these skills, while the majority (66%) struggled to execute the skills.

Figure 5.6 gives further clarification of learners' performance on this test. The figure shows a continuous distribution of scores from -20 to 119 which form a negatively skewed shape. In addition, the figure shows two scores (146 and 171) separated from the continuous distribution. However, only one of these scores (171) appears to be located beyond three standard deviations from the group mean score. As a result, it is the only score regarded as an outlier. Overall, the graph shows that the scores form a negatively skewed distribution which has one outlier.



mean = 64, median = 66, mode = 82, range = 172, inter-quartile range = 40, standard deviation = 31

Figure 5.6 Learners' performance on the Hidden Patterns Test (CF-2)

Analysis of Figure 5.6 shows a very small difference between values of the mean (64 = 32%) and the median (66 = 33%). The fact that these values are located below 39% suggests that on average, learners' competence was low in skill measured by this test. This suggests that on average, the learners struggled to mentally detach a figure from complex configuration. These results imply that the majority of learners would struggle to apply this skill when learning about phases of the Moon, e.g. when interpreting diagrams illustrating this phenomenon. This interpretation requires learners to concentrate on the Moon in one of the eight (usually illustrated) positions and ignore the Moon in other positions that might serve as distracting background. Failure to interpret diagrams means that learners would struggle to understand information illustrated in the diagrams.

Further analysis shows large values for the range (172 = 86%) and the inter-quartile range (40 = 20%). The standard deviation of 31.33 (16%) shows a low deviation of learners' scores from the mean. The high values of the range and inter-quartile range indicate a very large difference between the lowest and the highest scores of the learners, which suggests that the learners were not uniform in their ability to execute the skill measured by the test. These results imply that it is not every learner that would struggle to mentally detach a figure from complex configuration, and to apply the skill when learning about phases of the Moon. Learners with high scores would execute this skill with ease, but learners who obtained low scores would struggle to execute the skills. The low standard deviation means that values do not deviate much from the mean score of 33%, which gives further evidence that learners struggled to mentally detach a figure from complex configuration.

The average score obtained in this study is lower than the mean score of 43% obtained by American participants aged 12 years and older (Smalley et al., 1989) and much lower than the mean of 60% obtained by Canadian 20-to 35-year olds who wrote this test (Wickett et al., 2000). On the other hand, the average score obtained in this study is higher than the mean score of 23% obtained by American adults and university students (Burton & Fogarty, 2003), and also higher than the mean score of 27% obtained by American university students (Miyake et al., 2001). These low scores reported in studies that involved adults participants show that even older students and adults struggle to mentally detach a figure from complex configuration. These findings help to explain why older participants struggle to understand astronomy concepts, i.e. the concepts require use of skills that these participants are not able to execute.

Summary: The fact that only 2% of learners obtained high scores (above 60%) while 66% of obtained low scores (below 40%), and the fact that learners obtained the average score of about 33% indicate that the majority of learners encountered difficulties when mentally detaching a figure from complex configuration.

5.3.2 Spatial Orientation

Two tests (Card Rotations Test and Cube Comparisons Test) were used to measure learners' competence in this skill.

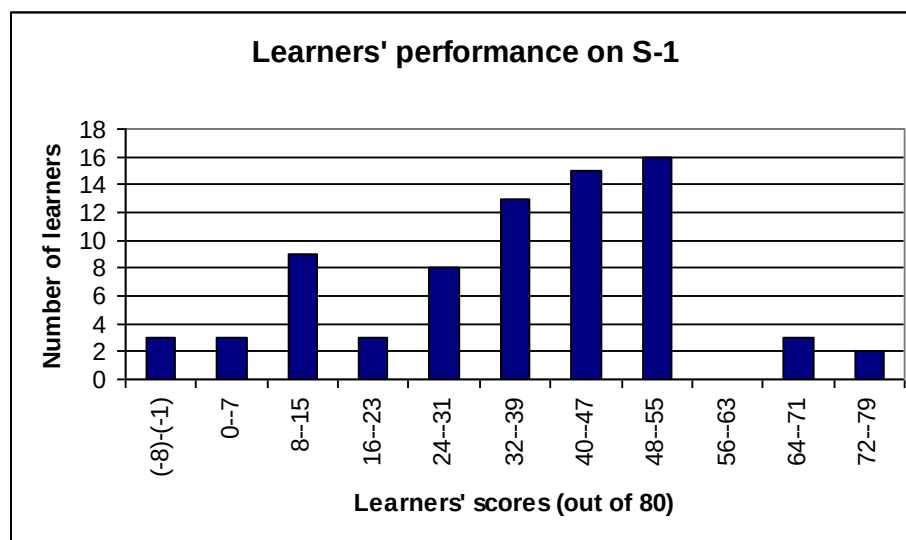
Learners' performance on the Card Rotations Test (S-1)

This test measured learners' ability to mentally rotate two-dimensional shapes on the plane of the paper. Table 5.3 illustrates learners' performance in this test.

Table 5.3 Learners' performance on the Card Rotations Test (S-1)

Scores		Competence level	Number of learners obtaining the scores	
Raw score (out of 80)	Score expressed as %		Actual number (out of 75)	Number expressed as %
≥ 64	≥ 80	Very high	5	7
$48 \geq 63$	$60 \geq 79$	High	16	21
$32 \geq 47$	$40 \geq 59$	Intermediate	28	37
$16 \geq 31$	$20 \geq 39$	Low	11	15
$0 \geq 15$	$0 \geq 19$	Very low	12	16
< 0	< 0	Extremely low	3	4

The table shows that few learners (28%) obtained high scores (above 60%). Thirty seven percent of the learners obtained intermediate scores while 35% obtained low scores. Thus, nearly the same number of learners obtained low, intermediate and high scores. This suggests that the number of learners who easily executed mental rotations is almost the same as the number that struggled to mentally rotate the shapes. Figure 5.7 illustrates learners' performance on this test.



mean = 35, median = 38, mode = 44, range = 78, inter-quartile range = 23.5, standard deviation = 18

Figure 5.7 Learners' performance on the Card Rotations Test (S-1)

The figure shows a continuous distribution of scores from -8 to 55 which form a negatively skewed shape. Furthermore, the figure shows few scores between 64 and 79, separated from the continuous distribution. A closer look at these scores shows that none falls beyond three standard deviations from the mean, suggesting that the distribution had no outliers.

Figure 5.7 shows a small difference between values of the mean of 35 (44%) and the median of 38 (48%). These figures indicate that on average, the learners were able to mentally rotate shapes used in the test. Ability to execute mental rotations suggests that on average, the learners would be able to mentally rotate the Earth and the Moon in order to understand astronomy concepts involving the Earth-Moon-Sun system. It is to be noted, however, that this test measured learners' ability to mentally rotate two-dimensional shapes on plane of the paper while astronomy concepts require mental rotation of three-dimensional objects in space. As a result, results obtained from this test give us little information about learners' ability to execute mental rotations needed to understand astronomy concepts.

Further analysis shows the range of 78 (98%) which shows a very high variability between minimum and maximum scores obtained by learners in this test. In addition, the analysis shows an inter-quartile range of 23.5 (29%). This suggests that a reasonable variation of scores among the 36 learners who obtained scores in the middle of the distribution. The standard deviation of 18 (23%)

shows a considerable variation of scores from the group mean. The high value of the range suggests that some learners obtained very high scores while others obtained very low scores in the test. This means that it was very easy for some learners to execute mental rotations measured by the test, but very difficult for others to execute these mental rotations. These differences might give an idea as to why some learners struggle to understand astronomy concepts while others cope fairly easily with these concepts.

The average score obtained in this study is somewhat similar to the mean score of 48% obtained by Israeli high school students (Barnea & Dori, 1999) and a mean score of 56% obtained by South African high school students (Sanders, 2004), which suggests that other high school students would be able to execute mental rotations measured by the Card Rotations Test. However, the mean score obtained in this study is much higher than a mean score of 24% obtained by Egyptian high school students (Abdel-Rahim et al., 1990) who answered this test. Scores obtained by the Egyptian students suggest that they encountered more problems when mentally rotating cards on plane of the paper, than students who performed in the current study.

The fact that 28% of learners obtained high scores while 37% obtained intermediate scores suggests that only few learners (35%) found it easy to mentally rotate shapes used in the test. The central score of 48% suggests that on average, were able to execute mental rotations measured by the test.

Learners' performance on the Cube Comparisons Test (S-2)

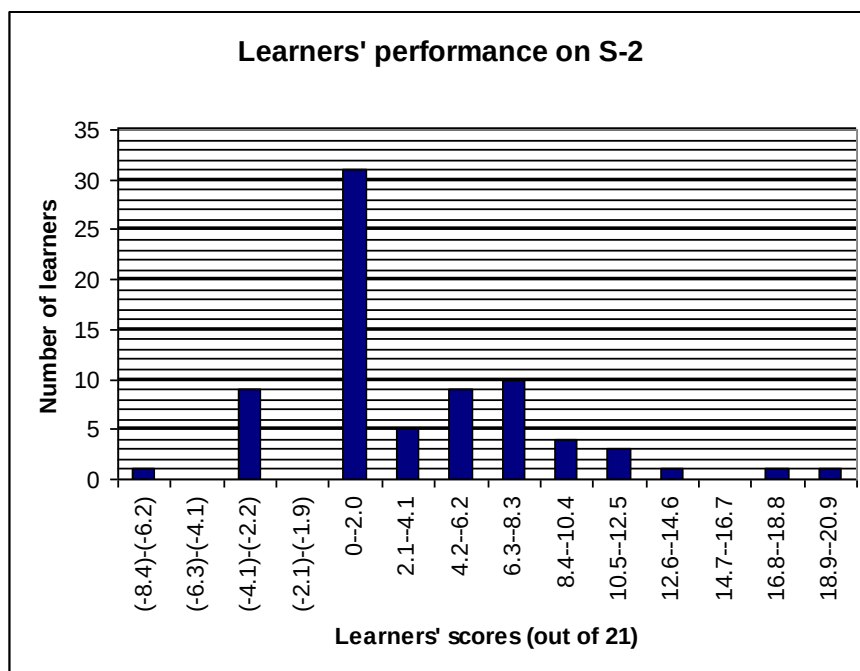
This test measured learners' ability to mentally rotate cubes in space. Table 5.4 illustrates learners' performance in this test.

Table 5.4 Learners' performance on the Cube Comparisons Test (S-2)

Scores		Competence level	Number of learners obtaining the scores	
Raw score (out of 21)	Score expressed as %		Actual number (out of 75)	Number expressed as %
≥ 16.7	≥ 80	Very high	2	3
$12.5 \geq 16.6$	$60 \geq 79$	High	1	1
$8.3 \geq 12.4$	$40 \geq 59$	Intermediate	7	9
$4.1 \geq 8.2$	$20 \geq 39$	Low	19	25
$0 \geq 4.0$	$0 \geq 19$	Very low	36	48
< 0	< 0	Extremely low	10	13

The table shows that only 4% of the learners obtained high scores (above 60%) while 9% of learners obtained intermediate scores. Eighty six percent of the learners obtained low scores (below 40%). These results suggest that the majority of learners struggled to execute mental rotations measured by the test.

Figure 5.8 illustrates learners' performance on the Cube Comparisons Test.



mean = 3, median = 2, mode = 1, range = 26, inter-quartile range = 8, standard deviation = 5

Figure 5.8 Learners' performance on the Cube Comparisons Test (S-2)

The figure shows a continuous distribution of scores between 0 and 14.6, which form a skewed shape. In addition the figure shows scores on both side of the graph, which are separated from the continuous distribution of scores. Only one of these scores (between 18 and 21) falls beyond three standard deviations from the mean, and therefore qualifies to be an outlier. The overall shape of the graph is positively skewed with one outlier.

The mean score is 3 (14%) while the median score is 2 (10%). These measures of central tendency indicate that on average, the learners struggled to execute mental rotations measured by this test. While results obtained from the Card Rotations Test show that learners were fairly able to execute mental rotations, results from the Cube Comparisons Test show that learners struggled to mentally rotate three-dimensional objects. These results suggest that learners would likely struggle to mentally rotate the Earth and the Moon to understand concepts associated with the Earth-Moon-Sun system. It has to be borne in mind, however, that this test measured learners' ability to mentally rotate cubes while astronomy concepts require mental rotation of spherical objects. Thus, performance on this test gives us only some idea about difficulties that learners might encounter when mentally rotating celestial objects.

The range of 26 (124%) shows a very large difference between the lowest and the highest scores of the learners. In addition, the inter-quartile range of 8 (38%) shows high variation of scores among 36 learners who obtained scores in the middle of the distribution. The standard deviation of 5 (24%) shows a considerable dispersion of scores from the group mean. The values of range and

inter-quartile range show that some learners were actually able to execute mental rotations measured by this test while others struggled to execute these mental rotations. These differences help to explain why some learners obtain high scores on tests assessing understanding of astronomy concepts while others obtain low scores in these tests.

The average score obtained in the current study is lower than the mean scores of 19% obtained by Israeli high school students (Barnea & Dori, 1999), 24% and 29% obtained by South African high school students in experimental and comparison groups respectively (Sanders, 2004), and 38% obtained by Egyptian high school students (Abdel-Rahim et al., 1990). A closer look at these scores shows that participants obtained average score below 39%, which implies that they also struggled to mentally rotate three dimensional objects in space. These results help to explain why school learners in different parts of the world struggle to understand astronomy concepts (i.e. learners lack skills needed to understand these concepts).

Overall performance of learners on the Spatial Orientation tests

The preceding discussion shows that learners' performance in the two Spatial Orientation tests was very low. This suggests that the majority of learners struggled to execute mental rotation, a skill measured by the two tests. This, in turn, suggests that the majority of learners would likely struggle to perform mental rotations required to understand phases of the Moon. Table 5.5 compares learners' performance on the two tests measuring Spatial Orientation.

Table 5.5 Comparison of learners' performance on the Card Rotations and Cube Comparisons Tests

Scores	Card Rotations Test	Cube Comparisons Test
Number of learners obtaining high scores (above 60%)	26	4
Number of learners obtaining intermediate scores (between 40% and 59%)	34	9
Number of learners obtaining low scores (below 40%)	33	66
Average (central) score (in %)	48	10

The table shows that the majority of learners obtained high and intermediate scores in the Card Rotations Test, while the majority obtained low scores in the Cube Comparisons Test. Furthermore, the table shows that learners' average score was 48% in the Card Rotations Test, but 10% in the Cube Comparisons Test. These results indicate that the learners' performance was better on the Card Rotations Test which measured mental rotation of two-dimensional objects on the plane of the paper, than in the Cube Comparisons Test which measured mental rotation of three-dimensional objects in space.

5.3.3 Spatial Visualization

I used three tests to measure this skill; the Form Board Test, the Paper Folding Test and the Surface Development Test.

Learners' performance on the Form Board Test (VZ-1)

This test measured learners' ability to execute a series of mental manipulations of two-dimensional objects on plane of the paper. Table 5.6 illustrates learners' performance on this test.

Table 5.6 Learners' performance on the Form Board Test (VZ-1)

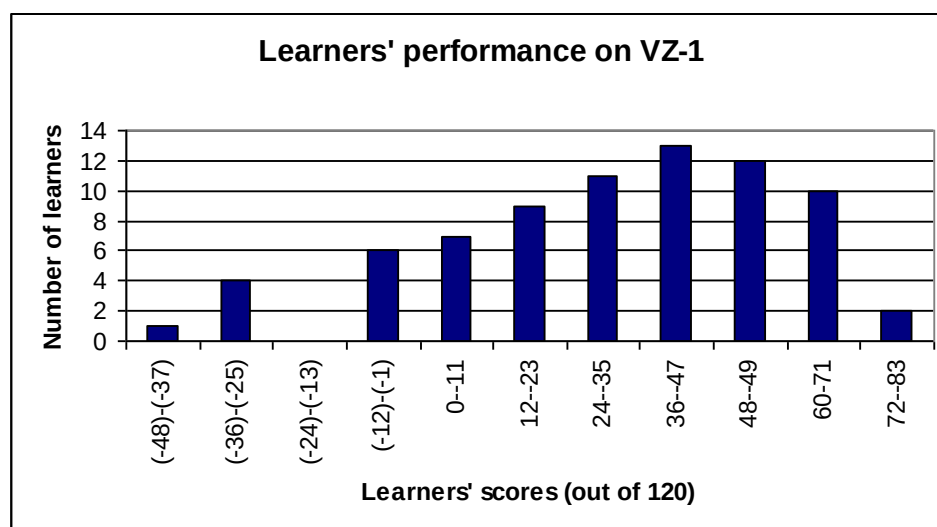
Scores		Competence level	Number of learners obtaining the scores	
Raw score (out of 120)	Score expressed as %		Actual number (out of 75)	Number expressed as %
≥ 96	≥ 80	Very high	0	0
$72 \geq 95$	$60 \geq 79$	High	2	3
$48 \geq 71$	$40 \geq 59$	Intermediate	22	29
$24 \geq 47$	$20 \geq 39$	Low	24	32
$0 \geq 23$	$0 \geq 19$	Very low	16	21
< 0	< 0	Extremely low	11	15

The table shows that only 3% of learners obtained high scores (above 60%), 29% obtained intermediate scores, while 68% obtained low scores. This suggests that only 3% executed the mental manipulations with ease. Twenty nine percent encountered moderate difficulty when executing these operations, while the majority (68%) struggled to execute these mental manipulations.

Figure 5.9 illustrates learners' performance on the Form Board Test. The figure shows a continuous distribution of scores from -12 to 83, and a few scores between -48 and -25 separated from the continuous distribution. None of the values fall beyond three standard deviations from the mean. As a result, the distribution has no outliers. Thus, the scores form a negatively skewed distribution without outliers.

The mean score is 31 (26%) while the median score is 34 (28%). These scores suggest that on average, the learners struggled to execute the mental operations measured by the test. These results imply that learners would likely struggle to execute a series of mental manipulations needed to understand astronomy concepts, e.g. to imagine the Moon spinning on its axis whilst orbiting the Earth, and to simultaneously imagine the Earth spinning on its axis whilst orbiting the Sun. It is important to note that the test measured learners' ability to mentally manipulate two-dimensional objects on plane of the paper, while astronomy concepts require mental manipulation of three-dimensional objects in space. This difference suggests that the results obtained from this test give

us an idea about learners' ability to execute mental transformations needed to understand phases of the Moon.



mean = 31, median = 34, mode = 50, range = 121, inter-quartile range = 36, standard deviation = 27

Figure 5.9 Learners' performance on the Form Board Test (VZ-1)

The range of 121 (101%) shows a large score-difference between the highest and the lowest scoring learners in this test. Furthermore, the inter-quartile range of 36 (30%) shows a large score-difference among the 36 learners who obtained scores in the middle of the distribution. The standard deviation of 27 (23%) shows a considerable variation of learners' scores from the group mean. These values of the range imply that some learners obtained very high scores while other obtained very low scores in this test. This suggests that some learners executed the skills measured by the test with ease while others struggled to execute these skills. This, in turn, suggests that some learners would easily use these skills when learning about the Earth-Moon-Sun system, while others would struggle to apply the skills.

The mean score obtained in this test is quite similar to the mean scores of 30% and 26% obtained by Egyptian high school boys and girls respectively (Abdel-Rahim et al., 1990). However, the mean score obtained in this study is much lower than the mean scores of 42% and 38% obtained by South African high school learners in experimental and comparison groups respectively (Sanders, 2004). The mean scores reported by Sanders and Abdel-Rahim et al. suggest that other high school students also struggle to execute mental transformations measured by this test (since no group obtained mean score above 60%).

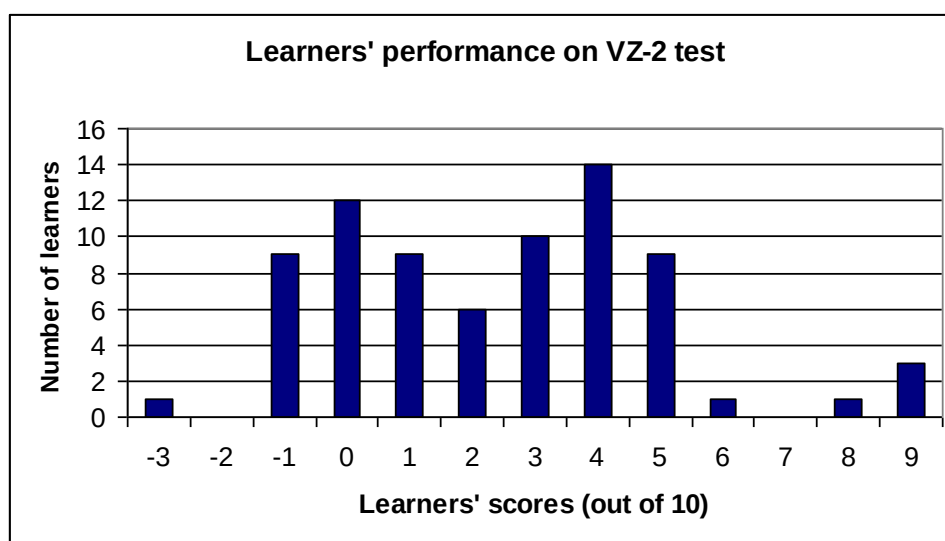
Learners' performance on the Paper Folding Test (VZ-2)

The test measured learners' ability to execute a series of mental manipulations on a three-dimensional object in space. Table 5.7 illustrates learners' performance on this test.

Table 5.7 Learners' performance on the paper Folding Test (VZ-2)

Scores		Competence level	Number of learners obtaining the scores	
Raw score (out of 10)	Score expressed as %		Actual number (out of 75)	Number expressed as %
≥ 8	≥ 80	Very high	4	5
$6 \geq 7.9$	$60 \geq 79$	High	1	1
$4 \geq 5.9$	$40 \geq 59$	Intermediate	23	31
$2 \geq 3.9$	$20 \geq 39$	Low	16	21
$0 \geq 1.9$	$0 \geq 19$	Very low	21	28
< 0	< 0	Extremely low	10	13

The table shows that only 6% of the learners obtained high scores (above 60%), 31% obtained intermediate scores while 63% obtained low scores. These results suggest that only 6% of the learners executed the skill measure by this test with ease. The majority (63%) struggled to execute these skills. Figure 5.10 illustrates learners' performance on the Paper Folding Test.



mean = 2, median = 3, mode = 4, range = 12, inter-quartile range = 4, standard deviation = 2.6

Figure 5.10 Learners' performance on the Paper Folding Test (VZ-2)

The figure shows a continuous distribution of scores between -1 and 6, and has some scores (-3, 8 and 9) separated from the continuous distribution. The continuous distribution of scores appears to be somewhat bimodal, i.e. there appears to be one cluster of scores between -1 and 2, which have 0 as their mode, and another cluster of scores between 2 and 6, which have 4 as their mode. No values fall beyond three standard deviations from the mean. As a result, the distribution has no outliers.

The mean score of 2 (20%) and the median score of 3 (30%) indicate that on average, the learners struggled to perform a series of mental manipulations on a three-dimensional object in space. While results obtained from the Form Board Test show that the majority of learners struggled to execute a series of mental transformations, the results of the Paper Folding Test indicate that the majority of learners encountered more difficulties when executing these mental transformations on a three-dimensional object in space. Results obtained from the Paper Folding Test give a better indication that learners were likely to struggle executing mental manipulations needed to understand astronomy concepts. It has to be borne in mind, however, that the Paper Folding Test measures ability to fold paper in space while astronomy concepts require people to mentally rotate and revolve spherical objects. Despite this difference, results of this test give us an idea about the kind of problems that learners are likely to encounter when trying to understand concepts associated with the Earth-Moon-Sun system.

The range of 12 (120%) shows a very high difference between the minimum and the maximum scores obtained by the learners. In addition, the inter-quartile range of 4 (40%) indicates a high variation of scores among the 36 learners who obtained middle scores in the test. The standard deviation of 2.6 (26%) shows a considerable deviation of learners' scores from the group mean. The high values of the range and inter-quartile range indicate that some learners executed the skills measured by this test with ease while others struggled to execute these skills. These results help to explain why some learners perform better in astronomy concepts while others struggle to understand these concepts.

The mean score obtained in this test is somewhat similar to mean score of 25% obtained by Israeli high school students (Barnea & Dori, 1999) and a mean score of 35% obtained by Egyptian high school students (Abdel-Rahim et al., 1990). However, the average score obtained in this study is lower than the mean score of 40% obtained by South African high school students (Sanders, 2004). A closer look at mean scores reported by Abdel-Rahim et al., Barnea and Dori and Sanders shows that all the learners struggled to execute skills measured by this test, which explains why many struggle to understand astronomy concepts.

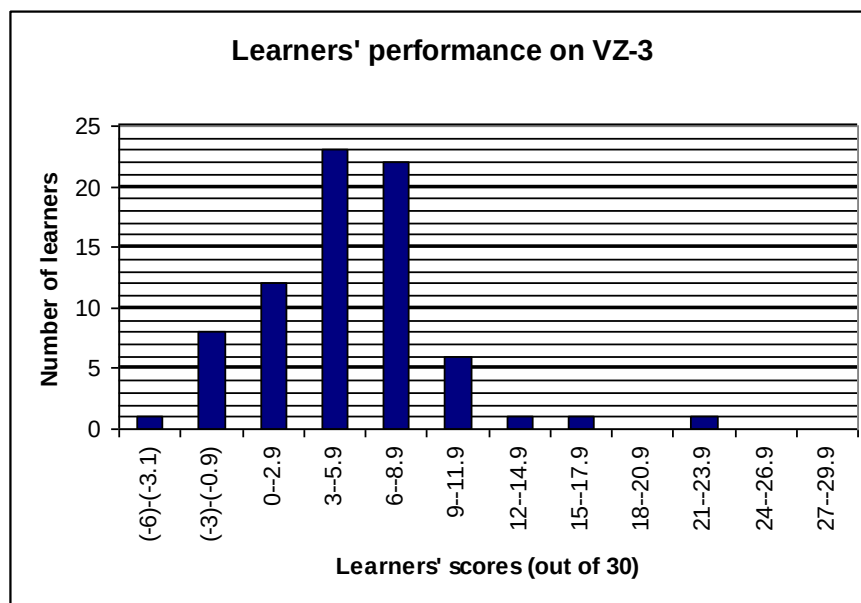
Learners' performance on the Surface Development Test (VZ-3)

This test measured learners' ability to mentally construct a three-dimensional object from its two-dimensional representation. Table 5.8 illustrates learners' performance on this test.

Table 5.8 Learners' performance on the Surface Development Test (VZ-3)

Scores		Competence level	Number of learners obtaining the scores	
Raw score (out of 30)	Score expressed as %		Actual number (out of 75)	Number expressed as %
≥ 23.9	≥ 80	Very high	0	0
$17.9 \geq 23.8$	$60 \geq 79$	High	1	1
$11.9 \geq 17.8$	$40 \geq 59$	Intermediate	2	3
$5.9 \geq 11.8$	$20 \geq 39$	Low	28	37
$0 \geq 5.8$	$0 \geq 19$	Very low	35	47
< 0	< 0	Extremely low	9	12

The table shows that only 1% of the learners obtained a high score while 3% obtained Intermediate scores. Ninety six percent obtained low scores (below 40%). These results suggest almost all learners struggled to execute the skills measured by this test. Figure 5.11 illustrates the distribution of learners' raw scores on the Surface Development Test.



mean = 4, median = 4, mode = 3, range = 26, inter-quartile range = 5, standard deviation = 4

Figure 5.11 Learners' performance on the Surface Development Test (VZ-3)

The figure shows a continuous distribution of scores between -6 and 18, and has one score (between 21 and 24) separated from the continuous distribution of scores. This score falls beyond three standard deviations from the mean, and qualifies to be an outlier. The distribution appears to be somewhat positively skewed with one outlier.

The mean and median scores of 4 (13%) suggest that on average, the learners encountered serious problems when trying to execute mental transformations measured by this test. Results obtained from the previous two tests show that learners struggled to perform mental transformations involving manipulations of two-dimensional objects on plane of the paper (Form Board Test), and three-dimensional objects in space (Paper Folding Test). Results obtained from the Surface Development Test show that learners encounter even more problems when mentally constructing three dimensions objects from diagrams of flat representations of the objects. All these results suggest that learners are likely to encounter problems when trying to understand astronomy concepts associated with the Earth-Moon-Sun system.

The range of 26 (87%) shows a high variation of minimum and maximum scores. The inter-quartile range of 5 (17%) indicates a low score difference among the 36 learners who obtained scores in the middle of the distribution. The standard deviation of 4 (13%) shows low variation of learners' scores from the group mean. The high value of the range suggests that some learners obtained high scores in this test while others obtained very low scores. This suggests that some learners might be able to apply this skill to the Earth-Moon-Sun system to understand astronomy concepts.

The mean score obtained in this test is somewhat similar to the mean scores of 17% and 13% obtained by Egyptian high school boys and girls who participated in Abdel-Rahim et al.'s (1990) study. However, the average score obtained by learners in this study is much lower than the mean score of 40% obtained by South African high school students who participated in Sanders's (2004) study. The results show that learners poor performance in this test compares to poor performance reported in literature.

Learners' overall performance on the spatial visualization tests

Table 5.9 compares learners' performance in the three spatial visualization tests.

Table 5.9 Comparison of learners' scores on the three spatial visualization tests

	Form Board Test	Paper Folding Test	Surface Development Test
Number of learners obtaining high scores (above 60%)	3%	7%	1%
Number of learners obtaining intermediate scores (between 40% and 59%)	29%	31%	3%
Number of learners obtaining low scores (below 40%)	68%	63%	96%
Average (central) score	28%	30%	13%

The table shows that very few learners obtained high scores in the three tests (3%, 7% and 1%) while the majority obtained low scores (68%, 63% and 96%). In addition, learners obtained average scores of 28%, 30% and 13% in the three tests. These results suggest that the majority of learners struggled to perform a series of mental transformations on two-and three-dimensional

object in space and on plane of the paper. This, in turn, suggests that the learners might struggle to undertake multiple mental processes needed to understand concepts associated with phases of the Moon.

Learners' performance in Form Board and Paper Folding Tests was about the same: very few learners (3% and 7% respectively) obtained high scores, reasonable number (29% and 31%) obtained intermediate scores, while the majority (66% and 63%) obtained low scores. In addition, learners' average scores were 28% and 30% in these tests. On the contrary, learners' scores were much lower in the Surface Development Test, where only 1% obtained high scores, 3% obtained intermediate scores while 96% obtained low scores. Learners' average score was 13% in this test. Poorer performance in the Surface Development Test suggests that the learners encountered more problems when mentally manipulating three-dimensional objects in space.

Poor performance reported in the current study and in researchers conducted elsewhere in the world helps to explain why many people struggle to understand astronomy concepts which require simultaneous mental manipulations of the Earth, the Sun and the Moon. For example, people who lack ability to imagine the Moon spinning on its axis at the same rate that it orbits the Earth might struggle to understand why only one side of the Moon is visible from Earth. In the same way, people who lack ability to imagine the Moon orbiting the Earth as the Earth orbits the Sun (so that relative positions of the Earth, the Moon and the Sun change slightly each day) might struggle to understand why the Moon rises later each day.

5.3.4 Summary of learners' performance on the six spatial ability tests

Table 5.10 summarizes learners' performance in the six spatial ability tests administered in this study.

Table 5.10 Summary of scores obtained by the learners across the six spatial ability tests

Spatial ability test	Central score for the group (in %)	Number of learners (in %) per competence		
		High	Moderate	Low
Card Rotations	48	28	37	35
Hidden Patterns	33	2	31	66
Form Board	28	3	29	68
Paper Folding	30	7	31	63
Cube Comparisons	10	4	9	87
Surface Development	13	1	3	96

Table 5.11 summarizes results illustrated in Table 5.10.

Table 5.11 Summary of scores illustrated in Table 5.10

Spatial tests	Central score for the group (in %)	Number of learners (in %) per competence		
		High	Intermediate	Low
Card Rotations Test	48	28	37	35
Hidden Patterns, Form Board & Paper Folding Tests	30 $\pm$ 3	4 $\pm$ 3	30 $\pm$ 1	65 $\pm$ 3
Cube Comparisons & Surface Development Tests	11 $\pm$ 2	3 $\pm$ 1	6 $\pm$ 3	91 $\pm$ 5

The table shows that learners' performance in the spatial ability tests can be categorized into three groups:

- **Card Rotations Test:** About the same number of learners obtained high, intermediate and low scores in this test. In addition, learners obtained an average score of 48% in this test. Analysis of Table 5.11 shows that this test was the easiest of all the six. Intermediate performance of learners on this test suggests that on average, learners were fairly able to mentally rotate objects, a skill required to understand phases of the Moon.
- **Hidden Patterns, Form Board and Paper Folding Tests:** Learners appear to have encountered difficulties when executing skills measured by these tests since only few ($\pm$ 4%) obtained high scores, a reasonable number ($\pm$ 30%) obtained intermediate scores, while the majority ($\pm$ 65%) obtained low scores. The group's central scores of about 30% in each test further suggest that the learners struggled to undertake skills measured by these tests. Table 5.11 shows that the learner's performance was poorer in these tests than in Card Rotations Test which measures only mental movement on the paper plane.

The Hidden Patterns and Form Board Tests measure learners' ability to mentally move and synthesize/separate two-dimensional objects on the plane of the paper. Poor performance on these tests suggests that the learners were likely to struggle with these mental manipulations when interpreting diagrams illustrating the Earth-Moon-Sun system. The Paper Folding Test measured learners' ability to mentally move and synthesize objects in space. Poor performance in this test suggests that the learners were likely to encounter problems in mentally moving and synthesizing objects in space, the skills needed to understand concepts associated with phases of the Moon.

- **Card Rotations and Surface Development Tests:** Learners appear to have encountered serious difficulties when undertaking mental processes needed to answer the tests. Very few learners obtained high and intermediate scores (i.e. $\pm$ 3% and $\pm$ 6% respectively), while the majority ($\pm$ 91%) obtained low scores. The learners' central scores of about 11% in each test further suggest that the learners struggled to execute skills measured by the tests. Both tests measured learners' ability to construct and manipulate mental images of three-dimensional objects from two-

dimensional drawings. Poor performance in these tests suggests that learners were likely to struggle executing these skills when interpreting diagrams illustrating phases of the Moon.

When analysing these results, we should remember that research shows correlations between spatial ability and learners' achievement in science subjects. These correlations suggest that learners with high spatial ability skills are more likely to succeed in these subjects, than learners with low spatial ability skills. Low scores obtained in the six spatial ability tests administered in the current study suggest that the majority of participants were likely to struggle understanding science subjects. In fact, low spatial ability scores obtained in this study and in research conducted elsewhere in the world help to explain why many people struggle to understand science subjects.

We should also remember that some researchers found results suggesting that spatial ability can be improved. These researchers used different activities, e.g. asking learners to imagine how an object would look after a particular mental transformation (or a series of transformations), and then asking the learners to use two-dimensional representations, three-dimensional objects and/or computer simulations to verify how the object looks after these mental transformations. Giving low spatial-ability learners practice in these tasks might increase their spatial ability skills, and consequently, their chances of understanding concepts requiring use of these skills.

It has to be borne in mind however, that spatial ability is only one of the factors that determine learners' academic ability (others include (but are not limited to) verbal ability, logical reasoning, and memory span). Thus, results obtained from spatial ability test give us important information about learners' ability to cope with tasks requiring mental manipulation of objects in space, but tell us very little about learners' overall academic ability.

5.3.5 Caution about interpretation of these results

Research on mental processes shows that poor performance in spatial ability tests could result from participants' inability to (i) form accurate mental images of stimulus shapes, (ii) undertake mental transformations measured by each test, and/or (iii) to compare stimulus shapes. It has been difficult, in this study, to know the number of learners who were able to encode and compare stimuli, but failed to undertake mental transformation measured by each test. Consequently, the results discussed in this chapter have to be interpreted with care.

Research on mental strategies shows that sometimes people answer spatial ability tests by using strategies not prescribed in manuals of the tests. This research further indicates that sometimes people change strategies when answering spatial ability tests. It has been difficult, in this study, to know the number of learners who consistently used strategies prescribed in the manual when answering the spatial tests. Thus, some students might have changed strategies, and others might have consistently used strategies not prescribed in the manual of tests used in this study. With this in mind, results discussed in this chapter should be interpreted with care.

5.4 Answer to Research Question 2

The second research question has been stated as follows: ***What is the level of Grade 9 Natural Science learners' spatial ability skills?***

The following discussion answers this question by considering the three spatial ability skills:

- *Spatial Perception (ability to detach a pattern from a complex configuration)*. Results obtained from the Hidden Patterns Test show that the majority of learners were weak in this skill.
- *Spatial Orientation (ability to mentally rotate objects)*: Results obtained from the Card Rotations Test indicate that on average, learners were able to mentally rotate objects. However, results obtained from the Cube Comparisons Test indicate that the majority of learners were very weak in mental rotation of three-dimensional objects in space.
- *Spatial Visualization (ability to execute a series of mental operations)*: Results obtained from the Form Board and Paper Folding Tests indicate that the majority of learners were weak in performing series of mental operations. Results obtained from the Surface Development Test indicate that the majority of learners were very weak in performing a series of mental operations involving three-dimensional objects.

An overall result is that the learners had low spatial ability skills, particularly those involving mental manipulation of three-dimensional objects in space.

5.5 Selection of learners for participation in interviews

Several researchers argue that spatial ability skills are necessary for understanding astronomy concepts. I have shown in Section 1.4 (p 5) that one of the aims of this study was to investigate possible links between spatial ability and learners' interpretation of diagrams illustrating phases of the Moon. As a result, I used spatial ability scores to select 10 learners for participation in interviews, five with high spatial ability scores and the other five with low spatial ability scores. It became important to find a suitable mechanism for selecting learners on the bases of the scores obtained in tests measuring different aspects of spatial ability.

Raw scores enable researchers to compare learners' performance on the same test, but not on different tests (Fraser, 1991). Rosenthal and Rosnow (2008) propose that raw scores be standardized in order to compare learners' performance on different tests. Standardization is a process of converting scores into units that express differences from the mean in standard deviation units (Haslam & McGarty, 2003). That is, standard scores (referred to as z-scores) indicate the difference between each score and the group mean score in standard deviation units. Z-scores of values below group mean have negative values while z-scores of values above the mean have positive values.

Haslam and McGarty (2003) and Fraser (1991) discuss advantages of using z-scores: these scores allow researchers to compare (a) performance of different learners on the same test, (b) performance of the same learner in different tests, and (c) performance of different learners in different test by indicating how far each score is from the group mean score in standard deviation units. Z-scores obtained from different tests may be added to get learners' total z-score (Rosenthal & Rosnow, 2008). Rosenthal and Rosnow warn that the sum of z-scores does not make a composite z-score for the learner. The composite z-scores can be calculated from the total z-scores of the learners.

I followed the advice of these authors by converting raw scores to z-scores per spatial ability test (see the z-scores in Appendix H). I numbered the learners from 1 to 75 depending on their composite z-scores. The first column of Appendix H shows learners' numbers. Columns 2 to 7 indicate learners' standardized scores in each test. Column 8 indicates the sum of the z-scores while Column 9 indicates the composite z-scores calculated from the sum of z-scores in Column 8.

My intention was to select five learners with the highest standard scores, and five with the lowest scores to participate in interviews. However, some of these learners could not participate in interviews because of reasons discussed in Table 5.12.

Table 5.12 Reasons explaining why some suitable learners could not participate in interviews

Reason	Learners with low spatial ability scores	Learners with high spatial ability scores
Some learners had indicated on the consent forms that they would not like to participate in interviews	1, 3, 5, 10, 12, 14 and 19	66 and 72
Some learners did not indicate on the consent forms, whether they would be willing to participate in interviews	2, 4, 6, 7, 9, 15, 17, 20, 21, 22, 23, 24, 25 and 26	65, 66 and 67
Some learners had indicated willingness to participate in interviews, but were no longer in the school when interviews were conducted	18 and 19	70 and 74

The table shows that nine learners had indicated their unwillingness to participate in interviews, 17 had left this section blank on the consent form while four had agreed to participate in interviews but were no longer in the school.

Table 5.13 summarizes standardized scores of ten learners selected to participate in the interviews (the learners are highlighted in Appendix H). The table shows that out of the five learners with low spatial ability scores: four scored more than one standard deviation below the group mean while the fifth (Karabo) scored 0.39 standard deviations below the group mean score. The table further shows that out of the five learners with high spatial ability scores: four scored more than one standard deviation above the group mean while the fifth (Seboka) scored 0.92 standard deviations above the group mean score. The table further shows that each of the high spatial-ability learners obtained low scores in at least two spatial ability tests (shaded in Table 5.13). Despite this, these

learners obtained the highest spatial scores because the learners' performance was low on these tests.

Table 5.13 Scores of learners who participated in the interviews

	Learner (No. from Appendix H)	Pseudonym	z-scores for each spatial test						Sum of z-scores	Composite z-score
			CF-2	S-1	S-2	VZ-1	VZ-2	VZ-3		
Low spatial ability	8	Lisebo	-1.47	-1.10	-0.42	-1.29	-0.21	-0.14	-4.64	-1.36
	11	Lehana	-0.96	-0.12	-0.22	-0.77	-0.01	-1.91	-3.99	-1.18
	13	Makalo	-0.77	0.20	-0.01	-2.15	-1.10	-0.14	-3.97	-1.17
	16	Motena	-1.35	0.80	-0.83	-1.11	-0.61	-0.38	-3.47	-1.02
	27	Karabo	-0.42	-0.18	-0.42	0.64	-0.21	-0.73	-1.32	-0.39
High spatial ability	64	Seboka	0.79	0.04	1.61	0.42	0.48	-0.20	3.14	0.92
	69	Fumane	1.14	1.02	0.60	0.23	0.58	1.03	4.60	1.35
	71	Masilo	-1.00	0.64	1.21	-0.06	1.07	4.21	6.06	1.78
	73	'Mamosa	0.95	0.80	0.39	1.39	2.55	0.74	6.82	2.01
	75	Selomo	1.08	0.91	-0.22	1.91	2.55	2.80	9.03	2.66

Throughout this thesis, I have arranged the ten learners in the order illustrated in Table 5.13, so that Lisebo obtained the lowest spatial ability scores while Selomo obtained the highest spatial ability scores. I used a thick line between Karabo and Seboka to differentiate between the five learners with low spatial ability scores (above this line) and five learners with high spatial ability scores (below this line).

5.6 Summary

The current chapter has presented scores obtained by learners on the six spatial ability tests, and provided an answer to the second research question. In addition, the chapter has shown how I used the results to select learners for interpretation of diagrams illustrating phases of the Moon. The next chapter presents results obtained from analyzing diagrams illustrating phases of the Moon.

Chapter 6 Diagram analysis

6.1 Introduction

This chapter presents analysis of diagrams illustrating phases of the Moon. The purpose of this analysis was to identify design problems in these diagrams, and to select diagrams which had fewer design problems to be used during interviews. Section 6.2 gives an overview of information used in the 24 books to explain phases of the Moon. Subsequent sections deal specifically with diagrams illustrating phases of the Moon. Section 6.3 presents a critical analysis of these diagrams, indicating design flaws and scientific problems found in the diagrams. Section 6.4 presents an answer to the third research question. Section 6.5 outlines conventions used in the diagrams. Section 6.6 describes how findings discussed in Sections 6.2 and 6.3 were used to select diagrams used in interviews.

6.2 Overview of information dealing with phases of the Moon

Teachers can use several resources when teaching about phases of the Moon, e.g. charts, models and textbooks, schools usually have more access to textbooks than to these other sources of information. Learning can be enhanced if these resources present accurate information. Furthermore, teaching can be easier when textbooks have all information needed to explain concepts, but might be hampered if textbooks provide less information than required to understand targeted concepts.

This chapter presents analysis of 28 diagrams illustrating phases of the Moon. These diagrams are taken from 24 books. All the diagrams are intended to help learners understand phases of the Moon. Thus, according to Duchastel's classification, these diagrams serve an ***explanatory role***. In addition to diagrams, the books use the following types of information to explain phases of the Moon.

- *Text*: Some books provide textual information dealing with phases of the Moon. Text can explain the cause of moon phases and describe the shape of the Moon during each phase. Furthermore, text can give information about the sequence of moon phases, and names given to these phases.
- *Modelling activities*: Some books recommend that learners use models to simulate changing configurations of the components of the Earth-Moon-Sun system. These activities can give information about the cause and sequence of moon phases.

- *Moon chart*: Some books recommend that learners observe the Moon daily for a period of a month, and record observations in a moon chart. These moon charts give information about the sequence of moon phases, but not about the cause of these phases.

Section 3.5.1 (page 73) discusses criteria used to arrange the books in order of complexity of diagrams (from 1 to 24). Simpler diagrams were considered to be those illustrating phases of the Moon only, while complex diagrams were considered to be those illustrating the Earth, the Sun, the Moon orbiting the Earth, and phases of the Moon. Table 6.1 illustrates the extent to which the books used each of the four information sources (diagrams, moon charts, modelling activities and text) when dealing with phases of the Moon.

Table 6.1 Types of information dealing with phases of the Moon in the 24 books

Book number	Grade level	Moon chart	Modelling activity	Text	Diagram			
					Sun	Earth	No. of moon positions	No. of moon phases
1	4		✓	✓				4
2	5	✓	✓	✓				4
3	6	✓	✓	✓				4
4	8	✓	✓	✓				14
5	7			✓				8
6	5	✓	✓	✓				8
7	6	✓		✓				6
8	5	✓		✓				8
9	8	✓	✓	✓				11
10	8	✓	✓	✓				8
11	4	✓		✓		✓	4	4
12	5		✓	✓	✓	✓		8
13	7		✓		✓	✓		8
14	4	✓		✓	✓	✓	4	8
15	6	✓		✓	✓	✓	8	8
16	5			✓	✓	✓	4	4
17	4	✓	✓	✓	✓	✓	8	4
18	6				✓	✓	8	8
19	4	✓		✓	✓	✓	8	8
20	6			✓	✓	✓	4	8
21	7	✓		✓	✓	✓	8	8
22	7			✓	✓	✓	8	8
23	7		✓	✓	✓	✓	12	12
24	8			✓	✓	✓	8	8

- Books 1 to 10 have diagrams illustrating the sequence of moon phases, but do not illustrate the Earth, the Sun, and the Moon orbiting Earth (the latter information would help to explain why the Moon appears to change shape as seen from the Earth). All these diagrams supplement

and/or complement other sources of information in the books. Nine of the books have textual information dealing with phases of the Moon; seven books prescribe modelling activities while eight recommend that learners complete a moon charts. Text and modelling activities can be used to explain the cause of moon phases while the diagrams and the moon charts illustrate the sequence of these phases.

- Book 11 has a diagram illustrating the Earth, the Moon in four positions around the Earth, and corresponding phases of the Moon. This diagram can be used to explain that the Moon orbits the Earth, and to further explain that the shape of the Moon appears to change as seen from the Earth. However, information in the diagram is not enough to explain the cause of moon phases since the Sun is not illustrated in the diagram. Martinez-Pena and Gil-Quilez (2001) found that the Sun and/or the Earth were missing in some diagrams. Thus, problems of missing information identified in this study corroborate a problem identified in a previous study. It is worthy to note that the book has textual information dealing with phases of the Moon. This text can be used to explain the cause of moon phases.
- Books 12 and 13 illustrate the Sun, the Earth, and phases of the Moon placed in eight positions around the Earth. The Moon as seen from space is not shown in the diagrams, and no explanation has been provided for this. Martinez-Pena and Gil-Quilez (2001) found a similar problem in diagrams illustrating phases of the Moon. That is, they found that some diagrams illustrating phases of the Moon did not illustrate the Moon as seen from space, and provided no explanation about this matter. Diagrams 12 and 13 can help learners to understand that the shape of the Moon appears to change as seen from Earth in the course of the Moon's orbits. Furthermore, these diagrams can help learners to understand the sequence of moon phases. However, information in the diagrams is not enough to explain the cause of moon phases. Each of the two books prescribes a modelling activity for the learners. In addition, Book 12 has textual information dealing with phases of the Moon. These other sources of information can help learners to understand why the Moon appears to change shape as seen from the Earth.
- Books 14, 16, 17 and 20 have diagrams illustrating the Sun, the Earth, the Moon orbiting the Earth, and phases of the Moon. However, each of these diagrams can help to explain only four phases of the Moon. Books 14 and 20 have diagrams illustrating the Moon in four positions around the Earth, and eight phases of the Moon. Book 16 has a diagram illustrating the Moon in four positions around the Earth, and corresponding phases of the Moon. Book 17 has a diagram illustrating the Moon in eight positions around the Earth and four phases of the Moon. All the four books have textual information dealing with phases of the Moon. In addition, Books 14 and 17 recommend that learners complete a Moon chart while Book 17 recommends a modelling activity for the learners. The text can be used to help learners understand the cause of all eight phases. In addition, the modelling activity in Book 17 can be used to help learners understand the cause of all Moon phases.
- Seven books (15, 18, 19, 21, 22, 23 and 24) have diagrams illustrating the Sun, the Earth, the Moon in at least eight positions around the Earth, and corresponding phases of the Moon. These diagrams can be used to explain all the eight phases of the Moon. Six of these books have textual information dealing with phases of the Moon. In addition, one of the six books

prescribes a modelling activity, while three books recommend that learners complete moon charts. Textual information and modelling activity can give additional information about the cause of moon phases. The diagram in a book that has no other information about phases of the Moon (Book 18) should illustrate all the concepts needed to understand moon phases. However, this is not the case because, for example, the names of moon phases are not presented in the diagram. This suggests that learning can be hampered if teachers do not provide additional information.

The curriculum requires learners in the Intermediate Phase to know the sequence of moon phases and to understand that these phases can be explained by the motion of the Moon relative to the Earth and the Sun. This curriculum requires Senior Phase learners to understand that motions of the Earth and the Moon can explain concepts such as phases of the Moon.

The discussion presented in this chapter shows that 13 books have simple diagrams mainly illustrating the sequence of moon phases, but occasionally giving information about the Moon's orbit around the Earth. Eight of these diagrams are in books designed for use in the Intermediate Phase while four are in books designed for use in the Senior Phase. All the 13 books present textual information and/or modelling activities to help learners understand the cause of moon phases. It appears that the diagrams are intended to supplement text and/or modelling activities by pictorially illustrating the sequence of moon phases.

Further analysis shows that four books have fairly complex diagrams that can explain four phases of the Moon while seven books have complex diagrams that can explain all the eight phases of the Moon. Understanding information illustrated in the complex diagrams requires learners to imagine looking at the Earth-Moon-Sun system from different perspectives, to mentally spin the Earth on its axis and to orbit the Moon around the Earth. These processes require learners to undertake processes at Piaget's formal operational level (Piaget's findings suggest that 12-year olds function at this level). Seven of the complex diagrams are in books designed for use in the Intermediate Phase while four are in books designed for use in the Senior Phase (Intermediate Phase learners are roughly 9-to-11 year old while senior phase learners are roughly 12-to-14 years old). According to Piaget's levels of development, complex diagrams are likely to be above the thinking ability of learners in the Intermediate Phase. One would expect publishers to use text and modelling activities to explain the cause of moon phases to these learners, and to provide simpler diagrams illustrating the sequence of these phases. The publishers would then use complex diagrams to explain the cause of moon phases for senior phase learners who operate at Piaget's formal operational level. However, this is not the case in the books surveyed in this study.

Analysis of Table 6.1 shows that 15 books deal with moon phases in the Intermediate Phase while nine deal with the topic in the Senior Phase. There appears to be no link between diagram complexity and grade level. That is, complex diagrams are found in books designed for lower grades (e.g. Diagram 19 in a Grade 4 book) and in books designed for senior grades (e.g. Diagram 24 in a Grade 8 book). In the same way, simpler diagrams are found in books designed for lower grades (e.g. Diagram 1 in a Grade 4 book) and in books designed for senior grades (e.g. Diagram 4 in a Grade 8 book). This observation corroborates Martinez-Pena and Gil-Quilez's (2001)

observation that the same diagram is found in books used by learners at different levels of education.

Analysis Diagrams 11 to 24 shows that artists illustrated the Earth's orbital path on the same plane as the Moon's orbital path. As a result, the Moon's orbit appears to be aligned with the ecliptic in these diagrams, so that New Moon erroneously occupies the position that results in a solar eclipse while Full Moon erroneously occupies the position that results in a lunar eclipse. Several researchers have made a similar observation, and proposed that this representation might enhance a common misconception in which people associate phases of the Moon's with the Earth's shadow (e.g. Dove, 2002; Engeström, 1991; Martinez-Pena & Gil-Quilez, 2001; Trundle et al., 2002). In reality, the Moon's orbit is tilted at 5° to the plane of the Earth's orbit. However, it is difficult to illustrate the Earth and the Moon's orbits in different planes while keeping diagrams simple enough to be understood by school learners. The theory of models suggests that differences between diagrams and the Earth-Moon-Sun system conceptualized by scientists should be explained to diagram users. However, the books analyzed in this study provided no information explicating the differences. This means that teachers should help learners to see these differences (but this might be difficult if teachers do not understand the topic). If the differences are not pointed out, learners might consider diagrams as exact replicas of the system.

Further analysis shows that relative sizes and distances between the Earth, the Sun and the Moon are not maintained in Diagrams 11 to 24. As a result, the Earth-Moon-Sun system illustrated in the diagrams differs from the system as conceptualized by scientists. Some researchers have noted this problem in diagrams illustrating phases of the Moon (e.g. Dove, 2002; Engeström, 1991 and Subramaniam & Padalkar, 2009). Engeström argues that this representation fails to indicate that the probability of the Earth's shadow falling on the Moon is very small. Furthermore, Engeström (1991) and Subramaniam and Padalkar (2009) argue that this representation could enhance a view that the Earth's shadow causes phases of the Moon.

6.3 Design problems associated with the diagrams

Section 6.3.1 gives a general overview of the instrument while subsequent sections discuss problems found in the diagrams.

6.3.1 Overview of the diagram-analysis instrument

The instrument consists of three levels of analysis: the syntactic level, the semantic level and the pragmatic level (see the instrument in Appendix D).

Syntactic level

This level of analysis investigates the extent to which diagram design enables viewers to perceive marks, and to organize the marks into perceptual units. Three principles are used for this purpose:

Perceptual Apprehension: This principle deals with perception of marks by viewers, and is stated as follows: *Diagrams should be designed so that marks are easily perceived, to allow viewers to see the visual message conveyed by each mark.* This principle is violated for example if marks are not (i) big enough to be perceived by viewers (ii), clearly printed and legible to be perceived, (iii) perceivable against the background.

Perceptual Organization: This principle deals with organisation of marks into perceptual units by viewers, and is stated as follows: *Design of diagrams should enable viewers to perceive associated marks as linked.* The following can help viewers to view marks as linked: (i) continuity (e.g. left-right and/or top-down arrangement used in the reading culture of learners, and usage of arrows and numbers to connect parts of a diagram), (ii) proximity, (iii) similarity in colour, pattern, and form, and (iii) framing (e.g. usage of empty spaces, lines, and colour discontinuities). The principle is violated for example if no mechanism is used to enable viewers to perceive 8 phases of the Moon as a unit, to perceive 8 positions of the Moon as a unit, and to link the Sun, the Earth, moon positions and phases of the Moon.

Processing Limitations: This principle deals with capacity limitations of working memory, and is stated as follows: *Diagrams should be designed so that information can be processed without overloading working memory.* This principle is violated for example if (i) a diagram contains more than 4 perceptual units (*only 4 units can be held in mind at once, although up to seven can be seen at a single glance*) or (ii) perceptual units deal with more than one main message.

Semantic level

This level of analysis focuses on interpretation of marks and their configurations. Three principles are used for this purpose:

Harmony: This principle deals with synchronization between messages conveyed by different parts of a diagram, and is stated as follows: *Diagrams should be designed so that there is consistency in the meaning associated with each mark.* The principle is violated, for example, if (i) size of the Moon (in its orbital path) differs from size of the Moon in the lunar phases, (ii), the number of moon shapes in the lunar circle differs from the number of lunar phases, (iii) colour of the unlit part of the Earth and/or Moon differs from colour of the night sky (if this is represented), (iv), colours of the illuminated part of the Earth differ from colour of the illuminated part of the Moon, and either of these differs from colour of the sun's rays (if colour is used for these rays).

Non-ambiguity: This principle deals with certainty of messages conveyed by the marks in a diagram, and is stated as follows: *Ambiguous use of marks should be avoided, as this might prevent viewers from understanding meanings of the marks.* This principle is violated for example if (i) the difference is not clear between the following phases: gibbous moon shapes and Full Moon, gibbous

shapes and half moon shapes, and crescent moon and half moon shapes, and (ii) readers cannot decide whether the black or the white colour represents the appearance of the Moon as seen from the Earth.

Scientific Accuracy: This principle deals with scientific accuracy of marks making the diagram, and is stated as follows: *Diagrams should be designed so that marks accurately represent scientific concepts.* This principle is violated for example if (i) the sequence of moon phases is not accurately represented (e.g. some phases have been misplaced), (ii) labels for phases of the Moon are inaccurate, or (iii) the Moon's orbit is drawn as circular, but a trace of Africa (or any country) is illustrated on the side.

Pragmatic analysis

This level of analysis focuses on appropriateness of diagrams for their intended purpose and for specific target audiences. Three principles are used for this purpose:

Purpose Compatibility: This principle deals with appropriateness of diagrams for their intended purpose, and is stated as follows: *Textual information should be provided to explain the purpose of each diagram. In addition, each diagram should have an appropriate amount of information needed to achieve its intended purpose.* This principle is violated for example if (i) no verbal elements are used to describe what the diagram is intended to show, (ii) some information is lacking, which is needed to fulfil the intended purpose of the diagram, (iii) irrelevant information is found in the diagram (as this could cause visual and cognitive overload).

Textual Compatibility: This principle deals with conformity between diagrams and the accompanying text, and is stated as follows: *If diagrams are intended to illustrate concepts described in text, there must be correspondence between the diagram and the textual content.* This principle is violated for example if diagram and the text employ different terminology or give contradictory messages.

Audience Compatibility: This principle deals with appropriateness of diagrams for the intended audience, and is stated as follows: *Diagrams should be designed to comply with culture and context of intended viewers.* This principle is violated for example if (i) diagrammatic information is presented against the top-down left-right reading convention used in schools, or (ii) a diagram intended for use in the southern hemisphere illustrates phases of the moon as they appear in the northern hemisphere.

6.3.2 Notes regarding critique of diagrams

I define a violation as an error made by designers of diagrams. These errors can be corrected. Thus, the issue of relative sizes and distances, and the fact that the Moon's orbit is drawn along the ecliptic are not considered to be violations because correcting those issues would be difficult. Also, it is important to note that some design flaws violate more than one principle. Such errors have

been discussed under different principles, the discussion indicating the nature of violation in each case.

6.3.3 Syntactic Analysis

This level investigates the extent to which diagram design allows viewers to perceive marks and to organize the marks into perceptual units. This analysis consists of three principles.

Principle 1: Perceptual Apprehension

Diagrams should be designed so that marks are easily perceived. This would allow viewers to see the visual message conveyed by each mark.

Only one diagram (Diagram 22b) violated this principle. In this diagram, arrows representing the Sun's rays (placed near a label 'sunlight') are not clearly visible, and could be missed altogether. Without these arrows, it might be difficult to link the label 'sunlight' with half of the Moon illuminated by the Sun's rays. Impact of this problem can be alleviated by using a modelling activity together with the diagram. The activity would show learners that the Sun's rays illuminate half of the Earth and the Moon at all times. Teachers who have no resources to model changing configurations of the components of the Earth-Moon-Sun system might have to draw a diagram showing that the Sun's rays illuminate halves of the Earth and the Moon. The fact that teachers have to make drawings in addition to the textbook diagram suggests that the diagram does not fully serve its intended purpose of visually presenting information.

Only one study has been found in literature, which reported problems of perceptual apprehension (i.e. Khanyane, 2002). Khanyane found that some information was difficult to see in a diagram illustrating causes of air pollution. Furthermore, she found that some captions were written in a font used in the text. As a result, the captions could not 'stand out' from the text, and were thus difficult to see.

Principle 2 (Perceptual Organization)

Design of diagrams should enable viewers to perceive associated marks as linked. Several mechanisms can be used to help viewers to perceive marks as linked. These include continuity, proximity, similarity, framing, and use of arrows and numbers.

Only three diagrams violated this principle. Diagram 17 has two parts; the first illustrates four phases of the Moon while the second illustrates the Sun's rays, the Earth, and the Moon in eight positions around the Earth. No visual cues (e.g. numbering and labels) have been used to enable viewers to link the two parts of the diagram. Without this information, it might be difficult to get the complete message intended by artists of the diagram (e.g. seeing associated symbols as linked). Using a modelling activity together with this diagram can help learners to link the two components

of the diagram (to see which of the eight moon positions correspond to the four phases). If the diagram is the only visual aid available, then teachers would have to show learners which of the eight positions correspond to the four phases. Again, the diagram does not fully serve its purpose as it requires teachers to do what could have been easily illustrated on the diagram.

Diagrams 15b and 22b illustrate the Sun, the Earth, and the Moon in eight positions around the Earth. Artists of the diagrams used no mechanisms (e.g. arrows or numbering) to indicate that the Moon moves around the Earth. Without this information, it might be difficult to realize that the eight moon shapes form one perceptual unit, i.e. the Moon orbiting the Earth. This problem can be easily corrected by asking learners to add arrows or numbers to the diagrams.

Only one study reported problems of perceptual organization, i.e. in a diagram illustrating formation and breakdown of ozone molecules (Khanyane, 2002). The diagram had three components each with a caption. The captions were placed midway between the components, and no cues were provided to show that each caption belongs to the figure above it. Khanyane speculated that this layout might confuse viewers. Furthermore, Khanyane found poor layout of information illustrating steps in formation of ozone molecules (the second component of the diagram). The sequence of these steps was not linear, but formed a c-shape. Khanyane speculated that this layout might confuse diagram viewers.

Principle 3 (Processing limitations)

Diagrams should be designed so that information can be processed without overloading working memory.

Books 1 to 10 have diagrams illustrating information in one perceptual unit (sequence of moon phases) while Books 11, 12 and 13 each has a diagram illustrating information in three perceptual units (the Earth, the Moon's orbit and phases of the Moon in Book 11, and the Earth, the Sun and moon phases in Diagrams 12 and 13). Books 14 to 24 have diagrams illustrating information in four perceptual units (the Earth, the Sun, the Moon's orbit and phases of the Moon). This shows that none of the diagrams analyzed in this study presented information in more than four perceptual units. This, in turn, suggests that information in the diagrams can be processed without overloading the working memory.

Although the diagrams analyzed in this study did not violate the third principle, research shows that some diagrams found in school textbooks present information in more than four perceptual groups, which can overload working memory. For example, du Plessis et al. (2003) found that a diagram illustrating the cardiac cycle had two figures of the heart and several arrows indicating blood entering and leaving the heart. These arrows formed more than four perceptual groups. Furthermore, du Plessis et al. found that a flowchart illustrating thermal regulation had several concepts and arrows between the concepts, making more than four perceptual units. du Plessis et al. concluded that both diagrams were complicated. Thus, some school textbooks have complex diagrams, despite the fact that the diagrams analyzed in the current study had less than four perceptual groups.

Summary of syntactic analysis

The above discussion shows that only three diagrams (15b, 17 and 22b) had problems at a perceptual level. If these problems are not solved, learners would most likely encounter problems of obtaining the entire message intended by artists. That is, if viewers have a problem of accurately perceiving information, then interpretation of the information would be hindered.

6.3.4 Semantic Analysis

This level of analysis focused on interpretation of marks and their configurations. This analysis consisted of three principles.

Principle 4: Harmony

Diagrams should be designed so that there is consistency in the meaning associated with each mark.

Design of several diagrams violates this principle.

Inconsistent use of colour: Artists of nine diagrams used colour in a way that might confuse viewers. Artists of Diagrams 14b and 20 used white colour to represent half of the Moon illuminated by the Sun's rays, and used dark colours to represent half of the Moon not lit by the Sun's rays. However these artists used only the white colour on the surface of the Earth, giving a false impression that the entire surface of the Earth is always illuminated by the Sun's rays. In Diagram 22b, white colour represents half of the Moon illuminated by the Sun's rays while a dark-grey colour represents half of the Moon not lit by the Sun's rays. However, only the dark-grey colour has been used on the surface of the Earth, giving false impression that the Sun never shines on Earth. Readymade visual aids like charts can be used to show learners that on paper, both halves of the Earth and the Moon are illuminated by the Sun at all times. In the absence of these aids, teachers would have to make diagrams showing that the Sun illuminates halves of the Moon and the Earth at all times.

In Diagrams 16 and 21a, yellow colour represents half of the Moon illuminated by Sun's rays while brown and blue colours represent half of the Earth illuminated by the Sun's rays (the latter colours probably indicate parts of the Earth covered by land and water respectively). In Diagram 11, white colour represents half of the Moon illuminated by the Sun's rays while light-grey colour represents half of the Earth illuminated by the Sun's rays. These inconsistencies give a false impression that sunlight shining on the surface of the Earth is different from sunlight shining on the surface of the Moon. Impact of these inconsistencies can be minimised by telling learners that the shaded colours should be the same, i.e. the same colour should represent halves of the Earth and the Moon illuminated by the Sun's rays and halves in darkness. Usage of readymade charts can help illustrate this point.

In Diagrams 8, 19 and 24, black and dark-grey colours represent unlit halves of the Earth and the Moon while a light-grey colour represents the area surrounding the Moon (i.e. the night sky). This gives a false impression that darkness of the night sky differs from darkness of the unlit half of the Moon. No inscriptions have been provided to explain what each colour represents. This problem can be solved fairly easily by telling learners that the dark colours have to be the same.

Inconsistent number of moon shapes in a diagram: The number of moon shapes in the Moon's orbital path should be equal to the number of moon phases illustrated in the diagram to help viewers understand the reason for the shape of the Moon in each position. Two diagrams violate this principle. Diagram 17 illustrates the Moon in eight positions around the Earth, but illustrates only four phases of the Moon. Learners using this diagram might not know what the Moon looks like in the other four positions. Diagram 20, on the other hand, illustrates the Moon in four positions around the Earth, but illustrates eight phases of the Moon. No explanation has been given as to why the other four positions of the Moon are not illustrated. Learners using this diagram would have no opportunity of using the Earth-Moon-Sun system to determine the appearance of the Moon in the missing four positions. This problem can be addressed by using charts and modelling activities which should show the Moon's orbit as continuous while at the same time illustrating corresponding phases. In the absence of resources these resources, teachers might have to draw diagrams illustrating the Moon in eight positions around the Earth, and corresponding Moon phases.

In Book 14, the first diagram (Diagram 14a) illustrates eight phases of the Moon while the second (Diagram 14b) illustrates the Moon in four positions around the Earth. However, authors made no effort to link information in the two diagrams. As a result, the two diagrams are independent of each other, and thus, do not violate this principle.

Inconsistent size of moon shapes in a diagram: In Diagrams 17 and 23, symbols representing phases of the Moon are larger than symbols representing the Moon in its orbital path around the Earth. In Diagrams 19 and 20, on the contrary, symbols representing phases of the Moon are smaller than symbols representing the Moon in its orbital path around the Earth. These inconsistencies give a false impression that the Moon orbiting the Earth is not equal in size to the Moon visible from Earth. Readymade visual aids (e.g. charts) could be mostly suited to show learners that the shapes are actually equal in size. In the absence of these aids, the problem can

easily be addressed by telling learners that the shapes should be the equal in size (the information that might be found in the text).

Khanyane (2002) found a similar problem of inconsistent size on a diagram using three steps to illustrate formation and breakdown of ozone. Oxygen atoms in the second step were larger than oxygen atoms in the other two steps, despite the fact that the three components were meant to give a unified message. Thus, the problem identified in this study has been documented in at least one previous study.

Inconsistency in representation of Sun's rays: In Diagram 18, a circular shape with radial lines represents the Sun and the Sun's rays. In addition, parallel arrows represent the Sun's rays illuminating the Earth and the Moon. The arrows overlap the radial lines representing Sun's rays. This erroneously implies that the Sun radiates both parallel and radial light rays. The book prescribes no other information dealing with phases of the Moon. Teachers who have access to other visual aids can use them to illustrate that the Sun radiates only one type of rays, and to further illustrate that the rays become parallel when they reach the Earth because of relative sizes and distance between the Earth and the Sun. In the absence of these aids, teachers might have to make appropriate drawings for the learners.

Principle 5: Non-ambiguity

Ambiguous use of marks should be avoided, as this might prevent viewers from understanding meanings of the marks.

Three types of violations have been noted.

Ambiguous use of black and white colours on phases of the Moon: In Diagrams 1, 5, 6, 7, 12, 13, 14, 19 and 24, bright colours (white or yellow) represent part of the Moon visible from Earth while dark colours (black or dark-grey) represent part of the Moon not visible from Earth. No inscriptions have been provided to explain what each colour represents. Some viewers might interpret the dark colours as representing part of the Moon visible from Earth because dark colours (on a white paper) attract the eye more than light colours.

This argument is supported by drawings made by two of 50 pre-service teachers who completed a moon chart in Bell and Trundle's (2008) study, and seven of 24 pre-service teachers who completed a moon chart in Wilhelm et al.'s (2008) study. The two pre-service teachers who participated in Bell and Trundle's study shaded part of the Moon visible from Earth and left the invisible part as white. On the other hand, the seven pre-service teachers who participated in Wilhelm' et al.'s study switched their method of shading, from shading visible part of the Moon to shading non-visible part of the Moon. These results indicate that some people consider the shaded part as representing visible part of the Moon; while on the other hand, diagram illustrators consider the white part as one being visible from Earth. Thus, without explanation of what each colour represents, different viewers might ascribe different meanings to dark and light colours in diagrams. This issue can easily be addressed by telling learners what each colour represents.

Ambiguous presence of lines inside moon shapes: Diagrams 20 and 21a have lines inside the moon shapes. There is no obvious meaning for these lines, and no explanations are provided to explain what the lines represent. For this reason, different viewers might ascribe different meanings to these lines. This problem would be difficult to correct because it is not clear what the lines represent.

Ambiguous presence of lines between the Earth and the Moon: Diagrams 15b, 22b and 24 have lines between the Earth and each of the eight positions of the Moon in its orbital path. In Diagram 15b, it appears as if the lines indicate half of the Moon visible from Earth, but no inscriptions have been provided to confirm this speculation. In Diagrams 22b and 24, there is no obvious meaning for these lines, and no inscriptions are provided to explain what the lines represent. As a result, different viewers might ascribe different meaning to these lines. This problem, too, would be difficult to correct because it is not clear what the lines represent.

Principle 6: Scientific accuracy

Diagrams should be designed so that marks accurately represent scientific concepts.

The design of several diagrams violates this principle.

Diagram 20 illustrates the Moon orbiting the Earth in a counter clockwise direction. This suggests that the Moon has been drawn as seen from the northern hemisphere. However, artists of the diagram drew phases of the Moon as they would be seen from the southern hemisphere. As a result, there is no correspondence between the Earth-Moon-Sun system and phases of the Moon (except for Full Moon and New Moon in which the Moon appears to be the same in both hemispheres). Modelling activities and charts can help to correct this information. Also, teachers' drawings can help to clarify problems made by the diagram.

The discussion under Principle 4 shows that for Diagram 18, the radial lines representing the Sun's rays overlap parallel arrows representing the Sun's rays shining on the Earth and the Moon. This implies that the Sun radiates both parallel and radial light rays. This is scientifically incorrect because the Sun emits radial rays only (fraction of these rays appears to be parallel because of relative sizes and distances between the Earth and the Sun). A further problem with Diagram 18 is that the Sun appears to illuminate more than half of the Earth and the Moon's surfaces. This is incorrect, and implies that the Sun illuminates more than half of the Earth and the Moon's surfaces at any particular point in time. Thus, the artists of this diagram have misrepresented the amount of the Earth and the Moon's surfaces illuminated by the Sun's rays. The fact that the diagrams is independent means that teachers using this book have to find other resources to help learners understand that the Sun emits radial rays only, and to further show that the rays illuminate half of the Earth and the Moon at any given point and time. Teachers who have no access to other resources might have to draw correct diagrams for the learners.

Artists of twelve diagrams used wrong symbols to represent phases of the Moon.

- Artists of six diagrams used wrong symbols to represent the New Moon phase. In three of these diagrams (2, 17 and 22a), artists used crescent shapes to represent New Moon while the in the other three diagrams (10, 13 and 23), artists used circular ring shapes to represent New Moon. These representations falsely imply that the Moon appears to be crescent-or ring-shaped during the New Moon phase (the Moon is not visible during this phase).
- Artists of Diagrams 6 and 7 mistakenly used gibbous shapes to represent the Waning Crescent moon phase.
- Artists of Diagram 13 used a waning crescent shape to represent both Waxing and Waning Crescent phases. In addition, the artists used a waning gibbous shape to represent both Waxing and Waning Gibbous phases.
- Artists of two diagrams used crescent shapes to represent quarter moons. Artists of Diagram 9 used a waning-crescent shape to represent Last Quarter, while artists of Diagram 11 used waxing and Waning Crescent shapes to represent First Quarter and Last Quarter respectively.
- Artists of two diagrams (18 and 20) each used the same shape to represent Waxing and Waning Gibbous phases. As a result, the Moon appears to be the same during Waxing and Waning Gibbous phases (which is not the case in real life).

Modelling activities can be a good way to show learners appropriate shapes of the Moon seen from Earth as the Moon orbits the Earth. Also, teachers can make drawings to show correct shapes to the learners. If teachers do not realise that the diagrams have incorrect information, then this information might be passed on to the learners.

None of the three studies which analyzed diagrams illustrating phases of the Moon in school textbook reported the problem of inaccurate shapes representing phases of the Moon (Dove, 2002; Engeström, 1991; Martinez-Pena & Gil-Quilez, 2001). However, Trundle et al. (2008) found this problem in diagrams illustrating moon shapes in children's story books. Trundle et al. (2008) found that one fifth of 772 illustrations were scientifically incorrect, and argued that these illustrations might enhance misconceptions.

Diagram 10 illustrates eight phases of the Moon in a linearly arranged manner. The diagram has arrows indicating waxing and waning phases of the Moon. The arrow indicating the waxing stage is positioned between New Moon and Waning Gibbous while the arrow indicating the waning stage is positioned between Waning Gibbous and Last Quarter. This incorrectly suggests that the Moon stops waxing only at the Waning Gibbous stage (it actually stops at Full Moon) and starts to wane from Waning Gibbous (not after Full Moon as should be the case). This inaccuracy can easily be corrected by telling learners that the Moon stops waxing at Full Moon, and starts waning immediately after the Full Moon phase. Textual information can also be used to correct this inaccuracy.

In Diagram 19, an outline of Africa can be seen on the earth shape, suggesting that the Earth has been drawn as seen from the side (not one of the poles). In this situation, the Moon's orbital path should be an oval. However, this orbital path has been drawn as circular in this diagram, violating

scientific accuracy of the illustration. A modelling activity can be used to show that Africa cannot be seen when the Moon's orbit is viewed from one of the poles.

Artists of five diagrams used **incomplete terms** to label phases of the Moon: artists of Diagrams 5 and 12 used the terms 'waxing' and 'waning' instead of Waxing Gibbous and Waning Gibbous. Artists of Diagrams 6 and 24 used the terms 'new' and 'full' instead of New Moon and Full Moon. Artists of Diagrams 5, 8, 12 and 24 used the term 'crescent' instead of Waxing Crescent and Waning Crescent. Artists of Diagrams 8 and 24 used the term 'gibbous' instead of Waxing Gibbous and Waning Gibbous. Learners using these diagrams might not know correct names of these moon phases. This problem can easily be corrected by telling learners appropriate names of Moon phases. Textual information can also help learners to know these names.

Artists of ten diagrams used **inappropriate terms**: Artists of Diagrams 5, 12 and 14a used the term 'half Moon' instead of the terms First Quarter and Last Quarter. Artists of Diagram 24 used the term 'half' to label each of these phases of the Moon. Artists of Diagrams 7, 9 and 10 used the terms 'first crescent' and 'last crescent' instead of Waxing Crescent and Waning Crescent respectively. Artists of Diagrams 13 and 15a used the term 'gibbous moon' instead of the terms Waxing Gibbous and Waning Gibbous. In addition, Artists of Diagram 13 used the term 'crescent moon' instead of the terms Waxing Crescent and Waning Crescent. Artists of Diagram 6 used the terms 'old crescent' and 'near full' instead of Waning Crescent and Waning Gibbous respectively. Artists of the same diagram used the term 'partly waned' to label a gibbous moon, erroneously drawn to represent a Waning Crescent phase. Learners using these diagrams might not know correct names of these moon phases. It appears that artists wanted to give learners an idea about phases of the Moon (e.g. half, crescent, gibbous or full), but not necessarily the exact names of these phases.

N.B.: Some books present this content in books designed for learners in lower grades while others present the information in books designed for learners in senior grades. If students learn about moon phases in earlier grades and never again, then the learners in these grades need to know the names of all phases of the Moon.

6.3.5 Pragmatic Analysis

This analysis focused on appropriateness of diagrams for their intended purpose, and for specific target audience. The analysis has three principles.

Principle 7: Purpose compatibility

Textual information should be provided to explain the purpose of each diagram. In addition, each diagram should have an appropriate amount of information needed to achieve its intended purpose.

Diagrams 1, 3, 5, 7, 8, 11, 13, 15a, 16, 18, 21b and 24 have captions explaining what each diagram represents, while diagrams 9, 10, 14b, 20 and 21a are placed near textual information clearly

explaining the purpose of each diagram. These diagrams do not violate this principle. On the other hand, Diagrams 2, 4, 6, 12, 14a, 17, 19, 22a, 22b and 23 have neither captions nor textual information stating what each diagram represents. However, the diagrams are placed under text explaining phases of the Moon. As a result, viewers can easily link diagram with phases of the Moon. These diagrams, too, do not violate this principle.

Diagram 15b is the only diagram which is considered to violate this principle. This diagram has no heading and/or textual information explaining what the diagram shows. The diagram is one of two illustrating information about the Earth-Moon-Sun system. Both diagrams are placed below text dealing with the Earth-Moon-Sun system (but not necessarily phases of the Moon). No textual information explains what each diagram illustrates. As a result, it could be difficult to know what each diagram illustrates.

Three diagrams lack information that would make them achieve their intended purposes. Diagram 11 consists of the Earth, the Moon in four positions around the Earth, and corresponding four phases of the Moon. The caption below the diagram says “As the Moon travels around the Earth; we can see different amounts of its sunlit face”. However, the Sun is not shown in the diagram. As a result, it becomes difficult to see the ‘sunlit face’ of the Moon from this diagram. Diagram 12 consists of the Sun’s rays, the Earth, and phases of the Moon placed around the Earth, (but not the Moon as seen from space). Text above the diagram says that “the changing shape of the Moon is called the phases of the Moon”, followed by a caption which says “Here’s how it happens”. The caption suggests that the diagram is intended to explain the cause of moon phases. The diagram would achieve this purpose only if it illustrated the Moon as seen from space. Thus, information in the diagram is not enough to achieve the intended purpose.

Diagram 13 consists of the Sun’s rays, the Earth, and eight phases of the Moon placed around the Earth. The diagram is placed below an activity instructing learners to “use the diagram ... to identify and name the phases of the Moon as you move (the Moon) around the Earth”. The diagram cannot fully achieve this purpose because of the following two problems. First, Waning Gibbous and Waning Crescent shapes have been incorrectly used to represent Waxing Gibbous and Waxing Crescent phases. As a result, learners using this diagram cannot find appropriate shapes for Waxing Gibbous and Waxing Crescent in the diagram. Secondly, an inappropriate label ‘gibbous moon’ has been used to label Waxing Gibbous and Waning Gibbous, and the label ‘crescent moon’ has been used for Waxing Crescent and Waning Crescent. For this reason, learners cannot identify appropriate names from the diagram.

Principle 8: Textual compatibility

If diagrams are intended to illustrate concepts described in text, there must be correspondence between the diagram and the textual content.

No contradictions have been found between the diagrams and the textual information. In addition, the diagrams and text used the same terminology (whenever textual information was provided). As a result, the principle has not been violated.

Principle 9: Audience compatibility

Diagrams should be designed to comply with culture and context of intended viewers. For example, information should be presented from left to right and from top to bottom in accordance with the reading convention used in schools. Also, a diagram designed for viewers in the southern hemisphere should illustrate moon phases as they appear in this hemisphere.

Fifteen diagrams illustrate phases of the Moon as seen from the northern hemisphere, despite the fact that the diagrams are intended for use in the southern hemisphere. Thus the principle has been violated in fifteen diagrams. This observation corroborates results obtained by Trundle et al. (2008) who found that diagrams in two story books designed for children living in the northern hemisphere illustrated the sequence of moon phases as seen from the southern hemisphere.

Principle 9 dictates that information on diagrams should be presented from left to right and from top to bottom in accordance with reading culture used in school. Diagrams 12 and 16 illustrate the Sun shining from the right-hand side of the page, requiring viewers pay attention to components on the right-hand side before components on the left-hand side. This, however, has nothing to do with reading but everything to do with ability to mentally change one's orientation on the page (i.e. it is a spatial ability issue). As a result, the diagrams are considered to have not violated this principle.

6.3.6 Summary

The curriculum requires Intermediate Phase learners to know the sequence of moon phases and to understand the cause of these phases. In addition, the curriculum requires Senior Phase learners to know that the movement of the Moon relative to the Earth and the Sun causes moon phases. On the basis of these requirements, publishers present information dealing with phases of the Moon in books intended for the Intermediate and Senior Phases. The discussion presented in this chapter shows that several diagrams have design problems that might hinder understanding of this information. Table 6.2 summarises design weaknesses found in diagrams analysed in this study. The table shows that only one diagram violated none of the principles used in this study. Three diagrams violated syntactic principles, meaning that viewers might encounter problems when trying to perceive information illustrated in these diagrams. In addition, 22 diagrams violated at least one of the semantic principles, suggesting that students might learn inaccurate information if teachers are not careful when using the diagrams. Furthermore, 19 diagrams violate at least one of the pragmatic principles, suggesting that these diagrams did not comply with the context of the intended learners.

Table 6.2 Summary of violations of the design principles

Diagram number	Syntactic analysis			Semantic analysis			Pragmatic analysis		
	1	2	3	4	5	6	7	8	9
1					✓				
2						✓			✓
3									
4									✓
5					✓	✓			✓
6					✓	✓			
7					✓	✓			✓
8				✓		✓			✓
9						✓			
10						✓			
11				✓		✓	✓		
12					✓	✓	✓		
13					✓	✓	✓		✓
14 (a & b)				✓		✓			✓
15 (a & b)		✓			✓		✓		
16				✓					✓
17		✓		✓		✓			✓
18				✓	✓	✓			✓
19				✓	✓	✓			✓
20				✓	✓	✓			✓
21 (a & b)				✓	✓				✓
22 (a & b)	✓	✓		✓	✓	✓			✓
23				✓		✓			
24				✓	✓	✓			✓

The large number of violations observed in the table suggests that the diagrams might fail to achieve their intended purpose of helping learners to understand concepts associated with phases of the Moon. I have shown in the preceding discussion that these problems can best be addressed by using either text, readymade visual aids like charts, modelling activities, or teachers' drawings. It is worthy to note that no research has been conducted to investigate accuracy of information presented in text and other visual aids such as charts dealing with phases of the Moon. Also, no research has been conducted to investigate whether, and the extent to which modelling activities prescribed in the books can help learners to understand phases of the Moon. The fact that textbook diagrams have design problems suggests that these other information sources might have problems. Learning would be hindered if these other information sources had problems (further research should be conducted to investigate possible problems in these information sources, so that teachers know the extent to which information presented in these resources can be trusted). If teachers do not fully understand astronomy concepts (as results of this study seem to suggest), then it would be difficult for them to correct information presented in these sources of information.

Teacher training programs should be designed to enhance pre-service teachers' understanding of basic astronomy concepts. In addition, these programs should help pre-service teachers to

understand challenges associated with teaching and learning of these concepts. Furthermore, these programs should equip teachers with strategies and techniques that help people to better understand these concepts, e.g. daily moon observations, usage of physical models, and usage of computer software.

As for practicing teachers (some of who have never been trained to teach astronomy concepts), there should be in-service training programmes that focus on (i) enhancing subject matter knowledge of these teachers, (ii) helping the teachers understand challenges associated with teaching the concepts, and (iii) equipping the teachers with strategies that help learners to better understand these concepts. The pre-service and in-service training programs would help teachers to realise strategies and materials that can be used in addition to textbook diagrams (which, as this study shows, have several problems).

6.4 Answer to the third research question

The third research question has been phrased as follows:

To what extent does the composition of diagrams illustrating phases of the Moon (in South African school textbooks) comply with design principles recommended in literature?

Out of 24 textbooks used in this study, diagrams found in 21 books complied with guidelines recommended in the first set of principles focusing on perception and organization of marks. Thus all information in these diagrams can be easily perceived and mentally arranged into perceptual units by viewers. However, only two diagrams complied with guidelines recommended by the second set of principles (focusing on interpretation of marks and their configurations). Thus, diagrams in 22 books have potential interpretation problems. Furthermore, diagrams in only 6 books complied with guidelines recommended by the third set of principles (focusing on appropriateness of diagrams for their intended purpose and for specific target audiences). Thus, nineteen diagrams violate at least one of the principles in this set.

6.5 Diagrams used in interviews

I selected four diagrams to be used in interviews. Here I present criteria used to select these diagrams, and discuss issues investigated in each diagram.

6.5.1 Criteria used to select diagrams

Diagrams used in interviews had to meet two criteria. Firstly, a diagram had to illustrate the following: the Sun (or the Sun's rays), the Earth, the Moon (as seen from space) in eight positions around the Earth, and corresponding eight phases of the Moon. These diagrams can be used to explain the cause of the eight moon phases. Only Diagrams 18, 19, 21(a & b), 22 (a & b), 23 and 24 met this criterion.

Secondly, I selected diagrams that violated very few design principles. Few violations would have minimum impact on diagram interpretation. In Diagram 18, the Sun (incorrectly) appears to illuminate more than half of the Moon's and the Earth's surfaces. In addition, artist of this diagram used the same shape for Waxing Gibbous and Waning Gibbous phases. I discarded this diagram because of these problems. In Diagram 22a, a crescent shape has been incorrectly used to represent New Moon. In Diagram 22b, arrows representing the Sun's rays are too faint (and therefore difficult to see). Furthermore, no mechanisms (e.g. arrows) have been provided to show that the Moon orbits the Earth in this diagram. As a result I discarded Diagrams 22a and 22b. I discarded Diagram 23 because it violates scientific accuracy (i.e. New Moon being represented by a ring shape, which would result in interpretation problems). Thus, only Diagrams 19, 21a, 21b and 24 remained, and were used in the interviews. It should be noted that all these diagram violate Principle 9, i.e. they illustrate Moon phases as seen from the northern hemisphere, but I designed the interview schedule so that this violation would have no impact on interpretation of the diagrams. The following points indicate issues investigated in each diagram.

6.5.2 Issues investigated in each diagram

I used Diagrams 21a and 21b to investigate learners' interpretation the Earth, the Sun's rays, the Moon's orbit and the Moon's phases. Consequently, interpretation of these diagrams allowed investigation of learners' interpretation of the first three conventions (see the conventions in Section 6.6). Furthermore, I used Diagrams 21a and 21b to investigate learners' ability to determine moon phases seen from earth during selected configurations of the components of the Earth-Moon-Sun system. That is, to link shapes in Diagram 21b with Diagram 21a.

I used Diagram 24 to investigate (a) learners' interpretation of the Moon's orbit and phases when these are presented as two concentric ovals, (b) learners' interpretation of the black and white colours on diagrams illustrating moon phases, and (c) whether learners consider the earth and the moon shapes as representing two-or three-dimensional objects. In addition, I used Diagrams 24 and 19 together to investigate learners' interpretation of the shape of the Moon's orbital path (and radiating lines). Interpretation of Diagrams 19 and 24 allowed me to make inferences about learners' interpretation of the last three conventions.

6.6 Conventions used in the diagrams

Interpretation of diagrams requires viewers to understand conventions used to convey information in such diagrams. Here I present conventions used to convey information in diagrams illustrating phases of the Moon, observable from the 28 diagrams analysed in this study.

1. The same symbol appears more than once, representing the same entity as it changes position (i.e. eight circles represent one moon not many)
2. The same symbol appears more than once, representing different entities
 - Half-shaded circles represent the Earth and the Moon
 - Arrows represent the directions of the Moon's orbit and the Sun's rays
3. Different symbols represent the same entity as it changes shape (i.e. representing the Moon changing shape).
4. Black and white colours have been used to indicate parts of the Moon visible and not visible from Earth.
5. Two-dimensional shapes are used to represent three-dimensional objects (the Earth and the Moon).
6. Shape of the Moon's orbit indicates perspective from which the Moon has been drawn. That is, a circular orbit indicates that the Earth-Sun-Moon system has been drawn from above the Earth and the Moon, while an oval shape indicates that the Earth-Sun-Moon has been drawn as seen at some angle from the top.

Chapters 7 and 8 report on learners' ability to interpret conventions used in the four diagrams used during interviews.

6.7 Summary

This chapter has presented results obtained from analyzing diagrams illustrating phases of the Moon. The analysis investigated (a) whether, and the extent to which information in the diagrams could be perceived and organized into perceptual units, (b) whether design of the diagrams could enable viewers to obtain message intended by illustrators, and (c) suitability of the diagrams for intended purpose and audiences.

The results show that for most diagrams, information can be perceived and organized into perceptual units. The results further show that the majority of diagrams had design problems that might prohibit learners from obtaining messages intended by illustrators. Furthermore, the results show that the majority of diagrams were not suitable for intended contexts and audiences. These results were used to select four diagrams that would be used in interviews (i.e. Diagrams 21a, 21b, 19 and 24). The next chapter presents learners' interpretation of Diagrams 21a and 21b.

Chapter 7 Diagram interpretation (Part 1)

7.1 Introduction

This chapter presents learners' interpretation of Diagrams 21a and 21b. I used these diagrams to investigate two issues:

- Learners' interpretation the Earth, the Sun's rays, the Moon's orbit and the Moon's phases. Consequently, interpretation of these diagrams allowed me to infer about learners' interpretation of the first three conventions discussed in Section 6.6 (pp 153-154):
 1. The same symbol appears more than once, representing the same entity as it changes position (i.e. eight circles represent one moon not many).
 2. The same symbol appears more than once, representing different entities:
 - a) Half-shaded circles represent the Earth and the Moon
 - b) Arrows represent directions of the Moon's orbit and the Sun's rays
 3. Different symbols represent the same entity as it changes shape.
- Learners' ability to determine moon phases seen from the shape representing the Earth in the diagram (i.e. the earth shape) for different configurations of the components of the Earth-Moon-Sun system. That is, to link Diagram 21a with the shapes in Diagram 21b.

I structured the interview so that design flaws identified in Chapter 6 would have no impact on interpretation of these diagrams. Table 7.1 illustrates two principles violated in Diagram 21a, and one violated in Diagram 21b. The table further explains why these violations would not prevent learners from interpreting information illustrated in the two diagrams.

7.2 Interpreting Diagram 21a

I asked each learner to look at Diagram 21a (Figure 7.1), and describe what they thought the diagram illustrated. The exact wording differed from learner to learner because the interviews were semi-structured. Furthermore, the semi-structured nature of the interview enabled each learner to discuss diagram components in any order. I ensured that learners discussed all components of the diagram.

This section deals with interpretation of components of the diagram in this order: the Earth shape, the lunar circle, and the Sun's rays. For each component, I give hints that could help the learners to

interpret the component, and also give interview extracts to show how the interview progressed (i.e. to show questions that I asked and responses given by the learners).

Table 7.1 Impact of design flaws on interpretation of Diagrams 21a and 21b

	Principle	Nature of violation	Impact on interpretation
Diagram 21a	Harmony	The illuminated half of the Earth is brown and blue but the illuminated half of the Moon is light-yellow.	Differences in colouring of illuminated parts of the Earth and the Moon give contradictory messages. A closer look at these colours suggests that they might help the learners to interpret the diagram. For example, the brown colour might be interpreted as indicating the African continent while the blue colour might be interpreted as showing water surrounding the continent.
	Non-ambiguity	Different meanings might be ascribed to dotted lines inside the moon shapes because no inscriptions have been provided to explain the purpose of the lines.	The dotted lines inside the moon shapes are intended either to indicate the orbital path of the Moon, or to help viewers determine section of the Moon visible from Earth. This uncertainty about the purpose of these lines cannot distract learners from interpreting the eight half-shaded circles as representing the Moon.
Diagram 21b	Audience compatibility	The Moon's orbit and phases are drawn as seen from the Northern hemisphere, despite the fact that diagram viewers live in the southern hemisphere.	The order of moon shapes cannot distract learners from interpreting the shapes as representing phases of the Moon.

7.2.1 The Earth

Helpful hints concerning interpretation of the Earth shape

The Earth shape is not labelled in the diagram. However, the following facts could help learners interpret the shape as representing the Earth.

- **African continent:** Brown colour indicates a trace of Africa while blue colour indicates water.
- **Linking the Earth and the Moon:** Learners who correctly identify the Moon in the diagram might realize that the shape at the centre of the diagram represents the Earth if they used
 - *Background knowledge:* Learners who know that the Moon orbits the Earth and that the Moon is smaller than the Earth might use this knowledge to infer that the shape at the centre of the Moon's orbit represents the Earth.
 - *Textual information on the page:* The second paragraph on the page states that the Moon orbits the Earth. Learners who realize that the eight half-shaded circles with arrows in-between represent the Moon's orbit might figure out that the shape at the centre of this orbit represents the Earth.

Unit 3: The Earth and the Moon

In Unit 2 you saw that many of the planets in our Solar System have moons. Moons are **natural satellites** that move around the planets they are attached to. Astronomers are discovering new moons all the time. Our Moon is the closest space object to Earth. We can see the Moon in the night sky because it reflects light from the Sun. We normally cannot see the Moon during the day, because it is too light, but it is still there!



The full Moon

Moon movements

The Moon revolves around Earth in an **elliptical orbit** once every $29\frac{1}{2}$ days. At the same time, the Moon rotates on its own axis. The Moon's rotation means that the same side always faces Earth and that we only ever see one side of the Moon from Earth. The side of the Moon that we never see is called the 'dark side of the Moon'.

The diagram below shows the position of the Moon at different times in its orbit.

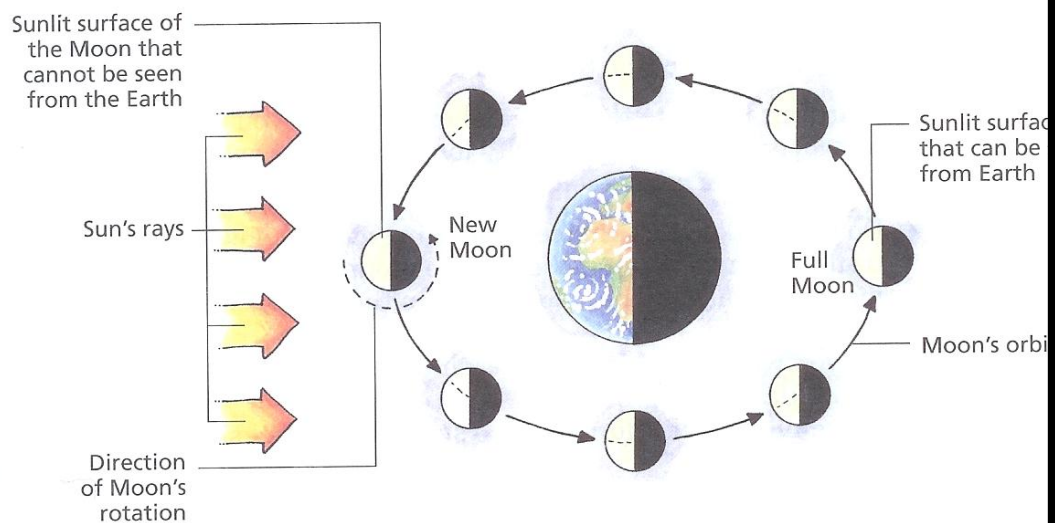


Figure 7.1 A page illustrating Diagram 21a

- *Inscriptions on the diagram:* A caption on the top-left corner of the diagram states that the sunlit half of the Moon cannot be seen from Earth when the Moon is between the Sun and the Earth. On the other hand, a caption on the top-right corner of the diagram states that the sunlit side of the Moon can be seen from Earth when the Earth is between the Sun and the Moon. These captions might help learners infer that the shape at the centre of the diagram represents the Earth.

Learners' interpretation of the Earth shape

Nine learners correctly interpreted the shape as representing the Earth. These learners used hints available on the page when interpreting the shape. It has to be borne in mind that the learners might use several hints when interpreting the diagram, but mention only some of these hints. That is, not mentioning a hint may not necessarily mean that learners did not use the hint when interpreting the diagram. As a result, it becomes difficult to know the hints not used by learners when interpreting the diagram. The following discussion considers only the hints mentioned by learners when interpreting the diagram.

- Four of the nine learners mentioned the brown and blue colours in the earth shape as the only hint they used to interpret this shape. The following extract illustrates a sample response from these learners.

R⁷: you know what I want, you're moving your hand and you're thinking of many things, take your time and tell me all the things you're thinking.

'Mamosa: I'm thinking, okay there's Earth here

R: where?

'Mamosa: here (*pointing at the Earth shape*)

R: why do you think that's the Earth?

'Mamosa: I see the picture with blue, it looks like water

R: okay

'Mamosa: and part of the land (*pointing at the brown section of the non-shaded part of the earth shape*)

R: okay

- Three learners mentioned the 'African continent', and also mentioned links between the Earth and the Moon. The following extract exemplifies their responses.

R: okay, what are these shapes (*pointing at the eight moon shapes*)

Seboka: the, these shapes are circles

R: What do you think the artist wanted the shapes to mean to us?

Seboka: the small circles are supposed to be the moons (*pointing at the eight moon shapes*), and this bigger one at the middle is supposed to be the world.

R: why do you think that would be the world, what gives you that clue?

Seboka: the Moon rotates around the world, and it has a bit of an African island

⁷ In all transcripts, the letter **R** denotes the researcher

These responses indicate that seven learners interpreted the brown and blue colours as representing land and water on surface of the Earth. This corroborates an observation made by Ehrlen (2009) in a study involving 18 six-to-nine year-old children. Ehrlen gave these children coloured pencils and asked them to draw the Earth. Most of these children used blue colour to represent water and used green colour to represent land (grass). This shows that children associate blue colour on Earth with regions covered by water (as has been the case in the current study).

- One learner mentioned ‘the colours’ as giving her a hint that the shape at the centre of the diagram represents the Earth. In addition, she used her background knowledge to link the Earth and the Moon. The following extract illustrates her response.

R: what have we got at the centre of the diagram?

Fumane: it’s the Earth

R: what gives you that clue?

Fumane: the colours, and the Earth is obviously in the centre, and I know for a fact that the Moon revolves around the Earth. If the Moon wasn’t revolving around the Earth it wouldn’t be.

R: so that makes it the Earth?

Fumane: yes

She did not explain what she meant by ‘the colours’. However, it is obvious that she was referring to the colours on the earth shape. As a result, I consider her to have used the colours as hints for interpreting the shape at the centre of the diagram as representing the Earth. Her statement ‘... I know for the fact that the Moon revolves around the Earth’ suggests that she used background knowledge to interpret the earth shape in the diagram.

- One learner mentioned links between the Moon’s orbit and the Earth as her only hint for saying that the shape at the centre of the diagram represents the Earth, as shown in the following extract.

R: This is the first page, so I want you to look at the page, and tell me what you think the topic is that is illustrated on the page.

Karabo: should I look at the picture?

R: you look at the whole page or anything that you want to

Karabo: the movement of the Moon around the Earth

R: okay, what else?

Karabo: I don’t know, when day and night (*silent*)

R: okay, first you said the movement of the Moon around the Earth, what gave you that clue from the page?

Karabo: okay, I can see this (*pointing at the Earth shape*) obviously that’s the Earth, and this is the movement of the Moon (*moving her hand along the circle of moon shapes*)

However, she gave no information regarding the hints she used to interpret the shape as representing the Earth. As a result, we do not know whether she used text or background knowledge when interpreting the Earth shape in the diagram.

The remaining learner said that he did not know what the shape represented. The following extract shows his response

R: I want us to come back to this diagram again (referring to Diagram 21a). And this is what I am going to ask you to do. I want you to imagine, oh did I ask you what we have at the centre here?

Lehana: (inaudible)

R: what do you think this is (pointing at the Earth shape)

Lehana: I have no idea

R: no idea about this

Lehana: yes

Table 7.2 summarizes learners' interpretation of the earth shape in Figure 7.1. I have arranged the learners according to spatial ability scores, so that the first five learners had low spatial ability scores while the bottom five learners had high spatial ability scores (as discussed in Section 5.5, p 131).

Table 7.2 Learners' interpretation of the Earth shape in Diagram 21a (Figure 7.1)

Learners	Response	Clues		
		Blue and brown colours on 'African continent'	Link Earth and Moon	
			Background knowledge	Not specific
Lisebo	✓	*		
Lehana	—	N/A	N/A	N/A
Makalo	✓	*		
Motena	✓	*		*
Karabo	✓			*
Seboka	✓	*		*
Fumane	✓		*	
Masilo	✓	*	*	
'Mamosa	✓	*		
Selomo	✓	*		

In this and subsequent tables, a tick (✓) indicates a correct answer, a cross (x) indicates a wrong answer, a tick and a cross (✓ x) indicate that a learner changed from a correct to a wrong response or vice versa, a dash (—) indicates that a learner did not know the answer, while a question mark (?) indicates that a response was difficult to classify. A star (*) indicates hints which learners appeared to have used when interpreting the diagram.

Table 7.2 shows that nine of the ten learners correctly interpreted the shape as representing the Earth, despite the fact that the Earth was not labelled in the diagram. The page had four hints which might help learners to interpret the shape at the centre of the diagram as representing the Earth. The first hint was the trace of Africa illustrated on the earth shape, while the remaining three hints had to do with linking the Earth to the Moon. Table 7.2 shows that none of the learners mentioned all the four hints while interpreting the earth shape. Seven of the ten learners mentioned the brown and blue colours on the earth shape when interpreting the Earth in the diagram. In addition, five of the

10 learners mentioned links between the Earth and the Moon when interpreting the Earth in the diagram. Two of the five learners appeared to have used background knowledge as a hint for linking the Earth and the Moon, while three learners gave no information regarding the hints they used to interpret the Earth.

These results indicate that when several hints are available to help interpretation of a diagram, learners select the hints they find suitable for interpreting the diagram. I have noted the following issues in learners' responses:

- Some of these learners appeared to have used background knowledge to interpret the Earth in the diagram. Results discussed in Chapter 4 show that the learners had poor background knowledge on phases of the Moon. Despite this, it appears that some of these learners knew that the Moon orbits the Earth, and used this knowledge when interpreting the diagram. Literature shows that background knowledge helps individuals to interpret diagrams (e.g. Ametller & Pinto, 2002; Kindfield, 1993/1994; Lowe, 1995). Thus, diagram interpretation becomes easier to learners who have some background knowledge of concepts illustrated in the diagrams.
- No evidence suggests that the learners used inscriptions on the diagram and text on the page when interpreting the Earth shape. As discussed earlier in this section, it is difficult to know whether the learners read but not mentioned the verbal information, or whether they never read this information at all. However, literature shows that learners sometimes do not read diagram inscriptions. For example, Ametller and Pinto (2002) asked high school learners to interpret a diagram illustrating energy transfer between two systems. The caption of the diagram indicated that energy was transferred between the two systems. Most of the learners realized that the diagram illustrated change, but very few associated the change with energy transfer. Ametller and Pinto suspected that the learners had not read the caption, and directed learners' attention to the caption. Most of the learners associated the change with energy transfer after reading the caption.

Paivio's dual coding theory can be used to explain how learners processed information on the page in order to interpret the shape as representing the Earth. This theory proposes that cognition consists of activity of two systems; a verbal system specialised for processing and storage of verbal information, and a nonverbal system specialised for processing and storage of nonverbal information. This theory further proposes that information processing occurs at three levels namely, the representational, the referential and the associative levels (as discussed in Section 2.2.3 p 48).

The Earth is drawn but not labelled on the diagram. Thus, the diagram provided only nonverbal information about the Earth. Despite this, seven learners mentioned the trace of an 'African continent' while interpreting the earth shape (see Table 7.2). The absence of verbal information about the Earth suggests that only the nonverbal systems were active in the beginning of information processing. Thus, the learners engaged in representational processing to form mental images of the 'African continent' illustrated on the diagram, and then engaged in referential

processing to interpret the 'African continent' as representing Africa and to further interpret the brown and blue colours as representing land and water. Finally, the learners engaged in associative processing to interpret the circular shape at the centre of the diagram as representing the Earth (on the bases of the African continent drawn on the shape).

Table 7.2 further shows that five of the 10 learners mentioned links between the Earth and the Moon while interpreting the earth shape. This suggests that the learners paid attention to the earth and the moon shapes on the diagram. None of the five learners mentioned verbal elements found on the page when interpreting the earth shape. As a result, it can be said that their verbal systems were not active at the beginning of information processing. It follows that these learners engaged in representational processing which enabled them to form mental images of the Earth and the Moon, and thereafter, engaged in referential processing to interpret the shapes as representing the Earth and the Moon. It is difficult to know whether they engaged in associative processing because both the Earth and the Moon were illustrated on the diagram.

7.2.2 The Moon's orbit

Helpful hints concerning interpretation of the Moon's orbit

The following facts might help learners to interpret the eight moon shapes and eight arrows as indicating the Moon's orbit around the Earth.

- Several labels on the diagram suggest that the circles and the arrows represent the Moon's orbit.
 - The labels *Full Moon* and *New Moon* indicate that the half-shaded circles represent the Moon.
 - The caption *Direction of Moon's rotation* placed near New Moon indicates that the half-shaded shape (New Moon) represents the Moon.
 - Two captions (top-left and top-right) show that the lit side of the Moon can be seen from Earth when the Moon is on one side of the Earth, but cannot be seen when the Moon is on the opposite side of the Earth. This might help to clarify that the Moon moves around the Earth.
 - The caption *Moon's orbit*, placed near one of the arrows, indicates that the arrows represent the direction of the Moon's orbit.
- Learners who realize that the shape at the centre of the diagram represents the Earth might infer that the eight circles represented the Moon if they used the following information
 - *Text:* As discussed in Section 7.2.1 (p 156), the text near the diagram states links between the Earth and the Moon. Having figured out one shape, learners can use text to figure out the other.

- *Background knowledge:* Also, as discussed in Section 7.2.1 (p 156), knowing that the Moon orbits the Earth can help learners to interpret the diagram.

Learners' interpretation of the Moon's orbit

Nine learners correctly interpreted the eight half-shaded circles and the arrows as representing the Moon's orbit.

- Seven of these learners clearly explained that the circles showed the Moon, and further explained that the arrows indicate the direction of the Moon's orbit. The following extract illustrates an example of these responses.

R: ... Let's look at this section of the diagram (*pointing at the moon's orbit*). What is happening here?

Lehana: I don't understand.

R: you don't understand? Okay. What do you think these arrows mean?

Lehana: the arrows?

R: yes, you see we have arrows here?

Lehana: isn't how the Moon moves around during the day?

R: how the Moon moves around during the day? Okay. And these objects? (*pointing at the moon shapes*)

Lehana: that is the Moon.

His response 'that is the Moon' suggests that he interpreted the shapes as illustrating the Moon. Thus, he correctly interpreted the Moon's orbit.

- Two of the nine learners (Karabo and Motena) clearly explained that the circles represent the Moon, but they did not discuss the arrows. However, they used hand movements to indicate the direction of the Moon's orbit. The following extract illustrates this point.

R: This is the first page, so I want you to look at the page, and tell me what you think the topic is, that is illustrated on the page.

Karabo: should I look at the picture?

R: you look at the whole page or anything that you want to

Karabo: the movement of the Moon around the Earth

R: okay, what else?

Karabo: I don't know, when day and night (*silent*)

R: okay, first you said the movement of the Moon around the Earth, what gave you that clue from the page?

Karabo: okay, I can see this (*pointing at the earth shape*) obviously that's the Earth, and this is the movement of the Moon (*moving her hand in a counter anticlockwise direction along the lunar circle*)

Moving a hand in a counter clockwise direction suggests that she interpreted the Moon as orbiting the Earth in this direction. This in turn suggests that she interpreted the arrows as indicating the direction of the Moon's orbit.

Research shows that learners use body movements when explaining astronomical phenomena. For example, several students who participated in Hans et al.'s (2008) study used 'hand waving and

gestures' when explaining the cause of Moon's phases. Learners use these body movements to supplement verbal explanations.

The remaining learner changed his ideas in the course of the interview about what the eight half-shaded circles represented. However, his response suggests that he correctly interpreted the arrows as indicating the direction of the Moon's orbit. The following extract shows that he first thought that the shapes represented the Moon.

R: here is the first page from one of the Natural Science textbooks., just concentrate on the page as a whole, and I want you to tell me what you think the topic is that is being illustrated here.

Makalo: it's like, most probably, that's whenever there becomes a New Moon and a Full Moon that rotates around the world

R: pardon

Makalo: that rotates around the world

R: is it about Full Moon and New Moon?

Makalo: yes

R: only?

Makalo: yes

R: and what gives you that clue?

Makalo: because first it says it's a New Moon (*pointing at the label "New Moon"*)

R: where does it say that?

Makalo: on the left-hand side there (*pointing at the label "New Moon"*) and the right says Full Moon

R: mmmh

Makalo: so whenever it rotates to the Moon it becomes New Moon

R: okay, you say when it rotates, what gives you a clue in the diagram, how does the Moon rotate?

Makalo: anticlockwise

R: what gives you this answer?

Makalo: because of, the arrows show that it goes anticlockwise (*moving his hand along the direction of the arrows*)

Moving his hand along the Moon's orbit in a counter clockwise direction to illustrate how the Moon 'rotates' suggests that he used the term 'rotate' to mean 'revolve'. This response suggests that he interpreted the eight half-shaded circles and the eight arrows as representing the Moon's orbit around the Earth. The following extract shows that he gave a different response as the interview continued.

R: okay, what are these circles? (*pointing at the moon shapes*)

Makalo: this is most probably, the dark side is when it's in the night and the other side is when it's like day time

R: the dark side is? (*pointing at the black part of the moon shape*)

Makalo: most probably night, and the white part is light

R: on?

Makalo: on the surface

R: of?

Makalo: of the Earth

R: this is the Earth? (*pointing at a moon shape*)

Makalo: yes

R: and this? (*another moon shape*)

Makalo: the Earth also

R: oh, these are the earths?

Makalo: yes

R: why are they eight, why do you think the artist has drawn eight?

Makalo: that's the, most probably the difference of earth or different types of planets

In this case, he appeared to have thought that the circles represented the Earth. However, he changed this response when asked why there were eight earths, saying that the shapes could be planets. It is not clear why he thought that the shapes represented planets, but it is possible that he read text while interpreting the diagram (the text mentions planets). Should this be the case, he would have failed to make appropriate links between the diagram and textual information, corroborating observations of Khanyane (2002) and Ametller and Pinto (2002). The next extract shows that he actually thought that the circles represented the Moon.

R: you see we have these, do you see those dots? (*inside the Waning Gibbous moon shape*)

Makalo: yes

R: what do you think they mean? What is their importance here?

Makalo: I think, they most probably represent the, how is the Moon's gonna be, it's either half or quarter

R: sorry, you said this is the what? (*pointing at the Last Quarter moon shape*)

Makalo: it's the Earth

R: and just now you said the Moon is doing what?

Makalo: that's most probably the, how its time of the period will the Earth, will the Moon be half or quarter or one third

R: so this (*First Quarter moon shape*) shows what, what does this (*the same shape*) tell us, for example?

Makalo: mmm, this is (*pause*); this (*moving his hand to indicate all the moon shapes*) is most probably the planets.

R: this is probably the planets?

Makalo: ja

R: okay, and this? (*pointing at the Earth shape*)

Makalo: that's eeemmm, that's most probably the Earth itself

R: Earth itself, what makes you think that?

Makalo: because of the picture that is also being shown on the diagram

R: which picture?

Makalo: this picture on Earth (*pointing at the trace of Africa*)

R: what does that picture tell us?

Makalo: that, this half tells us that it's, part is Earth (*pointing at the half not shaded black*)

R: what, on this picture, tells you that it's Earth, in this half?

Makalo: mmm, because of, because of the, that (*pointing at the brown colour in this half*) represents countries, and blue also represents that there's also water on land.

R: alright, the countries and the water on land, so this shows (*pointing at the circle of moons*), one last time, the movement of?

Makalo: of the Moon

R: the Moon?

Makalo: ja

R: but earlier you said?

Makalo: it's the Earth

R: you said the Earth and then you said the planets, so what are we settling for?

Makalo: I'm settling for the Moon

He mostly interpreted the half-shaded circles as representing the Moon, but he sometimes thought that they represented the Earth or planets. It is not clear why he mentioned planets, but as discussed above, it is possible that he read 'planets' from the neighbouring text.

Literature shows that learners sometimes change responses in the course of an interview (e.g. Ehrlen, 2009; Lelliott, 2007). For example, Ehrlen (2009) asked eighteen 6-to-9 year old children to draw the Earth. One of these children drew a circle which she referred to as the Sun, surrounded by ten circles which she referred to as planets. She labelled one of these planets as the Earth. When asked questions about the Earth, she said that some objects could be found on another 'earth', pointing at one of the circles that she had referred to as planets. At this stage, she defined the ten circles as the earths (not planets). When asked why she had drawn many earths she said that there were many earths around the Sun. It seems that she changed her responses to accommodate ideas she developed in the course of the interview.

Although Makalo had some problems of correctly interpreting what the eight circles represented, moving his hand in a counter clockwise direction along the lunar orbit suggests that he interpreted the arrows as indicating the direction of the Moon's motion. Table 7.3 summarizes learners' interpretation of the Moon's orbit in Figure 7.1.

Table 7.3 Learners' interpretation of the Moon's orbit in Diagram 21a (Figure 7.1)

Learner	Moon	Direction of orbit	Clues							Link to Earth
			Diagram captions							
			1	2	3	4	5	6		
Lisebo	✓	✓					*			
Lehana	✓	✓								
Makalo	✓ □	✓			*		*		*	
Motena	✓	✓					*			
Karabo	✓	✓							*	
Seboka	✓	✓	*		*		*			
Fumane	✓	✓						*		
Masilo	✓	✓			*		*			
'Mamosa	✓	✓								
Selomo	✓	✓		*					*	

Key on diagram captions

1. Sunlit surface of the moon that cannot be seen from the Earth
2. Direction of Moon's rotation
3. New Moon
4. Moon's orbit
5. Full Moon
6. Sunlit surface of the Moon that can be seen from Earth

Table 7.3 shows that all learners correctly interpreted the arrows as indicating the direction of the Moon's orbit. The table further shows that nine learners correctly interpreted the half-shaded circles as representing the Moon. One learner interpreted the circles as representing the Moon, but he appeared to be uncertain about this. It is possible that he read textual information near the diagram while interpreting the Moon's orbit. Research shows that learners sometimes misinterpret diagram because of reading irrelevant information presented in the text. For example, Khanyane (2002) asked ten learners to interpret a diagram illustrating formation and breakdown of ozone molecule. The diagram was placed near text entitled 'Ozone scare', which had information about ozone layer. When interpreting the diagram, two learners mentioned ozone scare while five mentioned ozone layer. Khanyane suspected that these learners failed to interpret the diagram because they read textual information adjacent to the diagram.

Table 7.3 shows that seven learners mentioned diagram inscriptions while interpreting the Moon's orbit. Most of these learners read 'New Moon' and 'Full Moon'. Dual coding theory posits that these learners engaged in representational processing to form mental images of visual information, and to read verbal information presented on the diagram. Then, these learners engaged in referential processing to interpret the circles as representing the Moon, and to identify the arrows as indicating the direction of the Moon's orbit.

One learner mentioned links between the Earth and the Moon while interpreting the diagram, while two learners gave no information regarding hints they used to interpret the Moon's orbit. It is difficult to know whether the learners' verbal systems were active at the representational processing of information. However, it can be concluded that their nonverbal systems engaged in representational processing which enabled them to form mental images of the Moon's orbit. Furthermore, these learners engaged in referential processing which enabled them to interpret the arrows and the eight half-shaded circles as representing the Moon's orbit.

7.2.3 Black and white colours on the moon shapes

Helpful hints about interpretation of colours on the moon shapes

Learners might use the following facts to interpret the white colour as representing half of the Moon illuminated by the Sun's rays, and to interpret the black colour as representing half of the Moon facing away from the Sun's rays.

- *Natural colour:* Learners might relate black colour with darkness/night and white colour with light/day.
- *Captions:* Two captions on the diagram (on top left and top right) show half of the Moon illuminated by the Sun's rays.

- *Link to the Sun's rays:* Learners might make a direct link between the Sun's rays and the white colour on the Moon.

Learners' interpretation of colours on the moon shapes

Seven learners discussed the black and white colours on the moon shapes while interpreting Diagram 21a. All the seven learners correctly interpreted the black and white colours on the moon shapes. The following extracts show examples of their responses.

R: alright. Now I'd like you to look at this diagram, this whole diagram. Study it carefully, and tell me what you think the artist is trying to show us here.

Selomo: *(silence)*

R: what are you looking at?

Selomo: at the *(pointing at the diagram)*

R: alright

Selomo: thanks, ja

R: just keep talking as you are looking at it

Selomo: ja, it shows how the Moon goes and when the Sun gets the Moon at a certain point

R: it shows how the Moon goes?

Selomo: how it circles the Earth

R: how it circles the Earth and?

Selomo: and how the Sun catches the Earth

R: okay how does the Moon circle the Earth?

Selomo: okay *(he moved his hand along the lunar circle in a counter clockwise direction)*

R: what gives you that clue?

Selomo: the arrows

R: alright the arrows?

Selomo: okay the pictures ja

R: alright you said how the Moon circles the Earth and how the Sun?

Selomo: how the Sun catches the Moon as it *(moving his hand along the Moon's orbit)*

R: okay, how does it, can you explain that for me?

Selomo: like here, the Sun shines from this side *(moving his hand from the four arrows representing the Sun's rays towards the moon shapes)* so it catches the Moon so all these sides closest to the Sun are illuminated by the Sun)

Another example

R: ... Why is half of each of these shaded black *(pointing at the moon shapes)* Do you have a clue?

Lehana: no

R: no clue what so ever, try to look carefully at the diagram. Okay let's take it one step further. What do you think these arrows, you see we have other arrows here *(referring to the arrows representing the Sun's rays)*

Lehana: it's how the Moon lights the Earth

R: pardon?

Lehana: the light that comes from the Sun

R: what gives you a clue that it's light that comes from the Sun?

Lehana: because on this side (*pointing at the caption*) it says Sun's rays

R: okay it says the Sun's rays

Lehana: and on this side (*pointing at the non-shaded side of the moon shapes*) there is light. It's light on this side

R: okay, let me go back to my question. Why do you think half of each circle is shaded black?

Lehana: because of the Sun

R: because of the Sun?

Lehana: (*inaudible*)

R: pardon

Lehana: because of the light

R: okay why are these (*pointing at the shaded part of the Moon*), I want us to get this straight, why are these

Lehana: black in colour?

R: yes why is the other one black?

Lehana: because there is no light

R: there is no light on the black ones?

Lehana: yes

Three learners (Lisebo, Seboka and Fumane) described the colours later in their interview (when determining the appearance of the Moon from Earth, using Diagram 21a as discussed in Section 7.6). However, I present their responses in this section to give an overall picture of learners' interpretation of these colours. All the three learners appeared to have a good understanding of what the colours represented. The following extract illustrates an example of their responses.

R: and you were looking at this moon (*pointing at the moon shape in a Waning Gibbous position in Diagram 21a*). I'd like you to tell me what you think you would see. Here are the Sun's rays, there is the Earth, the Moon is in that position.

Fumane: I'd see the sunlit side of the Moon.

R: how would it appear to you? Can you draw that?

Fumane: must I draw what I would see?

R: try to draw it if you can

Fumane: (*she drew a circle*) it would be a normal circle, it would be white

R: it would be?

Fumane: it would be like this part (*pointing at the non-shaded half of the moon shape*), sunlit it would be white.

R: a normal circle that would be white

Fumane: ja, like if I'm standing here (*pointing at the centre of the Earth shape*), and I'm looking straight ahead (*moving her hand from the earth shape to the moon shape in Waning Gibbous position*), I won't be able to see the dark part because of the angle.

R: alright

Fumane: so it'll just be white, it won't be shaded from the point that I look at it

Fumane's statement 'sunlit it would be white' made while pointing at the non-shaded half of the moon shape suggests that she interpreted this half as representing the surface of the Moon illuminated by the Sun's rays.

Table 7.4 summarizes learners' responses. The table shows that the learners used only two of the three hints available to help during interpretation of the diagram. All the learners linked the white colour with Sun's illumination. In addition, three indicated that the black colour represents darkness (or night) and further indicated that the white colour represents light (or daytime). None of the learners mentioned diagram inscriptions when interpreting the black and white colours. Despite this, all learners correctly interpreted the black and white colours on shapes representing the Moon. These responses suggest that learners can correctly interpret diagrams when there are hints to help with the interpretation.

Table 7.4 Learners' interpretation of the black and white colours on moon shapes in Diagram 21a (Figure 7.1)

Learner	Interpretation of Black/white colours	Cues	
		Natural colour	Linking to Sun's rays
Lisebo	✓		*
Lehana	✓		*
Makalo	✓	*	*
Motena	✓		*
Karabo	✓	*	*
Seboka	✓		*
Fumane	✓		*
Masilo	✓	*	*
'Mamosa	✓		*
Selomo	✓		*

It is possible that learners' verbal systems were not active in the beginning of information processing because none mentioned diagram inscriptions when interpreting the black and white colours on the moon shapes. It appears, therefore, that the learners engaged in representational processing which enabled them to form mental images of information illustrated in the diagram, and then engaged in referential processing which enabled them to correctly interpret the black and white colours on the moon shapes.

7.2.4 The Sun's rays

Helpful hints about interpreting arrows as representing the Sun's rays

Learners could use the following facts to determine that the arrows represent the Sun's rays

- *Natural colour*: Learners might associate the yellow colour with the Sun.
- *Label*: The caption *Sun's rays* should hint to learners that the arrows represent the Sun's rays.

- *Link with the Moon:* Two captions on the diagram (on top left and top right) show half of the Moon illuminated by the Sun's rays. Learners could use this information to infer that the arrows represent the Sun's rays.

Learners' interpretation of the arrows representing sun's rays

Nine learners correctly interpreted the arrows as representing the Sun's rays.

- Three of these learners mentioned the label 'Sun's rays' and the yellow colour as hints which helped them determine that the arrows represented the Sun's rays. The following extract illustrates their responses.

R: I want you to tell me, you see we have this whole diagram here, have a look at it and tell me what you think, tell me everything that is obtainable from the diagram. Remember I want to know what learners see. If you look at this diagram what is it saying to you?

Motena: must I just explain everything that I see?

R: everything

Motena: okay, from, this is Earth (*pointing at the Earth shape*)

R: okay

Motena: and I'm kind of confused because the Full Moon (*pointing at a moon shape labelled Full Moon*) is like, why is the Moon dark this side? Why is the Earth dark this side? Because it's a Full Moon and the half moon is bright, do you understand what I'm saying?

R: no

Motena: with, it's a Full Moon (*pointing at the Full Moon shape*)

R: okay, you said this is the Earth

Motena: it is

R: why do you think it's the Earth?

Motena: because these are drawings (*pointing at the blue and brown colours on the Earth shape*)

R: so drawings mean the Earth?

Motena: because the Moon is revolving around it (*moving a pen along the Moon's orbit in a counter clockwise direction*)

R: alright. So this (*the lunar circle*) shows the Moon revolving around the earth?

Motena: and the reason, okay for me, now I can think of something, the reason there's light this side (*pointing at the non-shaded half of the Earth shape*) is because the Sun's rays (*pointing at the parallel arrows*) come from this side

R: oh these (*pointing at parallel arrows*) are the Sun's rays?

Motena: ja

R: why do you think so?

Motena: because it's written "Sun's rays" and I can see the colour

R: tell me about the colour

Motena: the Sun is somewhat yellow, and that orange from that far, that's what we were taught when growing up that the Sun's yellow, so that's why I think it's the Sun

- Six learners mentioned the label 'Sun's rays' as their only reason for saying that the arrows represented the Sun's rays. The following extract gives an example of these responses.

R: alright, and what are these big arrows (*the four yellow arrows*), what do you think they are supposed to tell us?

Seboka: they are Sun rays

R: how do you know?

Seboka: it's written here (*pointing at the label "Sun's rays"*)

One learner said that she did not know what the arrows represented

R: okay, what do you think these four big arrows are?

Lisebo: I'm not sure

R: you're not sure

Lisebo: ja

R: just, can you look at the diagram. If you looked at the diagram, is there anything that could give you a clue about what they are?

Lisebo: it's probably pointing to this picture (*pointing at the Moon's orbit*)

R: for what, maybe? Can you think about that?

Lisebo: to give us example of how this diagram is meant to work.

Table 7.5 summarizes learners' responses.

Table 7.5 Learners' interpretation of arrows representing the Sun's rays in Diagram 21a (Figure 7.1)

Learners	Sunrays	Clues	
		Yellow colour	Diagram caption
Lisebo	—	N/A	N/A
Lehana	✓		*
Makalo	✓	*	*
Motena	✓	*	*
Karabo	✓		*
Seboka	✓		*
Fumane	✓		*
Masilo	✓	*	*
'Mamosa	✓		*
Selomo	✓		*

The results show that nine learners correctly interpreted the arrows as representing the Sun's rays. These learners used at least one of the hints available on the page: six explicitly referred to the caption of the arrows while three referred to the caption and mentioned the yellow colour. All these learners voluntarily read this caption, contrary to findings reported in literature that many learners do not read captions until they are asked to do so (e.g. Ametller & Pinto, 2002 and Khanyane, 2002). The fact that all these learners mentioned diagram inscriptions when interpreting the Sun's rays suggests that their verbal and nonverbal systems were active during information processing. The learners engaged in representational processing which enabled them to read captions and to form mental images of the arrows in the diagram. Then, they engaged in referential processing which enabled them to interpret the arrows as representing the Sun's rays. It is difficult to know

whether learners engaged in associative processing because the diagram provided both verbal and nonverbal information about the Sun's rays.

The learner who claimed not to know what the arrows represented referred to none of the hints available on the page. This suggests that not paying attention to hints available on diagrams might result in failure to interpret the diagram. Section 7.5 (p 181) discusses implication of these results on learners' interpretation of conventions used in this diagram.

7.3 Interpreting Diagram 21b

Learners were shown a page that has Diagram 21b, and they were asked to describe what they thought the diagram illustrated (Figure 7.2 illustrates this Diagram).

Helpful hints concerning interpretation of Diagram 21b

The following hints could help learners figure out that the eight shapes represented phases of the Moon.

- **Diagram captions:** Two types of labels could help learners figure out what the diagram shows.
 - *Heading of the diagram:* The heading 'The eight phases of the Moon' could help learners determine that the diagram illustrates phases of the Moon. However, the heading might be missed out altogether because it is written with a smaller font size (the design principles recommend that headings be more conspicuous than text).
 - *Names of lunar phases:* The names 'Full Moon' and 'New Moon' indicate that the shapes show the Moon. Other names are likely to have meaning only to learners who have learned about the topic.
- **Text:** Two issues on the text could help learners interpret the diagram as illustrating phases of the Moon
 - *Heading of the page:* This clearly states that the page is about phases of the Moon.
 - *The text:* This explains why the Moon appears to change shape.

Learners' interpretation of Diagram 21b

Nine learners correctly interpreted the shapes as representing phases of the Moon.

- Only one of these learners explicitly stated that the diagram illustrated phases of the Moon, as indicated in the following extract.

The phases of the Moon

As the Moon moves around Earth, it seems to change shape in the night sky. These changes are the result of the position of the Moon in its orbit around the Earth. One half of the Moon is always in sunlight but we cannot always see the entire sunlit section because of the Moon's position. The only time we do see the whole sunlit section is during full Moon. At new Moon the sunlit half of the Moon is facing away from Earth and we cannot see it at all.

The diagram on page 26 shows the eight main positions of the Moon during its orbit. The pictures below show you how the Moon appears in the sky at these eight points. We call these the **phases of the Moon**. The Moon goes through these phases every $29\frac{1}{2}$ days. This is called a **lunar month**. The first stage is called **waxing** because the Moon seems to be getting bigger from new Moon to full Moon. The next stage is called **waning** because the Moon seems to get smaller from full Moon to the next new Moon phase.



The eight phases of the Moon



Observing and recording Moon phases

LO1 AS2; LO2 AS3

- You are going to keep a record of Moon phases for 28 days. Start tonight!
 - Draw a chart with a simple sketch like this one showing 28 days.
 - Look at the shape of the Moon in the night sky each night and colour the part of the Moon you can see in yellow on your diagram.
 - Write the date on each block.
- At the end of the month, try to fill in on your chart the eight main phases of the Moon when they occurred .
- Will the full Moon occur on the same date every month? Give reasons for your answer.
- The start of the Muslim holy month of Ramadan is linked to the phases of the Moon. Find out how.

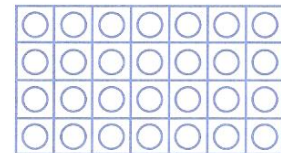


Figure 7.2 A page illustrating Diagram 21b

R: ... Now let's look at this page (*referring to Page 27 which has Diagram 21b*). What do you think the artist is trying to tell us here?

'Mamosa: he is trying to tell us, (*pause*) it has to do with the previous picture.

R: it has to do with the previous picture?

'Mamosa: with the phases of the Moon; oh bananas (*pointing at Waxing Crescent*)

R: oh you see the bananas?

'Mamosa: and half a moon and a full moon

Her reference of the crescent as a 'banana' is similar to a response given by one child in Wilhelm's (2009a) study. Wilhelm asked three young children (aged 6 to 8) several questions about the Moon. One of these children said that she had seen the Moon and it looked like a banana. It appears that people sometimes use 'banana' to describe the shape of the Moon seen from earth.

- Four learners (Lisebo, Lehana, Makalo and Fumane) said that the diagram illustrated 'types of moon'. However, their responses indicate that they used 'types of moon' to mean phases of the Moon. The following extract gives an example of their responses.

R: ... I'd like you to look at this diagram and tell me what you think is going on here (*referring to Page 27 which has Diagram 21b*).

Lisebo: these are the different types of moons

R: please explain to me

Lisebo: like I said in the first picture, the quarter moon, the half moon, the Full Moon, and the different shapes that the Moon comes up in the evening.

R: please explain that to me as well

Lisebo: (*she laughed*)

R: no, you see I need to know what you understand when you look at these

Lisebo: the way the Moon sits with the Earth, and then the light reflects, say the Moon reflecting and the Earth cutting half of the Moon or however much of the Moon

R: okay, can you tell me why these shapes are drawn to be different, why has the artist drawn different shapes here?

Lisebo: maybe to show that the Moon is never the same

- Two learners (Selomo and Seboka) said that the diagram illustrated quarters of the Moon. However, it was clear from their responses that they interpreted the diagram as illustrating phases of the Moon. The following extract illustrates their responses.

R: ... so have a look at this (*Diagram 21b*) and tell me what you think it's telling us.

Selomo: it's telling us about different quarters of the Moon, when the Sun shine whether it's New Moon or Full Moon

R: if you can try to speak louder

Selomo: okay it shows, okay it shows the, the, the different way the Moon, the Sun catches the Moon's light, and it shows the way the Moon looks when the Sun is in different places and the Moon is in different places

- Two other learners (Masilo and Karabo) interpreted the diagram as illustrating phases of the Moon. The following extracts show their responses.

R: ... so look at this diagram (Diagram 21b) and tell me what you think it's telling us. What is the artist telling us here?

Masilo: I think he is telling us the same thing he told us on that diagram, page 26. This would be the New Moon (*on Diagram 21b*) you can see the black part is not visible (*pointing at the black half of the Moon on Diagram 21a*)

R: okay

Masilo: and this (*Waxing Crescent on 21a*) would be the second following the New Moon

The other learner

R: ... What do you think is going on in this diagram (*referring to Diagram 21b*)?

Karabo: now this shows that Full Moon, quarter moon, half moon, but I don't see how it relates to that (*pointing at Diagram 21a*)

R: okay, let's talk about this one before trying to relate. Why do you think the artist has drawn these as different? What do you think is going on here?

Karabo: well, obviously the Moon doesn't stay the Moon as in full so it changes, that's why he used different pictures to show that it changes from quarter moon, Full Moon

The remaining learner appeared to have some confusion. First she interpreted the diagram as illustrating the Moon.

R: alright. Let's have a look at another diagram (Diagram 21b). Now this is what I have told the other learners. This is page 26 and that is page 27, so they are from the same book

Motena: yes

R: so the, what do you think is going on in this diagram? What do you think the artist wanted to show us here?

Motena: are these moons?

R: well, what do you think they are?

Motena: ja because it's banana-shaped it's the Moon (*pointing at the Waxing Crescent*)

R: so the Moon is banana-shaped?

Motena: if it's a half moon it's somewhat oval

R: okay,

As the interview progressed, she interpreted the diagram as illustrating a solar eclipse.

Motena: okay no I think it's the sss, okay, I don't know why they made it a moon because I would think it's the Sun

R: oh you think it's the Sun?

Motena: I would

R: oh, you would think it's the Sun because?

Motena: reason being that the Sun is bright and when the Moon comes over the Sun it becomes dark (*pointing at Waxing Crescent*).

R: pardon

Motena: the Sun is making light on to Earth

R: okay

Motena: and when the Moon appears, when the Moon rises, Earth becomes dark

R: okay

Motena: so I'd say that's why

R: you know I'm missing that one, when the Moon rises the Earth becomes dark?

Motena: yes somewhat

R: can you explain that to me?

Motena: you know in the bible when they say let there be light and let there be darkness

R: mmmm

Motena: the light is meant to be taken from the Sun

R: okay

Motena: and the Moon, the darkness is meant to be taken from the Moon

R: okay

Motena: so I would say that this yellow part is the Sun (*pointing at Full Moon*)

R: okay

Motena: and then the black that's coming over it is the Moon

This response suggests that she interpreted the diagram as illustrating the Moon obscuring the Sun from Earth viewers. This means that she interpreted the diagram as illustrating a solar eclipse. She changed this response after reading the diagram caption, saying that the diagram illustrates phases of the Moon.

Motena: but if you would read it, it says this is the Moon

R: okay

Motena: yes it says this is the Moon, which might mean

R: okay

Motena: which might mean, unless the Moon was revolving around the Earth, the Sun might be like this page here, this side (*pointing at Diagram 21a*), that's why in some pictures it's darker and the other side it's light (*pointing at First Quarter on diagram 21b*)

R: ja you see you've said many things. Okay, what are you saying finally is going on here?

Motena: it's like this picture (*pointing at Diagram 21a*)

R: okay

Motena: the Moon is revolving around the Earth

R: alright

Motena: and as it moves the part that's shining is when the Moon, is the part when the Sun is reflecting on it.

R: okay

Motena: do you understand me?

R: the part that?

Motena: the part that is shining is the part that

R: let's say the part that's drawn here (*pointing at Diagram 21b*) is the part that

Motena: the Sun is shining on

R: okay I'm not sure if I understand that, let's take it this way, maybe this will clarify what you're trying to tell me.

Motena: like here (*pointing at the Sun's rays on Diagram 21a*) the reason I say this part is light (*white half of the Moon in New Moon position*) is because the Sun is reflecting on it

R: mmmhhh

Motena: so the reason why this is light (*pointing at moon shapes on Diagram 21b*) is because light is reflecting on it.

Her response corroborates findings of Ametller and Pinto (2002) and Khanyane (2002) who found that some learners correctly interpreted diagrams after reading captions. Table 7.6 summarizes learners' interpretation of Diagram 21b.

Table 7.6 Learner's interpretation of Diagram 21b

Learners	Diagram Interpretation	Hints used by the learners			Heading
		Names of lunar phases			
		Full Moon	New Moon	Last Quarter	
Lisebo	✓	*			
Lehana	✓	*	*		
Makalo	✓	*			
Motena	✓ □				□
Karabo	✓	*			
Seboka	✓	*			
Fumane	✓	*		*	
Masilo	✓		*		
'Mamosa	✓	*			*
Selomo	✓	*	*		

The table shows that learners paid attention to different inscriptions on the diagram.

- *Names of lunar phases:* Nine learners mentioned at least one of these names. The tenth learner (Motena) mentioned none of these names while interpreting the diagram. Her response 'but if you would read it, it says this is the Moon' suggest that she read some inscriptions on the diagram, but did not specify the verbal element that she read. The overall result shows that learners read *Full Moon* and *New Moon* more than other names, as was the case in Diagram 21a. The reason for this is not clear, but literature suggests that these are the most commonly known names of moon phases (e.g. Hobson et al., 2010).
- *Other verbal elements:* Only one learner ('Mamosa) mentioned *Phases of the Moon* while interpreting the diagram. No other learners explicitly read this caption, corroborating results of researchers who found that sometimes learners do not read captions of diagrams (e.g. Ametller & Pinto, 2002; Khanyane, 2002).

It is possible, however, that the learners paid no attention to the caption because the caption was written in small font (similar to font used in the text), and therefore did not 'stand out' from the rest of the text. This would corroborate results obtained by Khanyane (2002). She asked ten learners to interpret a diagram illustrating a food web, which had a caption 'A food web' written in a font similar to the font of the text on the page. Only two learners mentioned 'food web' while interpreting the diagram. The remaining eight learners used other terms to describe what the diagram illustrated. Khanyane suspected that the learners paid no attention to the caption because the caption was written in a small font size.

An overall result is that almost all learners correctly interpreted the diagram as illustrating phases of the Moon, despite the fact that very few used appropriate terminology. The results further show that all learners paid attention to inscriptions when interpreting this diagram. The dual coding theory posits that these learners engaged in representational processing which enabled them to read verbal elements on the diagram, and to perceive nonverbal information on the diagram. Thereafter, the learners engaged in referential processing which enabled them to interpret the diagram as illustrating phases of the Moon. It is difficult to know whether the learners engaged in associative processing because both verbal and visual information were presented on the diagram.

7.4 Summary of learners' Interpretation of Diagrams 21a and 21b

Table 7.7 summarizes learners' interpretation of Diagrams 21a and 21b.

Table 7.7 Summary of learners' interpretation of Diagrams 21a and 21b

Learners	Earth			LUNAR CIRCLE						SUN'S RAYS				LUNAR PHASES		
	Interpreting Earth	Cues		Interpreting moon's orbit	Cues		Interpreting Black & white Colours	Cues		Interpreting Sun's rays	Cues			Interpreting lunar shapes	Cues	
		African continent	Link to Moon		Diagram captions	Link to Earth		Natural colour	Link to Sun's rays		Yellow colour	Diagram caption	Link to Moon		Diagram captions	Text on the page
Lisebo	✓	*		✓	*		✓		*	✓				✓	*	
Lehana	✓			✓			✓		*	✓		*		✓	*	
Makalo	✓	*		✓ x	*	*	✓	*	*	✓	*	*		✓	*	
Motena	✓	*	*	✓	*		✓		*	✓	*	*		x ✓		
Karabo	✓		*	✓		*	✓	*	*	✓		*		✓	*	
Seboka	✓	*	*	✓	*		✓		*	✓		*		✓	*	
Fumane	✓		*	✓	*		✓		*	✓		*		✓	*	
Masilo	✓	*	*	✓	*		✓	*	*	✓	*	*		✓	*	
'Mamosa	✓	*		✓			✓		*	✓		*		✓	*	
Selomo	✓	*		✓	*	*	✓		*	✓		*		✓	*	

The table shows that in general, the learners correctly interpreted information illustrated in the two diagrams. The five high spatial-ability learners and one low spatial-ability learner correctly interpreted all information illustrated in these diagrams while four low spatial-ability learners each had a problem with one component of the diagrams. These results show a very weak link between diagram interpretation and learners' spatial ability skills. That is, no remarkable difference is seen between the five low spatial-ability learners (top five on the table) and five high spatial-ability learners (bottom five on the table). The table further shows that learners paid attention to different

hints available on the diagrams. Two learners (Lisebo and Lehana) who said that they did not know what some components represented mentioned none of the hints. The results suggest that learners got the correct interpretation by paying attention to different components of the diagram.

Table 7.7 further shows that in many instances in this study, learners read verbal elements while interpreting diagrams. This suggests that the presence of verbal information helped the learners to interpret the diagrams. Dealing with verbal and nonverbal information helped the learners to engage in representational and referential processing, which helped them to understand information illustrated in the diagrams. This corroborates results reported in literature, which show that presentation of verbal and pictorial information helps learners to better understand of information (e.g. Chandler & Sweller, 1991; Mayer, 1989; Mayer & Gallini, 1990; Sweller et al., 1990).

The fact that the learners appeared to be able to interpret the diagrams used in this study contradicts results obtained in previous studies which show that learners struggled to interpret diagrams (e.g. du Plessis et al., 2003; Khanyane, 2002; Stylianidou et al., 2002). However, a careful analysis shows weaknesses in design of the previous studies, which might have prevented learners from accurately interpreting diagrams. For example:

- Some of the previous studies used poorly designed diagrams. For example, Stylianidou et al. (2002) asked learners to interpret a diagram illustrating energy conversions in which water was used to generate electricity. Stylianidou et al. realized that at a first glance the diagram appeared to illustrate water cycle, and suspected that some learners might misinterpret the diagram because of this. Indeed, the majority of learners interpreted the diagram as illustrating water cycle. In the current study, I investigated ambiguities in diagrams, and selected diagrams with very few design problems. This could be one of the reasons why the learners were fairly able to interpret diagrams in the current study.
- Some researchers asked questions requiring learners to use background knowledge when interpreting diagrams. For example, Khanyane (2002) asked ten learners to interpret a diagram illustrating formation and breakdown of ozone molecules. Whilst interpreting the diagrams, Khanyane asked the learners to describe the ‘balls’ and ‘sticks’ forming the molecules. Only six of the ten learners correctly interpreted the ‘balls’ as illustrating oxygen atoms, while four correctly interpreted the ‘sticks’ as representing bonds. The diagram gave no information regarding what the sticks represented. As a result, Khanyane’s question investigated learners’ background knowledge of the meaning of the ball-and-stick model, not necessarily interpretation of the diagram. In my study, I ensured that no background knowledge would be required to interpret Diagrams 21a and 21b. This might be another reason why the learners found the diagrams easy to interpret.
- Some researchers removed diagrams from their context. For example, du Plessis et al. (2003) asked learners to interpret a diagram illustrating the cardiac cycle. No verbal information (labels or text) was presented to explain what the diagram illustrated. The majority of learners failed to interpret information illustrated on the diagram, probably because they did not understand this information. In my study, I presented the diagram together with accompanying verbal information in the form of text and labels (which were the original context). This

provided several hints helping the learners to interpret the diagrams. It appears as if the questions asked by du Plessis et al. (2003) investigated learner's background knowledge of the cardiac cycle rather than learners' interpretation of the diagram. In fact, I suspect that a person who has high skills in diagram interpretation and no background knowledge on cardiac cycle would fail to interpret the diagram because no information was presented to explain components of the diagram. The presence of many helpful hints on Diagrams 21a and 21b could be another reason why the learners were able to correctly interpret what these diagrams illustrated.

The foregoing discussion suggests that careful selection of the diagrams, and presentation of diagrams within their context (e.g. adjacent text) is essential to help learners interpret what the diagrams illustrate.

7.5 Interpretation of Conventions

The following section evaluates the extent to which learners interpreted three conventions used in Diagrams 21a and 21b.

7.5.1 The same symbol appears more than once, representing one entity as it changes position

Learners had to realize that the eight shapes surrounding the earth shape represented one entity (the Moon) orbiting the Earth.

I used Diagram 21a to investigate learners' interpretation of this convention. Nine learners interpreted the shapes as representing the Moon's orbit around the Earth. These learners are considered to have been able to interpret the convention. The tenth learner (Makalo) appeared to be uncertain, saying the shapes represented the earths, the moons or the planets. Saying that the shapes represented the earths or the moons might suggest that he interpreted these as representing one entity (the Earth or the Moon) changing position over time. However, saying that the shapes showed different planets indicates that he thought that the shapes represented different entities, and therefore failed to correctly interpret the convention.

7.5.2 The same symbol appears more than once, representing different entities

Half-shaded shapes representing the Earth and the Moon

Learners had to realize that the larger half-shaded circle at the centre of the diagram represented the Earth, while the smaller half-shaded circles with arrows in-between represented the Moon.

I used Diagram 21a to investigate learners' interpretation of this convention. Eight learners correctly interpreted the Earth and the Moon in this diagram. As a result, they are considered to have correctly interpreted the convention. One learner (Lehana) correctly interpreted the Moon but not the Earth. It is difficult to ascertain his ability to interpret this convention.

One other learner (Makalo) appeared to be confused. He interpreted the larger circle as representing the Earth, but interpreted the smaller circles as the Moon, the Earth, or the planets. It appears that he somewhat interpreted the shapes as representing the same entity (Earth), as he mentioned Earth for the larger and the smaller circles. Also, he appeared to interpret the circles as representing different entities, as he said that the smaller (and not larger) circles represented the Moon or planets. These responses show that he was somewhat unable to interpret this convention.

Arrows representing directions of the Sun's rays and the Moon's orbit

Learners had to realize that parallel arrows represented the Sun's rays while curved arrows (between the moon shapes) indicated the direction of the Moon's orbit.

I used Diagram 21a to investigate learners' interpretation of this convention. Eight learners correctly interpreted parallel arrows as representing the Sun's rays and the curved arrows as representing the direction of the Moon's orbit. Thus, they correctly interpreted this convention. One learner (Makalo) correctly interpreted parallel arrows as representing the Sun's rays and interpreted the curved arrows as indicating the direction of the Moon's rotation. However, he got confused as to whether the shapes represented the Moon or the Earth or the planets. Despite this confusion, he interpreted these arrows to indicate the direction of the Moon's orbit. Thus, he is considered to have been able to interpret the convention. Another learner (Lisebo) correctly interpreted the curved arrows as indicating the direction of the Moon's orbit, but she did not know what the parallel arrows represented. It becomes difficult to ascertain whether she was able to interpret this convention.

These responses indicate that the learners were able to interpret the arrows in this diagram. It is possible that the learners were able to interpret this convention because the diagram provided enough information for interpretation of the arrows. Literature shows that learners correctly interpret arrows in well designed diagrams. For example, nine out of ten learners correctly interpreted arrows in a well designed diagram illustrating food web in Khanyane's (2002) study. However, only six out of ten learners correctly interpreted arrows in a diagram illustrating sections of a plant in the same study. The latter diagram had no hints helping learners to interpret the

arrows. This might explain why a number of learners failed to interpret arrows in the diagram illustrating sections of a plant. In another study, Stylianidou et al. (2002) found that several learners had a problem of interpreting arrows when the arrows represented different entities. However, Stylianidou et al. realized that the meaning of the arrows was not clear in the diagram.

7.5.3 Different symbols represent the same entity as it changes shape

Learners had to realize that the shapes in Diagram 21b represented the same entity (the Moon) as it changes shape over time.

All learners correctly interpreted the shapes as illustrating the changing appearance of the Moon. This includes Motena who first thought that the shapes illustrated a solar eclipse, but later realized that the shapes represented changes in the appearance of the Moon. All these learners are considered to have correctly interpreted the convention.

7.5.4 Summary of learners' interpretation of conventions

Table 7.8 summarizes learners' interpretation of the three conventions.

Table 7.8 Learners interpretation of three conventions used in Diagrams 21a and 21b

Learners	same symbol appearing more than once showing different entities		same symbol appearing more than once, representing one entity changing position	Different symbols representing the same entity changing shape
	Earth and Moon	arrows		
Lisebo	✓	?	✓	✓
Lehana	?	✓	✓	✓
Makalo	✗	✓	✗	✓
Motena	✓	✓	✓	✓
Karabo	✓	✓	✓	✓
Seboka	✓	✓	✓	✓
Fumane	✓	✓	✓	✓
Masilo	✓	✓	✓	✓
'Mamosa	✓	✓	✓	✓
Selomo	✓	✓	✓	✓

The table shows that five high spatial-ability learners and two low spatial-ability learners correctly interpreted all the three conventions used in Diagrams 21a and 21b. Two low-spatial ability learners each correctly interpreted two conventions, but could not be assessed on the third convention because they provided insufficient information. One learner (Makalo) correctly interpreted one component of the first convention, failed to interpret the second convention, but correctly interpreted the third convention.

In summary, there appears to be a very weak link between learners' spatial ability and interpretation of conventions used in these diagrams, as all learners generally interpreted the conventions correctly. That is, no remarkable difference is seen between the low spatial-ability learners and the high spatial-ability learners about interpretation of these conventions.

7.6 Lunar phase determination

The purpose of this section was to investigate learners' ability to determine the shape of the Moon seen from earth as the Moon orbits the Earth. I used the following criteria to select moon phases for this purpose.

- I used all phases: New Moon, a crescent-moon phase, a quarter-moon phase, a gibbous-moon phase, and Full Moon.
- The selection included phases at the waxing and waning stages.
- The phases were selected so that learners would imagine looking towards the left-hand side, the right-hand side, the top, and the bottom of Diagram 21a using the earth shape as a reference point.

Table 7.9 indicates the phases that were selected, and location of the Moon relative to the Earth during each phase.

Table 7.9 Selected moon phases, and location of the Moon relative to the Earth during each phase

Moon phase	Stage	Location of the Moon relative to the earth shape
New Moon	New	Left
First Quarter	Waxing	Bottom centre
Full Moon	Full	Right
Waning Gibbous	Waning	Top right
Waning Crescent	Waning	Top left

Accurate determination of the Moon's shape required learners to find out (a) the fraction of the lit surface of the Moon facing the Earth, (b) the shape of this fraction as seen from the Earth, and (c) side of the Moon not visible to earth viewers during each phase. Table 7.10 illustrates these issues for the five selected phases.

Table 7.10 Side of the Moon not visible to Earth viewers during five of the phases illustrated on Diagram 21b (Figure 7.2)⁸

Phase of the Moon	Fraction of the unlit surface facing Earth	Fraction of the illuminated Surface facing Earth	Side of the Moon not visible to earth viewers	
New Moon	The entire surface	None	The entire surface	
First Quarter	Half	Half	Left-hand side	
Full Moon	None	The entire surface	None	
Waning Gibbous	Less than half	More than half	Right-hand side	
Waning Crescent	More than half	Less than half	Right-hand side	

This part of the interview consisted of two sections; Section 7.6.1 in which learners responded by making drawings, and Section 7.6.2 in which learners responded by selecting shapes cut out from Diagram 21b.

7.6.1 Drawing phases of the Moon

Each learner was shown Diagram 21a while Diagram 21b was hidden away. They were asked to imagine being at the centre of the earth shape, i.e. at the intersection of the equator and the terminator line (the terms ‘equator’ and ‘terminator line’ were not used, but learners’ attention was drawn to this point). I preferred the centre because it is the only point from which viewers on the earth shape could see the Moon in all the eight positions (the Earth would obscure viewers from seeing the Moon in certain positions if a different location was used as a reference point).

The learners were asked to draw what they thought the Moon would look like in each of the selected five positions as seen from the Earth. Learners’ attention was directed to the moon shape in each of the five positions, but the names of these phases were not used during interviews (interview excerpts clarify this). For most learners, the phases were approached in this order: Waning Gibbous, First Quarter, Waning Crescent, New Moon and Full Moon. However, some learners used a different order (as the interviews were only semi-structured, and therefore allowed some freedom to the learners).

N.B.: One learner (Karabo) indicated that she would prefer to select shapes from Diagram 21b. As a result, she did not participate in the drawing phase of the interview.

⁸ Diagram 21b illustrates phases of the Moon as seen from the northern hemisphere. As a result, this table shows the moon shapes as seen from this hemisphere. Section 4.3.2 (pp 86-87) shows that the shapes would face the opposite direction if viewed from the southern hemisphere.

Waning Gibbous

Learners were instructed to imagine being at the centre of the earth shape looking at the moon shape located in Waning Gibbous position (their attention was drawn to this shape). They were asked to draw what they thought the Moon would look like as seen from the earth shape.

Only three learners appeared to have correct ideas about appearance of the Moon in this position.

- Selomo said that more than half of the Moon would be seen from earth during this phase, as illustrated in the following extract.

R: alright. I want you to imagine standing here on earth (*pointing at the centre of the earth shape*), and you are looking at this moon (*pointing at the moon shape in Waning Gibbous position*)

Selomo: ja

R: what do you think you would see, what would the Moon look like to you?

Selomo: it would look like (*he drew a shape*)

R: you see this is the shape that I'm asking you about, so I'd like you to write one (1) there

Selomo: (*he drew a gibbous-like shape, and then shaded a small section that would represent part not visible from earth.*)

R: this would be the (*referring to the shaded section of the shape he had drawn*)

Selomo: this will be the part that will be blocked out

R: can you write that

Selomo: (*he labelled the shaded section as "part that is dark"*)

R: alright, how did you get this answer?

Selomo: because when the Sun shines from this way (*moving his hand from the Sun's rays to the moon shape*), the Moon will be caught from right here (*pointing at the section of the Moon that can be seen from the earth shape*), catch sort of, just a little bit, because it's not exactly

R: remember we're looking at that moon (*pointing at the moon shape in Waning Gibbous position*) and you are here (*centre of the earth shape*)

Selomo: we would see that part there (*moving a pen to show the part of the Moon that can be seen from earth*), but little bit will be dark (*pointing at the black part on the section he says can be seen from the Earth*), and the rest of the Moon will shine

R: you know what, you moved your hand. Can you show us the part that you think will be seen as light and the part that will be seen as dark?

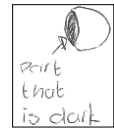
Selomo: as light?

R: yes

Selomo: from right here (*he made a curved line on the Waning Gibbous moon shape, which includes a large white section and a smaller dark section*)

R: and the other one will be seen as dark

Selomo: yes



The above extract shows that Selomo attempted to draw a gibbous moon shape. However, he drew a shape in which the terminator line extends into the Moon instead of extending out of the Moon, a shape referred to by Bell & Trundle (2008) as a 'false gibbous'. Several participants drew this shape when asked to illustrate the sequence of moon phases by Bell and Trundle (2008) and Subramaniam and Padalkar (2009). These drawings suggest that some people have inaccurate conceptions about the shape of a gibbous moon, or have poor observation skills if they ever observe the Moon in the sky (as suggested by Wilhelm et al., 2008).

Selomo drew a shape in which the non-visible side of the Moon is on the left-hand side instead of being on the right-hand side (see Table 7.10 for the appropriate shape). The diagram illustrates moon phases as seen from the northern hemisphere, suggesting that all users of the diagram deal with moon phases from this hemisphere (in which the non-visible side of the Moon is on the right-hand side during the waning gibbous phase). People who use this diagram cannot draw moon phases as seen from the southern hemisphere. Drawing a ‘false gibbous’ facing the wrong direction suggests that Selomo was able to determine the shape of the Moon, but failed to determine the direction in which the gibbous moon would face.

- Masilo said that more than half of the Moon would be seen from Earth. Like Selomo, he failed to draw a correct gibbous shape. He drew a shape that is more than half, but not gibbous-shaped (see Table 7.12, p188).
- 'Mamosa's ideas about appearance of gibbous moon changed during the course of the interview. First she thought that the Moon would be crescent-shaped during both crescent and gibbous phases, as illustrated by her drawings in Sketches 1-to-4 in Table 7.11.

Table 7.11 'Mamosa's ideas about crescent and gibbous phases

Sketch 1	Sketch 2	Sketch 3	Sketch 4	Sketch 5	Sketch 6
Waxing Crescent	Waning Gibbous	Waxing Gibbous & Waning Gibbous	Waxing Crescent & Waxing Gibbous	Waxing Gibbous & Waning Gibbous	Waning Gibbous & Waning Crescent
					Confused

However, when asked to explain her drawing in Sketch 4, she said that a small portion of the Moon would be visible from Earth during the crescent phase while more than half would be visible during the gibbous phase. When asked to draw the appearance of the Moon during the two gibbous phases, she drew shapes illustrated in Sketch 5, and said that they represented shapes that are more than half (she appears to have drawn ‘false gibbous’ shapes, which means that she attempted, but failed to draw correct shapes). When asked to draw the appearance of the Moon during Waning Gibbous and Waning Crescent phases, she said that she was not sure whether she would see the same or different shapes. Thus, at some stage she realized that more than half of the Moon would be visible from Earth during the Waning Gibbous phase.

Drawings made by the remaining six learners indicate that they failed to determine the appearance of the Moon during this phase. The following extract illustrates an example of their responses.

R: alright. Let's go back to our first diagram (*Diagram 21a*). Now I'm going to ask you to do some little bit of imagination here. I want you to imagine that you were to stand here at the centre of the Earth where I'm making x,

Fumane: okay

R: and you were looking at this moon (*pointing at the moon shape in Waning Gibbous position*). I'd like you to tell me what you think you would see. Here are the Sun's rays, there is the Earth, the Moon is in that position.

Fumane: I'd see the sunlit side of the Moon.

R: how would it appear to you? Can you draw that?

Fumane: (*she wrote "I would see the sunlit surface of the Moon" and then asked*) must I draw what I would see?

R: try to draw it if you can

Fumane: (*she drew a circle*) it would be a normal circle, it would be white

R: it would be?

Fumane: it would be like this part (*pointing at the non-shaded part of the Moon*), sunlit it would be white.

R: a normal circle that would be white?

Fumane: ja, like if I'm standing here (*centre of the Earth*), and I'm looking straight ahead (*moving her hand from the earth shape to the moon shape in Waning Gibbous position*), I won't be able to see the dark part because of the angle.

R: alright

Fumane: so it'll just be white, it won't be shaded from the point that I look at it

Table 7.12 illustrates the shapes drawn by the learners.

Table 7.12 Learners' drawings of a shape seen from Earth during the Waning Gibbous phase

Learners	Learners' Drawings	Black/white colours Facing Earth	Moon shape	Side of the Moon not visible to Earth viewers
Lisebo		×	×	×
Lehana		×	×	×
Motena		×	×	×
Makalo		×	×	×
Karabo	N/A	N/A	N/A	N/A
Seboka		×	×	×
Fumane		×	×	×
Masilo		✓	×	×
'Mamosa		✓	×	×
Selomo		✓	×	×

The table shows that only three learners who had the highest spatial ability scores correctly determined the fraction of the illuminated surface of the Moon facing Earth. However, these learners failed to determine the shape of the Moon as seen from the earth shape in the diagram. The table further shows that six learners failed to determine the fraction of the lit surface of the Moon

facing Earth, and the shape of this surface. Consequently, they could not determine the side of the Moon that is not visible to earth viewers during this phase.

First Quarter

Learners were asked to imagine being at the centre of the earth shape looking at the moon shape in First Quarter position. They were asked to draw what they thought the Moon would appear to be like as seen from the Earth shape. Only one learner (Lisebo) drew a wrong shape (i.e. a shape other than half).

R: okay, let's take this as our second position (pointing at the moon shape in *First Quarter position*), you're still standing on earth. Draw just what you think you would see

Lisebo: I'd see that half (*drawing a shape illustrated on the right hand side*). This half over here

R: you'd see which half

Lisebo: this half (*her hand obscured the camera from seeing the half*)

R: oh you'd see that half

Lisebo: yes



She said that she would see half of the Moon, but she did not state what the half would appear to be like to her. She drew a shape other than half, suggesting that she failed to determine the appearance of the Moon during this phase.

Eight learners drew half-moon shapes, suggesting that they were able to determine fraction of the illuminated surface of the Moon visible from earth, and the shape of this surface as seen by viewers on earth. However, only one of these learners (Lehana) drew a half Moon correctly indicating the side of the Moon that is not visible to earth viewers.

R: okay, you are still in that position on earth (*pointing at the centre of the earth shape*) and you are looking at this moon (*pointing at the moon shape in First Quarter position*). What do you think you would see?



Lehana: maybe this as well (*drawing a half moon similar to one he had drawn earlier*)

R: maybe that as well

Lehana: yes

Analysis of his drawings shows that he drew the same shape for all the five phases (see Table 7.16, p 194), and he could not explain why the Moon would appear to be the same in all the five phases. This suggests that his correct shape for the First Quarter phase might have been some guesswork.

Table 7.13 shows that of the remaining seven learners, six drew the half moon as seen from the diagram-viewer perspective, not from the earth shape illustrated on the diagrams. Thus, they failed to determine the side of the Moon that is not visible to earth viewers during this phase, regardless of spatial ability skills. It is notable that the shapes drawn by the six learners are somewhat similar to the shape of the “First Quarter” phase seen in the southern hemisphere sky. However, it should be borne in mind that the name “First Quarter” was not used in the interview. As a result, learners with poor background knowledge in phases of the Moon are less likely to have known that the Moon in this position represented the First Quarter phase. The results suggest, therefore, that the

learners failed to perform mental rotations needed to imagine looking at the moon shape located at the bottom of the page, using the earth shape as a reference point.

Table 7.13 Learners' drawings of the shape visible from Earth during the First Quarter phase

Learners	Learners' Drawings	Black/white Facing Earth	Moon shape	Side of the Moon not visible to earth viewers
Lisebo		×	×	×
Lehana		✓	✓	✓
Motena		✓	✓	×
Makalo		✓	✓	×
Karabo	N/A	N/A	N/A	N/A
Seboka		✓	✓	×
Fumane		✓	✓	×
Masilo		✓	✓	×
'Mamosa		✓	✓	×
Selomo		✓	✓	×

Waning Crescent

Learners were asked to imagine being at the centre of the earth shape looking at the moon shape located in a Waning Crescent position, and to draw what they thought the Moon would appear to be like as seen from the earth shape. Four high spatial-ability learners appeared to have some correct ideas about the appearance of the Moon during this phase.

- Selomo and Masilo drew crescent shapes correctly indicating side of the Moon that is not visible from earth. They are the only learners who completely determined the appearance of the Moon during this phase. The following extract illustrates an example of their responses.

R: alright that is your third diagram (pointing at *the moon shape in the Waning Crescent position*)

Masilo: (he drew a crescent-shaped moon, facing the correct direction)

R: and your answer again is going to be

Masilo: it's a quarter I think



- 'Mamosa realized that less than half of the Moon would be seen from earth during this phase, and she was able to draw the shape of the Moon, but she missed the direction this moon had to face as seen by viewers in the northern hemisphere (as discussed in Table 7.11).
- Seboka said that a small portion of the Moon would be visible from Earth during this phase, but he failed to draw a crescent shape.

The remaining five learners failed to determine the shape of the Moon seen from earth during this phase. The following extract illustrates a sample response from these learners.

R: alright we are here (pointing at the *moon shape in Waning Crescent position*). This is the next one.

Motena: (she drew a half moon again saying) it'll be the same

R: can you explain that to me?

Motena: no sorry it won't, can I (she attempted to cancel her drawing)

R: no you don't cancel this you draw again

Motena: okay (she drew a vertical line) that's what I would see

R: okay

Motena: because the light is shining on this part (pointing at the *illuminated half of the Moon in this position*), but I'm standing here (pointing at the *centre of the earth shape*) so I can't really see what shape it is (moving a pen on the curved line that forms the outside boundary of the white section of the Moon) so I'll see the line (pointing at the *terminator line*), I'll see the straightness of it.



Table 7.14 illustrates learners' drawings of the Waning Crescent moon.

Table 7.14 Learners' drawings of a shape visible from Earth during the Waning Crescent phase

Learners	Learners' Drawings	Black/white Facing Earth	Moon shape	Side of the Moon not visible to earth viewers
Lisebo		×	×	×
Lehana		×	×	×
Motena		×	×	×
Makalo		×	×	×
Karabo	N/A	N/A	N/A	N/A
Seboka		✓	×	×
Fumane		×	×	×
Masilo		✓	✓	✓
'Mamosa		✓	✓	×
Selomo		✓	✓	✓

The table shows that learners with high spatial ability generally performed better in this phase, than learners with low spatial ability.

Full Moon and New Moon

Learners were asked to imagine being at the centre of the earth shape looking at the Moon in New Moon phase, and to draw the shape they thought they would see. After this, they were asked to do the same for the Moon in Full Moon position.

All the high spatial-ability learners drew a complete circle to represent appearance of the Moon during the Full Moon phase. For New Moon, three of these learners drew a shaded circle saying that the viewers on Earth cannot see the Moon. The remaining two learners made no drawings, but said that the Moon would not be visible from earth. The following extract illustrates a sample response from these learners.

R: ... Then this will be our fourth position (*pointing at the moon shape in New Moon position*)

Fumane: it will be the same as number three

R: alright

Fumane: (*she drew a shaded circle writing "won't see the moon", and also writing these words near the shape drawn for Waning Crescent position*)

R: and can you tell us why you think so

Fumane: you don't get a black moon

R: you don't get a black moon?

Fumane: so you won't be able to see it

R: alright, and that (*pointing at Full Moon position*)

Fumane: this one (*pointing at Full Moon position*)

R: yes, this is our fifth position

Fumane: (*she drew a non-shaded circle*) ... because it's light, its Sun shining on, so it'll be visible.



These responses suggest that the learners were able to determine the amount of the sunlit surface of the Moon visible from the earth shape during the Full Moon and New Moon phases. On the contrary, none of the low-spatial ability learners correctly determined the appearance of the Moon from Earth during these phase, as exemplified by the following extract.

R: alright. Let's take this as our diagram number four (*pointing at the New Moon position*), position number four, and draw for me what you think you would see. You are standing here (*pointing at the centre of earth shape*) looking at this position number four.

Makalo: (*silent*)

R: tell me what you are thinking

Makalo: I'll be able to see this (*pointing at the black part of the Moon*)

R: please draw that for me

Makalo: I'll be able to see this part over here, with the shaded area (*he drew a shaded half moon similar to one he'd drawn for Waning Gibbous*)

R: because?

Makalo: because if I stand here I can't see what's behind

R: let's take this one (*Full Moon*) as the last

Makalo: I'll look at this as the white part first

R: draw only what you think you would see



Makalo: (he drew a non-shaded half moon, similar to the shapes he'd drawn for Waning Gibbous and First Quarter, i.e. what appears to be a Last Quarter moon)

R: alright you would see this

Makalo: yes

R: because

Makalo: if I stand over here, it's exactly like number four (referring to New Moon) I won't be able to see that shaded area I'll only see what's on this side.



Table 7.15 illustrates learners' responses for these two phases of the Moon.

Table 7.15 Learners' drawings of shapes visible from Earth during New Moon and Full Moon phases

Learners	New Moon			Full Moon		
	Learners' Drawings	Black/white facing earth	Moon shape	Learners' drawings	Black/white Facing earth	Moon shape
Lisebo		×	×		×	×
Lehana		×	×		×	×
Motena		×	×		×	×
Makalo		×	×		×	×
Karabo	N/A	N/A	N/A	N/A	N/A	N/A
Seboka		✓	✓		✓	✓
Fumane		✓	✓		✓	✓
Masilo	Not visible	✓	✓		✓	✓
'Mamosa	Not visible	✓	✓		✓	✓
Selomo		✓	✓		✓	✓

Summary of learners' drawings

Table 7.16 illustrates drawings made by the learners while Table 7.17 summarises information illustrated in Table 7.16. The two tables show that the majority of learners failed to determine fraction of the Moon visible from earth during several phases of the Moon. Colin et al. (2002) found a similar problem in a study involving 34 high school students. They presented the students with a diagram illustrating the Sun's rays approaching the planet Jupiter, and asked them to explain why two regions on the planet could not be seen from the earth shape on their diagram. Only four learners gave correct explanations. Thus Colin et al.'s results corroborate findings made in the current study which show that some high school learners struggle to explain why certain regions of an illuminated planet cannot be seen from Earth.

Table 7.16 Illustration of shapes drawn by the learners

Learners	Waning Gibbous 	First Quarter 	Waning Crescent 	New Moon 	Full Moon 
Lisebo					
Lehana					
Motena					
Makalo					
Karabo	N/A	N/A	N/A	N/A	N/A
Seboka					
Fumane					
Masilo				Not visible	
'Mamosa				Not visible	
Selomo					

Table 7.17 Frequency of moon shapes drawn by the learners⁹

Learners		Frequency of shapes				
		Crescent	Half	Gibbous	Circle	Other
5	Lisebo	0	2	0	0	3
1	Lehana	0	5	0	0	0
10	Motena	0	1	0	0	4
4	Makalo	0	5	0	0	0
9	Karabo	N/A	N/A	N/A	N/A	N/A
6	Seboka	1	1	0	2	1
7	Fumane	0	1	0	4	0
2	Masilo	1	1	0	1	1
8	'Mamosa	2	1	0	1	0
3	Selomo	1	1	1	2	0

⁹ I have arranged the learners from top to bottom according to spatial ability test scores. Numbers in the first column indicate the order in which learners were interviewed. That is, Lehana was the first to be interviewed while Motena was the last to be interviewed.

The nature of shapes drawn by the learners

Low spatial-ability learners: None of these learners drew a crescent shape, a complete circle or a gibbous shape. Lehana and Makalo drew half-moon shapes only. These drawings seem to suggest that Lehana and Makalo drew the Moon as seen from the diagram-viewer perspective, not as seen from the earth shape (the Moon would take other shapes if perceived from the earth shape). This in turn suggests that Lehana and Makalo failed to perform mental rotations needed to imagine looking at the Moon using the earth shape as a reference point. Lisebo drew two half-moon shapes and three shapes that are difficult to classify. Her reasoning could not explain why the Moon would appear to be as she had drawn in the three shapes. It appears as if she was confused.

Motena drew one half-moon shape and four unclassifiable shapes. When drawing moon appearance for Waning Gibbous and Full Moon phases, she said that she would see the curved side of the illuminated half of the Moon, and she drew curved lines facing the right-hand side as a result of this. When drawing moon shapes for Waning Crescent and New Moon positions, she said that she would see the vertical line making the dark/light interface (i.e. the terminator line), and she drew vertical lines as a result of this. Her drawings seem to suggest that she failed to imagine the Moon as a spherical object. If she imagined the spherical moon, she would not see the terminator line during New Moon because the black side of the Moon would obscure parts of this line. In the same way, she would not see a curved line during Full Moon.

High spatial-ability learners: Each learner drew a half-moon shape and at least one circle. Four of these learners each drew a crescent shape, and one of the four learners drew a gibbous shape. The following issues observable from learners' drawings need some special attention: Seboka's unclassified shape was his attempt to draw a crescent shape while Masilo's unclassified shape was his attempt to draw a gibbous shape. Fumane drew four circular shapes in an attempt to illustrate the appearance of the Moon during New Moon, Full Moon, Waning Crescent and Waning Gibbous. She said that she would see a black circle during New Moon and Waning Gibbous phases, and further said that she would see a white circle during Full Moon and Waning Gibbous phases. These responses suggest that she failed to realize that portion of the black half of the Moon faces the Earth during Waning Gibbous, and that portion of the white half of the Moon faces Earth during Waxing Crescent.

In summary, low spatial-ability learners struggled to determine the shape of the Moon seen from Earth during the five moon phases, while high spatial-ability learners correctly determined the appearance of the Moon during two phases and struggled to determine the appearance of the Moon during three phases. These results somewhat indicate a link between spatial ability and learners' ability to determine shape of the Moon seen from earth illustrated in diagrams illustrating the Earth-Moon-Sun system. Such a link supports findings showing that spatial ability correlates with learners' understanding of astronomy concepts (e.g. Black, 2005 and Rudmann, 2002).

Correctness of learners' drawings: I use the following criteria to evaluate correctness of learners' drawings. I consider a response to be

- ^ **Correct** if a learner correctly determined the shape of the Moon visible from earth, and the side of the Moon that is not visible to earth viewers during each phase¹⁰.
- ^ **Partially correct** if a learner correctly determined fraction of the Moon visible from Earth, and the shape of this fraction, but failed to determine the side of the Moon that is not visible to earth viewers.
- ^ **Wrong** if a learner failed to determine the fraction of the Moon visible from Earth, the shape of the Moon and the side of the Moon that is not visible to earth viewers.

Table 7.18 illustrates correctness of learners' drawings.

Table 7.18 Summary illustrating correctness of learners' drawn responses

Learners		Number of wrong Responses	Number of partially correct responses	Number of fully correct responses
5	Lisebo	5	0	0
1	Lehana	4	0	1
10	Motena	4	1	0
4	Makalo	4	1	0
9	Karabo	N/A ¹¹	N/A	N/A
6	Seboka	1	2	2
7	Fumane	2	1	2
2	Masilo	0	2	3
8	'Mamosa	0	3	2
3	Selomo	0	2	3

Each learner failed to draw at least one phase correctly. This supports results of previous studies in which participants drew 'non-scientific' shapes when asked to draw moon shapes they expected to see when making daily moon observations (e.g. Bell & Trundle, 2008; Trundle et al., 2007b; Wilhelm et al., 2008). The learners who participated in the current study drew wrong shapes despite having seen correct moon shapes while interpreting Diagram 21b. This suggests that the learners had poor background knowledge and/or personal experience of the shapes so that they could not draw accurate shapes. The following trends are observable from Table 7.18.

¹⁰ Table 7.10 illustrates the side of the Moon that is not visible to Earth viewers during each of the five moon phases.

¹¹ Karabo declined to draw her responses. Instead, she asked for permission to select answers from the cut-out moon shapes (as discussed in Section 7.6.1, p 185). Thus, she did not participate in the drawing phase of the interview.

- ▲ *Low spatial-ability learners:* Each of the four learners made five drawings, which resulted in 20 drawings. Table 7.18 shows that in total, these learners made one fully correct drawing, two partially correct drawings, and seventeen wrong drawings.
- ▲ *High spatial-ability learners:* Three of these learners made five drawings each, while two learners each made four drawings and gave a verbal response. This resulted in 23 drawings and two verbal responses, i.e. 25 responses. Table 7.18 shows that in total, these learners gave 12 fully correct responses, 10 partially correct responses and three wrong responses.

These results indicate that high spatial-ability learners were better able to determine the appearance of the Moon from earth, than low spatial-ability learners.

Phases of the Moon by difficulty: Table 7.19 illustrates phases of the Moon by difficulty, starting with the shape whose determination appeared to be easy for the learners, ending with the one whose determination appeared to be the most difficult for the learners.

Table 7.19 Phases of the Moon by difficulty, from the easiest to the most difficult

Moon phases	Number of learners who correctly determined fraction of the white/black portions of the Moon facing earth	Number of learners who correctly determined shape of the Moon seen from earth	Number of learners who correctly determined the side of the Moon that is not visible to earth viewers
First Quarter	8	8	0
New Moon	5	5	-
Full Moon	5	5	-
Waning Crescent	4	3	2
Waning Gibbous	3	1	0

The table shows that First Quarter was the easiest phase to determine, where eight learners (five with high spatial ability and three with low spatial ability) realized that half of the Moon would be seen from earth, even though none correctly determined the side of the Moon that is not visible to earth viewers. During this phase, the non-visible part of the Moon appears to be on the left-hand side as illustrated on the diagram, but appears to be in the right-hand side as seen from the earth shape drawn on the diagram. Drawing a half-moon facing the wrong direction suggests that the learners failed to change perspectives in order to imagine looking at the Moon from the earth shape.

The table further shows that only five learners correctly determined the shape of the Moon visible from Earth during Full Moon and New Moon phases. All these were high spatial-ability learners. In addition, the table shows that few learners determined fraction of the Moon visible from Earth during crescent and gibbous phases. Again, all these were high spatial-ability learners. However, only two correctly determined the direction the crescent would face, and none correctly determined the direction the gibbous would face. These results indicate that in general, learners encountered

more problems with crescent and gibbous phases than other phases of the Moon. These results indicate, however, that high spatial-ability learners performed better than low spatial-ability learners in determination of moon shape during these phases.

The semi-structured nature of interviews conducted in the current study allowed the learners to draw different shapes, many of which were incorrect. This is in agreement with Vosniadou et al.'s (2004) claim that open-ended questions allow learners to give a variety of responses, some of which are not correct, contrary to forced-choice questions which bias learners' responses towards scientifically acceptable ideas. In fact, learners who participated in Vosniadou et al.'s (2004) study gave more scientifically acceptable responses about the shape of the Earth when presented with a globe, than when answering without the globe.

7.6.2 Selecting phases of the Moon

The purpose of this part of the interview was to investigate whether the cut-out moon shapes¹² would help the learners to determine the shape of the Moon seen from the Earth during the five phases discussed in Section 7.6.1. For all interviews, the cut-out moon shapes were arranged in this order:



Figure 7.3 Arrangement of cut-out Moon shapes during interviews

Each learner was asked to imagine being at the centre of the earth shape looking at the Moon in each of the five positions discussed in Section 7.6.1, and to select a shape which they thought represented appearance of the Moon during each position (the moon would appear to take the following shapes: Waning Gibbous, First Quarter, Waning Crescent, New Moon and Full Moon). Again, learners' attention was drawn to positions of the Moon in the orbital path, but the names of moon phases were not used. The following results were obtained from learners' responses.

Waning Gibbous

Six learners selected non-gibbous shapes: three selected half-moon shapes while the other three selected crescent shapes. The following extract illustrates a sample response from these learners.

R: alright, let's come back to this diagram. Now I'm going to ask you to do one simple thing. I'm going to ask you to imagine standing here on earth; these are the Sun's rays (*pointing at the four arrows*), this is you on earth (*pointing at the centre of the earth shape*), these are the moons, I want you to consider this first moon (*pointing at the moon shape in Waning Gibbous position*); if you stood here (*centre of the earth shape*) and the Sun was coming from this side, and you looked at this moon, how would the Moon appear to be like to you?

Karabo: not very clear

R: mmmm

¹² These shapes were cut out from Diagram 21b as discussed in Section 3.6.2 (page 77)

Karabo: but I could see a bit of sunlight because of the light that's coming from the back

R: okay, let's do it this way, here they are (*revealing the cut-out moon shapes*) you are here looking there

Karabo: okay, light rays come from this side; mmmmm, I think I'd see probably that one (*selecting a cut-out Waxing Crescent shape*)

R: okay, can you tell me why you think so?

Karabo: because there's light rays coming from the back (*moving a hand from the arrows representing the Sun's rays towards the earth shape*), and I'm standing here facing there (*moving the hand from the earth shape towards the moon shape in Waning Gibbous position*); so these light rays will help me to see a bit but not much

Selection of the non-gibbous shapes suggests that the six learners failed to determine the shape of the Moon visible from earth during this phase.

One learner selected a Waxing Gibbous shape as exemplified by the following extract.

R: I want you to look at those shapes. Let's go back to the beginning, and you stand here (*the earth shape on Diagram 21a*). If I say to you when you look at the Moon in this position (*Waning Gibbous position*) you would see one of these shapes, which one do you think it would be?

Lehana: this one (*selecting the Waxing Gibbous moon shape*)

R: why?

Lehana: because it's also a D shape but it's higher, it's up

R: what do you mean?

Lehana: (*he was silent*)

R: u ka e hlalosa ka Sesotho, [*can you explain it in Sesotho*]?

Lehana: ha ke le tlase moo (*pointing at the earth shape*) ke e shebetse holimo akere? [*When I am down here (pointing at the earth shape) it appears to be above me, right?*]

R: Okay

Lehana: ha ele holimo joalo ha ke no bona, D eo ha e no hlaha seka ha e hlahile mona (*pointing at New Moon*) o tlo hlaha a se a kh'athehile [*when it is above me I won't see, the D won't appear like it appears here (pointing at New Moon), it will appear to be cut*].

R: okay, let's see, show me here (*pointing at the Moon in the Waning Gibbous position*), which section will appear to be cut?

Lehana: this section (*moving a hand as if to indicate the dotted line inside the moon shape*)

He got stuck when trying to justify his selection of a Waxing Crescent Moon shape. It was not clear whether he did not have a reason for selecting the shape, or whether he had encountered language problems. I asked him to explain in Sesotho language to eliminate a possible problem of language articulation, and this seemed to help because he gave further explanation about his selection of the shape. Selection of a Waxing Crescent shape suggests that he failed to determine the shape of the Moon visible from earth during this phase (the Moon would appear to be a Waning Gibbous).

Only three learners selected the gibbous shape that correctly indicated the side of the Moon that is not visible to earth viewers during this phase. These learners had the highest spatial-ability skills. The extract from Selomo's response illustrates a sample of these responses.

R: you know what, I have these shapes here (*referring to the cut-out moon shapes*), I'd like you to look at them. Alright here is the first one, this position (*pointing at the moon shape in the position of Waning Gibbous in the diagram*). So which of these have you drawn (*referring to the cut-out moon shapes*)?

Selomo: (*he selected a Waxing Gibbous*)

R: you have not drawn this one (*Waning Gibbous*)?

Selomo: (*he attempted to select Waning Gibbous*)

R: wait, take your time and choose the one you think it's going to be

Selomo: (*he looked at them for a while and then selected a Waning Gibbous cut-out moon shape*)

R: why

Selomo: because the Sun will be shining this way (*moving a hand from the arrows representing the Sun's rays towards the Waning Gibbous moon shape on the diagram*) so just that part of the Moon will be in the dark, we'll see most of the Moon

The three learners had drawn partly correct shapes earlier in the interview (see Section 7.6.1, Page 188). It appears that the presence of cut-out moon shapes enabled them to determine the appearance of the Moon during the Waning Gibbous phase.

First Quarter

Learners were asked to select a shape that they would see if they were standing on the earth shape looking at the Moon in the First Quarter position. Six learners selected wrong shapes. Two of these learners (Lisebo and Karabo) selected a Waning Gibbous shape. This response suggests that they failed to determine the shape of the Moon that would be seen from the earth shape. This response further suggests that the presence of cut-out moon shapes did not help them to determine fraction of the Moon visible from the earth shape during this phase. Lisebo's response requires special attention. First she selected a Waning Gibbous cut-out moon shape, but changed her mind saying that the appropriate shape was not among the eight cut-out moon shapes. The following extract illustrates her response.

R: alright. And this was our second one (*pointing at the moon shape in First Quarter position*)

Lisebo: this one (*selecting a cut-out Waning Gibbous*)

R: the Moon would appear to be like that?

Lisebo: ja, no, I don't know. You don't have the one that would go like that in your diagram here (*pointing at the cut-out moon shapes*)

R: so the right one is not here?

Lisebo: yes the one I'm thinking of

R: that's okay; I'm going to ask you to draw it somewhere on the page

Lisebo: (*she drew a circular shape and made a curved line in the circle saying*) I'd see this half

R: you know there's two things here, there's one half above and one half below. Show me, which half would we see?

Lisebo: the one above, this one (*writing 'above' on this part*)



Saying that she would see the top half of the Moon suggests that she imagined looking at the Moon using the earth shape as a reference point (since the Earth is above the First Quarter moon position on the page), which further suggests that she was able to change her orientation on paper. Selection

of a gibbous and then saying that the appropriate shape was not among the eight cut-out shapes suggests that she failed to determine fraction of the Moon visible from earth during this phase, and further suggests that the cut-out moon shapes could not help her determine this shape.

Four of the six learners selected a Last Quarter instead of the First Quarter shape. That is, they selected a half-moon facing an opposite direction as exemplified by the following extract.

R: ... You've chosen this (*pointing at the Waxing Crescent cut-out moon shape*) for that one (*pointing at the moon shape in Waning Gibbous position on the diagram*). And then my second one was this one (*pointing at the moon shape in First Quarter position*). Can you select the appropriate one for me?

Seboka: (*he selected the Last Quarter cut-out Moon shape*)

R: why?

Seboka: because it's half of the Moon shaded in

It is possible that these learners imagined looking at the Moon from the diagram viewer perspective (i.e. as drawn on paper) and not from the earth shape on the diagram. The shape of the Moon faces the right hand side when viewed from the earth shape.

Only four learners selected the correct shape, i.e. a half moon facing the right-hand side. Three were high spatial-ability learners while the fourth was a low spatial-ability learner. All these learners had drawn half moon shapes earlier in the interview, but only one (Lehana) had drawn the half moon facing an appropriate direction (see Table 7.13, p 190). Selection of the correct shape suggests that the cut-out shapes helped three high spatial-ability learners to determine the shape the half moon had to face.

Waning Crescent

Learners were asked to imagine being on the earth shape looking at the Moon in Waning Crescent position. They were asked to select a shape which they thought represented appearance of the Moon in this position. All the high spatial-ability learners selected the correct shape. The following extract illustrates an example of their responses.

R: so this is the first (*pointing at Waning Gibbous position*), this was our second (*pointing at the First Quarter position*), and this is our third shape of the Moon (*pointing at Waning Crescent position*)

Fumane: (*she turned the page at about 30° clockwise from the vertical, to look at the Moon in the Waning Crescent position*) I think it will be this one (*selecting the Waning Crescent cut-out moon shape*)

R: and tell me why you think so

Fumane: because if you look at it in this angle (*moving her finger from the earth shape towards the Moon in Waning Crescent position*) you'll see mostly like nothing, because it's dark, okay, but then you'd see a slightest bit of it, like at the bottom, for example like that part there (*pointing at the cut-out moon shape that she selected*) alright

Only two of the high spatial-ability learners had drawn correct shapes for this phase. This suggests that the presence of the cut-out moon shapes improved performance of the other three high spatial-ability learners.

None of the low spatial-ability learners selected a crescent shape. The following extracts illustrate some of their responses.

R: alright. I think we had our third diagram here (*pointing at Waning Crescent position*)

Lehana: it would be this one (*selecting Waning Gibbous cut-out moon shape*)

R: alright, why, I always ask why because I want to know what you are thinking.

Lehana: because it's in the same position as this one (*Waning Gibbous position*)

R: it's in the same position as this one?

Lehana: but it's just on a different side

R: okay

Lehana: so it would be the same

Another extract

R: now we have our position three here (*Waning Crescent position*). Select, we've still got our eight shapes on the table.

Makalo: can I, is it possible that I can use these again (*pointing at First and Last Quarter cut-out moon shapes*)

R: oh yes

Makalo: if I'm looking over here (*moving his hand from the earth shape towards the Moon in Waning Crescent position*) I must probably see this part first (*selecting a Last Quarter cut-out shape*)

For the low spatial-ability learners, one selected a First Quarter shape, another selected a Waning Gibbous shape, two selected a Last Quarter shape, while the fifth said that the Moon would look like any of the gibbous shapes, but she could not decide which one it would be. These results indicate that high spatial-ability learners outperformed low spatial-ability learners in determining the shape of the Moon during this phase.

New Moon

One learner (Masilo) was not asked to select a shape which would be visible during New Moon phase because his response while drawing indicated that he had a good understanding of the appearance of the Moon during this phase. Out of the remaining nine learners, five selected the correct shape (one with low spatial ability and four with high spatial ability). The following extract illustrates one of their responses.

'Mamosa: this (*Full Moon*) would definitely be this one (*selecting the cut-out Full Moon*)

R: alright, why?

'Mamosa: because the sunrays show on a circle, and, okay the sunrays, I think they show one half of the Moon, and the other half, the dark side of the Moon is behind, so you don't see the behind part of the Moon, you see the front, and I think it will be a Full Moon.

R: alright

'Mamosa: and then this one (*pointing at New Moon*) I'm starting with the easier ones

R: alright

'Mamosa: this one (*New Moon*) will be this one (*selecting the cut-out shape representing New Moon*)

R: mmmhhh

'Mamosa: because you see, you don't see anything, you just see the dark, you don't see because the sky is dark it's also dark and you see the dark side of the Moon

R: okay

'Mamosa: and the light rays are shining on the side that we don't see

R: okay

Four of the five learners had drawn the correct shape for this phase earlier in the interview, while the fifth had drawn a wrong shape. Thus, the presence of cut-out moon shapes helped one learner to realize that the Moon would not be visible from Earth during this phase.

The remaining four learners selected wrong shapes. All these learners had low spatial ability skills. The following extract illustrates one of their responses.

R: okay, and here (*pointing at the Moon in New Moon position*)?

Karabo: obviously I'd see, what's this, the Moon? (*referring to shape representing New Moon*)

R: what do you think it is?

Karabo: (*she laughed*)

R: remember I'm only trying to find out what the diagram means to you, so just tell me what you think it is.

Karabo: I think it's the Moon

R: alright

Karabo: and there's light rays coming from that side

R: mmmm

Karabo: so I'll see this one (*selecting the cut-out Full Moon*)

Selection of wrong shapes suggests that the four learners failed to realize that the Moon cannot be seen from earth during this phase.

Full Moon

Two learners were not asked about this phase; one high spatial-ability learner (Masilo) was not asked about this phase as his response while drawing moon shapes (discussed in Section 7.6.1) indicated that he had a good understanding of the appearance of the Moon during this phase, while a low spatial-ability learner (Lehana) was not asked (error made by the researcher). Out of the remaining eight learners, all four low spatial-ability learners gave wrong responses; three selected half-moon shapes while the fourth said that the Moon would be dark. On the contrary, all four high spatial-ability learners selected the correct shape. The high spatial-ability learners had drawn the correct shape of the Moon earlier in the interview (see Section 7.6.1). These results indicate that the high spatial-ability learners outperformed the low spatial-ability learners on determination of the moon shape seen from earth during this phase.

Summary

Table 7.20 illustrates shapes selected by the learners, while Table 7.21 illustrates correctness of (i) shapes selected by the learners and (ii) the side of the Moon that is not visible to earth viewers during each phase. In the latter table, a cross (✗) indicates a wrong answer while a tick (✓) indicates a correct answer.

Table 7.20 Moon shapes selected by learners

Learners	Waning Gibbous 	First Quarter 	Waning Crescent 	New Moon 	Full Moon 
Lisebo					
Lehana					N/A
Motena					
Makalo					
Karabo			Any of the two gibbous shapes		it would be dark
Seboka					
Fumane					
Masilo				N/A	N/A
'Mamosa					
Selomo					

The tables show that low spatial-ability learners tended to select a shape more than once: three selected half-moon shapes more than once while two selected a gibbous moon more than once. The table further shows that only two high spatial-ability learners selected a shape more than once. Selecting a shape more than once suggests that the learners failed to make a one-to-one correspondence between the eight cut-out moon shapes and the appearance of the Moon in the eight positions around the Earth.

In summary, the tables show that low spatial-ability learners selected mostly wrong shapes facing the wrong direction, while high spatial-ability learners selected mostly correct shapes facing the correct direction. These results indicate that high spatial-ability learners were better able to match phases of the Moon with configurations of the components of the Earth-Sun-Moon system, than the low spatial-ability learners. However, the results show that some high spatial-ability learners had

problems matching some phases of the Moon with configurations of the components of the Earth-Sun-Moon system.

Table 7.21 Correctness of shapes selected by learners

Learners		Waning Gibbous		First Quarter		Waning Crescent		New Moon		Full Moon	
		Shape	Side not visible from Earth	Shape	Side not visible from Earth	Shape	Side not visible from Earth	Shape	Side not visible from Earth	Shape	Side not visible from Earth
5	Lisebo	×	×	×	×	×	×	×	N/A	×	N/A
1	Lehana	✓	×	✓	✓	×	×	×	N/A	—	N/A
10	Motena	×	×	✓	×	×	×	✓	N/A	×	N/A
4	Makalo	×	×	✓	×	×	×	×	N/A	×	N/A
9	Karabo	×	×	×	×	×	×	×	N/A	×	N/A
6	Seboka	×	×	✓	×	✓	✓	✓	N/A	✓	N/A
7	Fumane	×	×	✓	✓	✓	✓	✓	N/A	✓	N/A
2	Masilo	✓	✓	✓	✓	✓	✓	—	N/A	—	N/A
8	'Mamosa	✓	✓	✓	✓	✓	✓	✓	N/A	✓	N/A
3	Selomo	✓	✓	✓	×	✓	✓	✓	N/A	✓	N/A

Three points might explain poor performance of high spatial-ability learners in determination of First Quarter, Waning Crescent and Waning Gibbous phases. First, literature shows that some learners use strategies not prescribed in manuals when answering spatial ability tests. For such learners, tests measure skills not intended by designers of the tests. Furthermore, some learners change strategies while answering spatial ability tests. For such learners, each test measures several skills (not necessarily the one prescribed in the manual of the test). It was impossible to investigate whether each learner used prescribed skills when answering each item in the spatial ability tests. As a result, some learners might have obtained high scores by using skills not measured by the tests. This could explain why these learners encountered problems with determination of moon phases for certain configurations of the components of the Earth-Moon-Sun system.

Secondly, the high spatial-ability learners who participated in interviews had obtained the highest spatial ability scores compared to other learners in the group. However, each of these learners had obtained low scores in at least two spatial ability tests administered in this study. This suggests that the high spatial-ability learners who participated in interviews were weak in some spatial ability skills needed to understand phases of the Moon. This, too, might help explain why these learners encountered problems with determination of moon phases, particularly for gibbous and crescent phases.

The third possible explanation has to do with the nature of the study, i.e. the fact that only a few learners participated in the interviews. A large sample would help to establish whether stronger or weaker links exist between spatial ability and lunar phase determination.

7.7 Discussion

The following issues are the main observations in the chapter.

- The discussion on sections 7.2 to 7.5 shows that learners were generally able to interpret conventions used in Diagrams 21a and 21b. As a result, the learners were able to describe what the diagrams illustrate. These diagrams consist of visual and verbal information as discussed in Sections 7.2 and 7.3. I have used dual coding theory to argue that the learners used nonverbal systems when processing visual information, and used verbal systems when processing verbal information. I proposed that the presence of visual and verbal information helped the learners to interpret these diagrams.
- Literature shows that learners struggle to interpret poorly designed diagrams (e.g. Stylianidou et al., 2002). I have argued in the course of this chapter, that learners who participated in the current study were able to interpret Diagrams 21a and 21b because the diagrams had very few design problems, and had several hints that helped the learners with the interpretation.
- Section 7.6 shows that the learners encountered problems when mentally manipulating objects in space. Similar problems have been reported in literature. For example, several high school students who participated in research conducted by Russell-Gebbett (1984) and Sanders (2002) encountered problems of determining shapes of cross-sections in biological diagrams, and in perceiving spatial relationships of entities inside the cross sections. Also, several students who participated in research conducted by Seddon and his associates encountered problems of accurate perception of molecular structures, and manipulation of the structures in space so as to perceive them from different perspectives (Nicholson & Seddon, 1977; Seddon et al., 1984; Seddon & Eniaiyaju, 1986; Seddon & Moore, 1986; Seddon & Shubba, 1985). All these studies show that learners encounter problems when performing spatial skills required to understand illustrations used in science diagrams.
- Results obtained in the current study show some links between spatial ability and learners' ability to manipulate the components of the Earth-Moon-Sun system in space. That is, high spatial-ability learners were better able to manipulate this system in space when determining phases of the Moon visible from Earth, than low spatial-ability learners. This finding supports results obtained by other researchers who investigated links between spatial ability and students' understanding of Earth science concepts. For example, Black (2005) found significant positive correlations between spatial ability and learners' performance on Earth Sciences tests. Also, Rudmann (2002) found some relationships between spatial ability scores and learners' conceptions about the cause of seasons (see Section 2.1.3, p 22).
- The results obtained in this study show that both low and high spatial-ability learners encountered more problems with determination of crescent and gibbous phases than Full Moon,

New Moon and First Quarter phases. It is worthy to note that determination of appearance of crescent and gibbous phases is more demanding than determination of other phases. In fact, determination of New Moon and Full Moon is easy because the entire surface of the Moon facing the Earth is either visible or not visible. Determination of quarter moon phases is also easy because half of the Moon is visible from Earth, which is usually indicated as a white half in diagrams illustrating phases of the Moon. Determination of crescent and gibbous phases requires viewers to deduce a shape of the Moon that is not drawn on diagrams (illustrating the Moon's orbit). Thus, viewers need to do more work when determining these phases, than when determining the other moon phases.

Literature shows that learners encounter problems when undertaking mental manipulations that require several processes. For example, Ferk et al. (2003) found that students' performance on a Chemistry Visualization Test (CVT) dropped as the number of mental processes increased. In addition, they found some positive correlations between scores obtained in spatial tests and performance on the CVT. Ferk et al. concluded that students with superior spatial ability skills were the most successful in CVT, while students with least spatial ability skills were the least successful. Their results help to explain why learners encountered more problems with crescent and gibbous phases.

- In summary, results obtained in my study show some links between spatial ability and learners' ability to determine phases of the Moon associated with a given Earth-Moon-Sun alignment. However, the results show weaker links between spatial ability and learners' interpretation of conventions used in diagrams illustrating phases of the Moon. This observation supports results obtained by Rochford (1985), who administered several spatial and anatomical tests to university students. Rochford found that performance of high and low spatial-ability learners was almost the same on anatomy questions that required no mental manipulation of objects in space. However, his results showed that high spatial-ability learners outperformed low spatial-ability learners on anatomical questions that required mental manipulation of objects in space. The results obtained by Rochford (1985), together with the results obtained in this study, seem to suggest that spatial ability determines learners' performance on tasks requiring mental manipulation of objects in space, but has very little impact on performance of learners on tasks which can be solved without manipulating objects in space.

7.8 Chapter summary

In this chapter, I have used Diagrams 21a and 21b to investigate learners' interpretation of three conventions used in diagrams illustrating phases of the Moon. Furthermore, I have used these diagrams to investigate learners' ability to use configurations of the components of the Earth-Moon-Sun system to determine phases of the Moon seen by viewers on Earth. In the next chapter, I use Diagrams 19 and 24 to investigate learners' interpretation of three other conventions used in diagrams illustrating phases of the Moon. Thereafter, I present answers to Research Questions 4 and 5 associated with learners' interpretation of diagrams.

Chapter 8 Diagram Interpretation (Part 2)

8.1 Introduction

Chapter 7 presented learners' interpretation of the following three conventions:

1. The same symbol appears more than once, representing the same entity as it changes position (i.e. eight circles represent one not many moons)
2. The same symbol appears more than once, representing different entities:
 - c) Half-shaded circles represent the Earth and the Moon
 - d) Arrows represent the directions of the Moon's orbit and the Sun's rays
3. Different symbols represent the same entity as it changes shape

This chapter presents learners' interpretation of the following three conventions not investigated in the previous chapter:

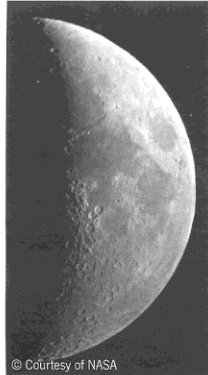
4. Black and white colours indicate parts of the Moon visible and not visible from earth.
5. Two-dimensional shapes represent three-dimensional objects (with no depth cues used in diagrams).
6. Shape of the Moon's orbit indicates perspective from which the Moon has been drawn.

Sections 8.2, 8.3 and 8.4 present learners' interpretation of the 4th, the 5th and the 6th conventions respectively. Subsequent sections summarize results obtained in the interviews, and provide answers to the last two research questions.

8.2 Interpretation of colours on shapes representing Moon phases

All learners had correctly interpreted the Moon's orbit and phases presented separately in Diagrams 21a and 21b. Diagram 24 (Figure 8.1) illustrates these as two concentric ovals, the Moon's orbit in the inner oval and the Moon's phases in the outer oval. Section 8.2.1 presents learners' interpretation of information illustrated in the two concentric ovals, while Section 8.2.2 presents learners' interpretation of black and white colours on shapes in the outer oval.

UNIT 2: The Moon's phases



Look at the night sky and identify which phase the Moon is in at the moment.

As you know from earlier grades, many of the planets have smaller bodies that move in orbits around them. These bodies are called **moons**. For example, Jupiter has 16 moons. Like all the other bodies in the solar system, moons make regular motions. They revolve around planets in regular orbits.

Earth's moon

Earth has one moon. It takes $29\frac{1}{2}$ days for the Moon to complete its orbit around the Earth. During the month, we can sometimes see half the Moon, sometimes a whole circle of Moon and sometimes no Moon at all. This is because, like Earth, only half the Moon can be lit up by the Sun at any one time. The part of the lit half of the Moon that we can see from Earth is called the **phase** of the Moon. We see all the phases of the Moon in $29\frac{1}{2}$ days or one month. Look at the diagram of the Moon in its different phases below.

The phases of the Moon

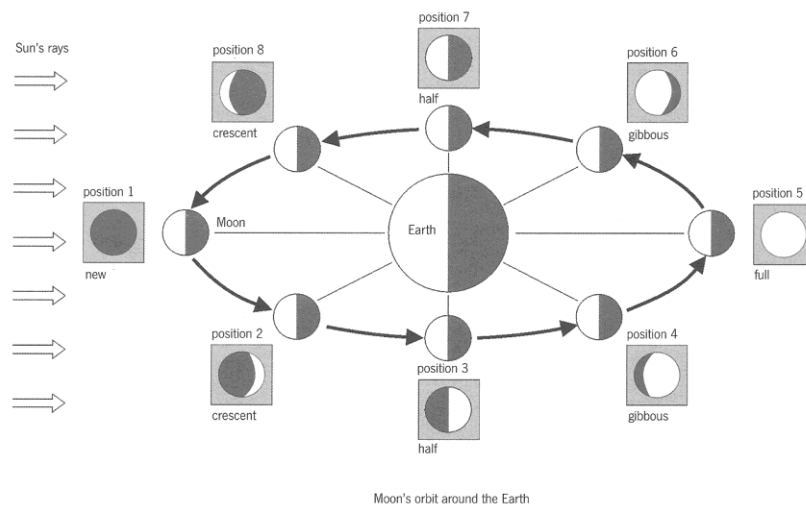


Figure 8.1 A page illustrating Diagram 24

Table 8.1 illustrates design problems identified on Diagram 24. The table further shows that the interview was designed to minimize impact of these violations on interpretation of the diagram.

Table 8.1 Impact of design problems on interpretation of Diagram 24

Principle	Nature of violation	Impact on diagram interpretation
Harmony	Darkness of the unlit part of the Moon differs from darkness of the night sky.	This creates an avenue for investigation of learners' interpretation of the black colour of the Moon when presented against grey background.
Non-ambiguity	The invisible part of the Moon can be seen (as black) on the diagram.	This creates an avenue for investigation of whether learners considered the black or the white colour as representing part of the Moon visible from Earth.
	No inscriptions have been provided to explain the purpose of radiating lines between the Earth and the Moon.	This creates an avenue for investigation of learners' interpretation of these lines.
Scientific accuracy	Incomplete terms (<i>new, crescent, half, gibbous</i> and <i>full</i>) have been used to label phases of the Moon.	Incomplete terms would not prohibit learners from identifying constituents of each oval shape (the Moon's orbit or phases).
Audience compatibility	The Moon's orbit and phases are drawn as seen from the Northern hemisphere.	Learners would be able to identify phases of the Moon, despite the fact that the phases are illustrated as seen from the northern hemisphere.

8.2.1 Interpretation of the two concentric moon ovals

Learners were asked to look at Diagram 24 (Figure 8.1) and describe what they thought the diagram illustrated. Their attention was drawn to the two concentric moon ovals (if they had not done this already). This section presents learners' interpretation of the Moon's orbit and phases.

- Eight learners correctly interpreted the inner oval as illustrating the Moon's orbit and further interpreted the outer oval as illustrating phases of the Moon. The following extracts illustrate examples of their responses.

R: okay, do you see we have a kind of a circle here (*moon's orbital path*) and another one here (*phases of the Moon*), we have one circle inside and another outside, what do you think is going on in those two circles?

Seboka: I think in the circle outside

R: outer circle

Seboka: they show us what we would be able to see on the Moon if we stand on Earth

outer oval: moon's phases

R: okay, and the inner circle?

Seboka: the inner circle would be how the Moon looks I think when we're in space.

inner oval: moon's orbit

Another example

R: This diagram (*placing Diagram 24 on the table*) I want you to study it and tell me what you think is going on.

Fumane: must I study it and tell you what I think is going on here?

R: just tell me what you think the artist wants us to understand when you look at this diagram

Fumane: I think that they wanted us to understand that the Moon doesn't only have one shape, and has different, like shapes like, whatever; and it doesn't stay in one place, it moves

moon's orbit and phases

R: so far you've said two things; that the Moon has more than one shape and that it doesn't stay on one place it moves.

Fumane: ja

R: can you show me how you obtain that information from the diagram?

Fumane: not as in shapes, obviously it's gonna be circular, but the different shapes as in these (*pointing at shapes in the outer oval*)

R: okay

Fumane: because you see, that part of, there, is shaded of the Moon (*pointing at the shaded part of the Waning Crescent in the outer oval*), so you only see a certain portion of the Moon ..., okay that's where I got the shape thing from

Outer oval: moon's phases

R: okay

Fumane: and the movement of the arrows; arrows show that the Moon moves around.

Inner oval: moon's orbit

- The remaining two learners correctly interpreted the outer oval as illustrating phases of the Moon, but failed to interpret the inner oval as illustrating the Moon in its orbital path. One of these learners (Makalo) first said that the inner oval illustrated earths, but changed to say that it illustrated the planets.

R: alright, let's look at this diagram (*Diagram 24*). Have a look at the diagram and tell me what you think it's showing.

Makalo: it shows the phases of the Moon

R: where are they? What gives you that clue?

Makalo: because of, we do get quarter Moon, Full Moon, and so on, so whenever it's like this (*pointing at Waning Gibbous in the outer oval*) it's one phase of the Moon and this is half Moon (*Last Quarter in the outer oval*), this (*Waning Crescent in the outer oval*) is maybe one third of the Moon

Outer oval: moon's phases

R: okay, let's do this first, what do you think these are, you said these are the what? (*pointing at the shapes in the outer oval*)

Makalo: that's the Moon

R: and these (*shapes in the inner oval*)

Makalo: those are the Earth, eerrr, different planets

Inner oval: other entities than the Moon

R: this (*outer oval*) is the Moon, this (*inner oval*) is different planets, this is (*pointing at the earth shape*)

Makalo: the Earth

R: what gives you the clue that this is the Earth?

Makalo: because (*long pause*)

R: what are you thinking? Tell me.

Makalo: I'm most probably going back on my word and maybe thinking it's the Sun

R: what?

Makalo: maybe thinking that this is the Sun (*pointing at the Earth*)

R: what would make you think that it is the Sun?

Makalo: because there are planets around us, because this is one side of the Sun and this is the other

R: alright, what gives you the clue that these are the planets?

Makalo: because there's eight of them, and there are eight planets, and it's also because it orbits around the Sun.

This interpretation mirrors his confusion when interpreting Diagram 21a (Section 7.2.2, p 164), where he appeared to be uncertain as to what the eight half-shaded circles represented (he said the Moon, and then the earths, and then the planets). It appears that he was confused as to what the eight half-shaded shapes illustrated.

The other learner (Lehana) first said that the inner oval illustrated the Moon, but when asked about shapes in the outer oval, he said he was not sure as to what the inner oval represented. Finally he interpreted the inner oval as illustrating the Moon's orbit. The following extract illustrates his response.

R: what are these arrows? (*pointing at the parallel arrows representing the Sun's rays*)

Lehana: how the Sun lights the Moon

R: how the Sun lights the Moon, and those arrows? (*arrows in the Moon's orbital path*)

Lehana: how the Moon changes during the day

R: changes what?

Lehana: shape

R: oh, how the Moon changes shape during the day?

Lehana: yes

Curved arrows: changing shapes of the moon

R: and these shapes, these ones? (*shapes in the inner oval*)

Lehana: the ...

R: the circles, what are these circles?

Lehana: the Moon

inner oval: the moon

R: okay

Lehana: no, these circles (*pointing at the shapes in the outer oval*)

R: the outer circle is the Moon?

Lehana: yes

outer oval: the moon

R: and this one? (*pointing at the inner oval*)

Lehana: I'm not sure about these ones

R: alright. You said you don't know what these are? (*referring to the shapes in the inner oval*)

Lehana: yes

R: can I take you one step back. What did you say these were? (*moon shapes on Diagram 21a*)

Lehana: I thought these were moons

R: you thought these were moons?

Lehana: but now I've got a different idea

R: you've got a different idea, now what do you think they are?

Lehana: I'm still not sure

Inner oval: uncertain

R: you are not sure about those, (*back to Diagram 24*) okay you don't know what these are (*shapes in the inner oval*) but you know that this is the Moon (*shapes in the outer oval*). You said the arrows show?

Lehana: how the Moon changes during the day

Curved arrows: changing shapes of the moon

R: how the Moon changes during the day, and you said these are not the moons (*pointing at the shapes in the inner oval*) these are the moons (*pointing at shapes in the outer oval*)

Lehana: I think so

outer oval: the moon

R: the outer circle shows the Moon (*pointing at phases of the Moon*), and the inner circle, you don't know what it shows?

Lehana: maybe this is the Moon (*referring to the inner oval*)

R: maybe it's the Moon?

Lehana: ja but these pictures (*pointing at shapes in the outer oval*) show how the Moon becomes. They don't show exactly how, this (*pointing at a shape in the inner oval*) it just shows how the Moon looks like

R: this one? (*pointing at the inner oval*)

Lehana: ja and this (*pointing at the outer oval*) how, the exact shape.

R: you know you've got to explain this to me, one shows how the Moon looks like, one shows?

Lehana: it shows how it looks like to us, not how it looks like in, wherever, in the skies.

inner oval: the moon

The above responses indicate that all learners correctly interpreted the outer oval as illustrating phases of the Moon, while only eight correctly interpreted the inner oval as illustrating the Moon's orbit. The dual coding theory can help to explain how the learners processed information when interpreting shapes in the two ovals. First, it is noteworthy that no verbal explanations are provided in the diagram to explain what each oval represents. As a result, I assume that learners' verbal systems were not active in the beginning of information processing. The dual coding theory proposes that the learners' engaged in representational processing to form mental images of information illustrated in the two ovals. Then they engaged in referential processing which enabled

them to name information presented in each oval (although two learners gave wrong names to information presented in the inner oval).

The next step of the interview investigated learners' interpretation of colours in the outer oval.

8.2.2 Interpretation of black and white colours on shapes in the outer oval

Learners were asked to explain what the black and white colours represented on shapes in the outer oval. Learners' attention was drawn to two moon phases (Positions 2 and 6) for consistency's sake. These phases were selected because they both have crescent and gibbous shapes, the crescent representing visible part of the Moon in Position 2, and representing the invisible part of the Moon in Position 6. Learners' responses are discussed below.

- Five high spatial-ability learners and one low spatial-ability learner correctly interpreted white colour as representing part of the Moon visible from earth, and black colour as representing part of the Moon not visible from earth. The following extracts illustrate their responses.

R: okay I want you to look at just one of these shapes. Let's take Position 6, this position six (*in the outer oval*), tell me what is going on here.

Masilo: okay, I think the dark part

R: sorry which dark part, can you point at it

Masilo: the dark part (*pointing at the black part of the Moon*) is the part of the Moon that won't be visible if you're on earth

dark colour: fraction of the Moon not visible from earth

R: alright

Masilo: then the white part is the part that will be visible

R: and how did you work that answer out

Masilo: because seeing the direction of Sun's rays I can see that as it hits the moon circle, this part will be visible (*the white section of the Moon in the outer oval*) and the dark part is something that you can't see.

white colour: fraction of the Moon visible from earth

Another example

R: I want you to imagine being on earth, at the centre of the Earth, and you're looking at this (*pointing at Waning Gibbous moon in the outer oval*), what do you think the artist, according to the drawing here, what do you think we would see?

'Mamosa: (*silent*)

R: you said this (*pointing at phases of the Moon*) shows what we would see. What would we see if we looked at this (*Waning Gibbous*)? What do you think?

'Mamosa: I don't know what you mean

R: okay, what do you think is going on here (*pointing at Waning Gibbous in the outer oval*)? What do you think the artist is trying to show us here?

'Mamosa: here I think he's telling us that the light side of the circle is what we see as the Moon

R: mmmh

'Mamosa: at a specific time

white colour: fraction of the Moon visible from earth

R: and the dark part?

'Mamosa: is what we don't see.

Dark colour: fraction of the Moon not visible from earth

R: and the shading around, this grey you see this picture is grey here? We have this white, we have this, let's call it black, and then the surrounding is grey.

'Mamosa: (*laughing*) I don't know

R: alright, now you said the artist is showing us what you think you'd see. You said the white part is what you'd see. can you draw that for me?

'Mamosa: draw?

R: ja

'Mamosa: draw this part?

R: can you?

'Mamosa: ja

R: or you can choose from these (*pointing at the cut-out moon shapes*); we've still got these shapes.

'Mamosa: it's this one (*selecting a Waning Gibbous cut-out shape*)

white colour: fraction of the Moon visible from earth

R: okay, if you came here to Position two (*Waxing Crescent in the outer oval*)?

'Mamosa: then this one would be this one (*selecting a Waxing Crescent cut-out shape*)

white colour: fraction of the Moon visible from earth

- The remaining four learners (i.e. Lehana, Lisebo, Makalo and Karabo, all with low spatial ability scores) appeared to be uncertain as to whether the black or the white colour represented part of the Moon visible from earth. The following extract illustrates an example of their responses.

R: alright here we are. If you're on earth standing there (*pointing at the centre of the earth shape*) looking at this shape (*Waning Gibbous in the outer oval*), what do you think the artist, what according to the diagram do you think is what you would see?

Karabo: what I would see?

R: ja, which shape?

Karabo: would I see?

R: yes, which shape of the Moon? How would the Moon appear to be according to this diagram?

Karabo: I think here if the Moon was lighter I would see that part (*pointing at the black crescent*), that part would be dark (*pointing at the white gibbous*)

dark colour: fraction of the Moon visible from earth

R: okay, the white part would be

Karabo: dark because it (*not audible*)

white colour: fraction of the Moon not visible from earth

R: and the black part would be what you'd see

Karabo: yes

R: what do you think this is? You see the Moon is white, there is that black part again, there's this grey shading surrounding the Moon

Karabo: mmmm

R: what do you think it is?

Karabo: I don't know, space

R: Can I ask you, let's come back to these shapes here (*cut-out moon shapes*), just select the one that you think you'd see, here (*pointing at Waning Gibbous in the outer oval*).

Karabo: the one that I would see?

R: yes

Karabo: it's this one (*selecting a cut-out Waxing Crescent*)

white colour: fraction of the Moon not visible from earth

At this stage, she appeared to have interpreted the black colour as representing part of the Moon visible from earth. The next part of the interview investigated her interpretation the black and white colours on the Waxing Crescent phase.

R: thanks, and then we come to this one (*Waxing Crescent in the outer oval*), and then again you select the one that you think you'd see.

Karabo: this one (*selecting a cut-out Waxing Crescent again*)

white colour: fraction of the Moon visible from earth

This time she appeared to have interpreted the white colour as representing part of the Moon visible from earth.

R: okay now I'm going to ask you why you think so

Karabo: it's not this one

R: are you changing your mind?

Karabo: but there is no shape (*inaudible*)

R: it's okay if you want to change you can change but you have to tell us why you are changing

Karabo: I said this one here (*pointing at the Moon in Waning Gibbous position*) because it's curved you see (*pointing at the cut-out Waxing Crescent chosen for the Moon in this position*), and on that side

R: alright

Karabo: but here (*Waxing Crescent position*) I think it's that one again (*pointing at the cut-out Waxing Crescent*)

white colour: fraction of the Moon visible from earth

R: that same one again?

Karabo: yes

R: because?

Karabo: because it's curving on that side

R: mmmm

Karabo: it doesn't make any sense

confused

R: why do you think it doesn't make sense?

Karabo: no this one's this one (*selecting a cut-out Waning Gibbous*)

R: wait, let's put them all together again and you show me which one is which (*rearranging the cut-out shapes*), start here show me which

Karabo: this one (*pointing at Waning Gibbous in the outer oval*)

R: is which one?

Karabo: would be that one (*selecting a cut-out Waxing Crescent*)

R: okay

white colour: fraction of the Moon not visible from earth

Karabo: and that one (*Waxing Crescent position*) would be that one (*selecting a cut-out Waning Gibbous*)

dark colour: fraction of the Moon not visible from earth

R: why?

Karabo: because if I was here (*centre of the Earth*), looking there (*Waxing Crescent in the outer oval*), and these are the Sun's rays (*pointing at the parallel arrows*) I'd see that part (*white crescent*) right? So it would be this one (*pointing at the cut-out Waxing Crescent*)

R: okay, this one (*Waxing Crescent in the outer oval*) would be?

Karabo: that one (*pointing at the cut-out Waxing Crescent*)

white colour: fraction of the Moon visible from earth

R: is it the one you had selected earlier?

Karabo: (*laughing*) no

R: alright let's do it again, you said this one (*Waxing Crescent in the outer oval*) would be?

Karabo: this one (*selecting Waxing Crescent*)

R: okay, because?

Karabo: because I'll be standing here (*centre of the Earth*) and sunlight is coming from there (*pointing at the parallel arrows*) so I'd see that part (*pointing at the white crescent*)

white colour: fraction of the Moon visible from earth

R: okay, and this one (*Waning Gibbous in the outer oval*)

Karabo: this one would be that one (*selecting a cut-out Waning Gibbous*)

R: because?

Karabo: because it's darker there (*pointing at the crescent*) and light is coming from this side so I'll see this part here (*pointing at the gibbous section of the Moon*)

white colour: fraction of the Moon visible from earth

This extract shows that Karabo first interpreted the black colour as representing part of the Moon visible from earth. However, she changed her mind as the interview progressed, interpreting the white colour as representing part of the Moon visible from Earth.

Again, dual coding theory can be used to explain how learners processed diagrammatic information to interpret colours in the outer oval. It is notable that the illustrators of the diagram provided no

inscriptions to explain what the black and white colours represented. As a result, it is possible that learners' verbal systems were not active in the beginning of information processing. I propose that the learners engaged in representation processing to perceive information illustrated in the outer oval. Thereafter, the learners engaged in referential processing which enabled them to interpret what the black and white colours represented (these interpretations were not always correct, as discussed above).

Artists of diagrams use white colour to represent part of the Moon visible from earth, and use black colour to represent part of the Moon not visible from earth. However, literature shows that some people use black colour to represent part of the Moon visible from earth. For example, Trundle et al. (2010) asked pre-service teachers completing a moon chart to shade shape of the Moon visible from earth, and leave the unseen part of the Moon as white. Thus, Trundle et al. (2010) advised the participants to use black and white colours in a way contradicting the meanings used by artists of textbook diagrams. In another study, two of 50 pre-service teachers who completed a moon chart in Bell and Trundle's (2008) study shaded visible part of the Moon and left the unseen part of the Moon as white. Thus, these participants too, used black colour to represent visible part of the Moon. In yet another study, seven of 24 pre-service teachers who completed a moon chart in Wilhelm et al.'s (2008) study switched their method of shading, from shading visible part of the Moon to shading non-visible part of the Moon. Thus, they changed the meaning of shaded and non-shaded parts of the Moon. It appears, therefore, that uncertainty about meanings of black and white colours, demonstrated by some learners who participated in the current study, mirrors uncertainties documented in literature.

8.2.3 Summary

Table 8.2 summarizes learners' interpretation of the Moon's orbit and phases.

Table 8.2 Learners' interpretation of the Moon's orbit and phases in Diagram 24

Learner	Moon's orbital path	Moon phases	Black and white colours in the outer oval
Lisebo	✓	✓	✓ x
Lehana	✓ ?	✓	✓ x
Makalo	x	✓	✓ x
Motena	✓	✓	✓
Karabo	✓	✓	✓ x
Seboka	✓	✓	✓
Fumane	✓	✓	✓
Masilo	✓	✓	✓
'Mamosa	✓	✓	✓
Selomo	✓	✓	✓

The table shows that all learners correctly interpreted the outer oval as illustrating phases of the Moon while only eight correctly interpreted the inner oval as illustrating the Moon's orbital path. The table further indicates that high spatial-ability learners correctly interpreted the black and white colours in the outer oval, while most of the low spatial-ability learners had problems of interpreting these colours.

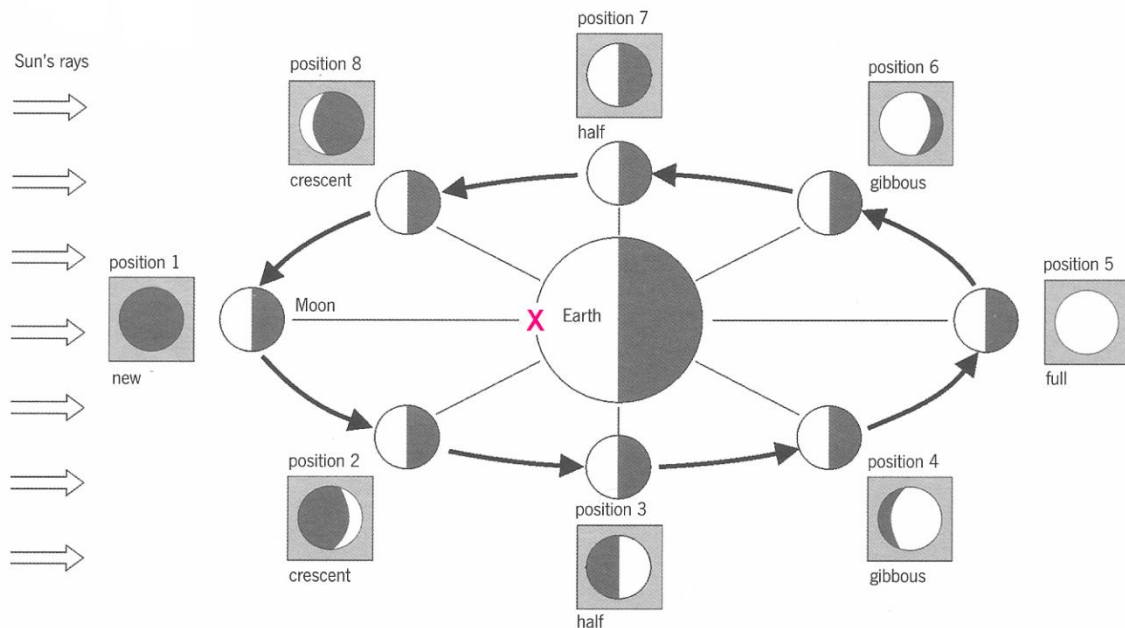
Earlier in the interview, the high spatial-ability learners had correctly determined the shape of the Moon visible from earth when the Moon is in selected positions in its orbital path around the Earth (see for example Table 7.2.1, p 205). It is possible that these learners correctly interpreted the black and white colours on Diagram 24 because they knew what the Moon would appear to be like in each position on its orbital path. In the same way, it is possible that the low spatial-ability learners who changed their responses in the course of the interview did not know what the Moon would appear to be like in each of the eight positions in its orbital path around the Earth.

8.3 Interpreting the Earth and the Moon as spherical objects

Accurate understanding of information illustrated on moon phase diagrams requires viewers to interpret the Earth and the Moon as spherical objects. However, most diagrams use circles to represent the Earth and the Moon, providing no depth cues to help viewers perceive the circles as representing spherical objects (see Diagrams 21a and 24 for example). This part of the interview investigated whether learners interpreted the earth and the moon shapes as representing two-or three-dimensional objects.

8.3.1 Perceiving beyond the Earth

The spherical shape of the Earth means that not all people can see the Moon at a given point in time. That is, when people on one side of the Earth see the Moon, people on the opposite side of the Earth cannot see the Moon. When investigating whether learners interpreted the earth shape as representing a two-or a three-dimensional object, each learner was asked to imagine being located at Point X on the Earth shape in Diagram 24 (see the red X in the diagram below).



They were asked to imagine looking at the moon shape located in Position 5 in the inner oval, and to explain whether they could see the Moon and to explain what the Moon would appear to be like (if the Moon could be visible at all). Learners who interpreted the earth shape as representing a three-dimensional object would realize that the Moon would not be visible to a viewer located at Point X. That is, these learners would realize that the Earth would obscure these viewers from seeing the Moon. On the other hand, learners who imagined the earth shape as representing a flat object would envision seeing the Moon from Point X. The following results were obtained from learners' responses.

- Two learners said that they would not see the Moon from this position of the earth shape, as indicated in the following extracts.

R: I want you to imagine yourself, remember in the previous diagram I asked you to imagine being at the centre (*pointing at the centre of the earth shape*). Now imagine you're standing here at the cross (cross made at the 9 o'clock position on earth shape), and you're looking at the Moon in this position (*Position 5 in the inner oval*)

'Mamosa: that's a bit difficult

R: please explain to me

'Mamosa: because the Earth is known to be round, and if I'm on this side (*pointing at the cross*), and the Earth is round, you can't see over the Earth and look at the Moon, so I don't think I'd see the Moon.

earth as three-dimensional

The other response

R: alright, let's do this now, I want you to imagine standing here on earth (*pointing at the nine o'clock position*), looking at this moon (*Position 5 in the inner oval*), would you be able to see the Moon, and if you can, how would it look like?

Makalo: eeeemmmmm

R: you are standing on this side (*pointing at the nine o'clock position on the earth shape*) remember that last time I asked you to imagine standing at the centre, now you are on this side

Makalo: I would not be able to see the Moon

R: how did you get that answer?

Makalo: because if I stand here (*nine o'clock position on earth shape*) I look beyond my point

R: beyond your point? Please explain that to me.

Makalo: beyond meaning I'm looking past, past the Earth to here (*Full Moon*) which, my eyes aren't really sensitive

earth as three-dimensional

These responses suggest that the two learners interpreted the earth shape as representing a three-dimensional object beyond which they could not see the Moon.

One learner first said that he would see the Moon, but changed to say that he could not see the Moon because of sunlight on the surface of the Earth.

R: okay. Now here's what I want you to imagine doing. I want you to imagine that you were to stand here on earth (*9 o'clock position*). You are standing here, you are looking at this moon (*Position 5 in the inner oval*). Do you think you can see the Moon?

Lehana: yes I would see the Moon

earth as two-dimensional

R: when you are standing here?

Lehana: when I'm standing in the

R: let's make x here (*at the 9 o'clock position on the earth shape*), you are standing at the x, the point I made x. you can see that moon?

Lehana: no

R: why?

Lehana: because there's sunlight here (*pointing at the white half of the earth shape*)

R: there's sunlight?

Lehana: ja

R: so?

Lehana: the white part I think is the sunlight; you won't see the Moon because of the Sun

earth as two-dimensional

In the first part of his response, Lehana said that he would see the Moon, suggesting that he interpreted the earth shape as representing a flat object beyond which he could see the Moon. In the second part of his response, he said that he could not see the Moon because of sunlight on the surface of the Earth. He is one of the four learners who, at one point, thought that the black colour represented part of the Moon visible from the Earth. It appears that he now thought that brightness of sunlight would prohibit him from seeing the Moon (represented by black colour). This means that he interpreted the earth shape as representing a flat object beyond which he could see the Moon.

- Six learners clearly said that they could see the Moon. Five of these learners (Seboka, Lisebo, Fumane, Masilo and Selomo) said that they would see Full Moon. The following extract gives an example of their responses.

R: okay, you know now I want you to do a little bit of imagination, I want you to imagine being here, you see on the cross here on earth (*pointing at the cross at the 9 o'clock position on the earth shape*)

Selomo: yes

R: and I want you to look at the Moon in Position five (*Position 5 in the inner oval*)

Selomo: (*he drew a circle*)

R: that is what we can see?

Selomo: yes

R: so we can see the Moon?

Selomo: ja, the whole moon

earth as two-dimensional

The sixth learner (Karabo) appeared to be uncertain about the shape of the Moon visible from earth, but she was certain that she could see the Moon as exemplified in the following extract.

R: alright. You know what I'm going to ask you to do; I'm going to ask you to imagine standing here (*9 o'clock position on the earth shape*) looking at the Moon in this position (*Position 5 in the inner oval*). What do you think you'd see?

Karabo: should I look at those shapes (*cut-out moon shapes*)

R: oh yes you can

Karabo: I think I'd see probably this one (*selecting the Waning Gibbous cut-out shape, and then the First Quarter cut-out shape*)

earth as two-dimensional

R: okay, let's put them back so that you make your choice (*rearranging the lunar shapes again in order*) you are standing here (*9 o'clock position on earth*), looking at the Moon in this position (*Full Moon position*). What do you think you'd see?

Karabo: I'd see this one (*selecting a Last Quarter cut-out shape*)

R: can you explain this to me? How did you make your choice?

Karabo: okay the line might say it's probably bright (*pointing at the line between the Earth and the Moon shape representing Full Moon*) but then looking at it probably from further, and light coming that way (*moving her hand from the Sun's rays towards the Moon's orbit*) you'll see the white part not the black part

R: okay, so you can actually see the Moon

Karabo: yes

earth as two-dimensional

- The tenth learner said that the Moon would be bright, which suggest that she interpreted the Earth as a flat object beyond which she could see the Moon.

R: ... Let's imagine that you were standing here (*9 o'clock position on the earth shape*), looking at this moon (*Position 5 in the inner oval*). What do you think you would see?

Motena: (*silent*)

R: remember earlier I asked you to imagine standing at the centre

Motena: yes

R: now you're standing here at the cross (made at the 9 o'clock position on the earth shape)

Motena: now I'm standing here looking at this Moon

R: what would the Moon look like to you?

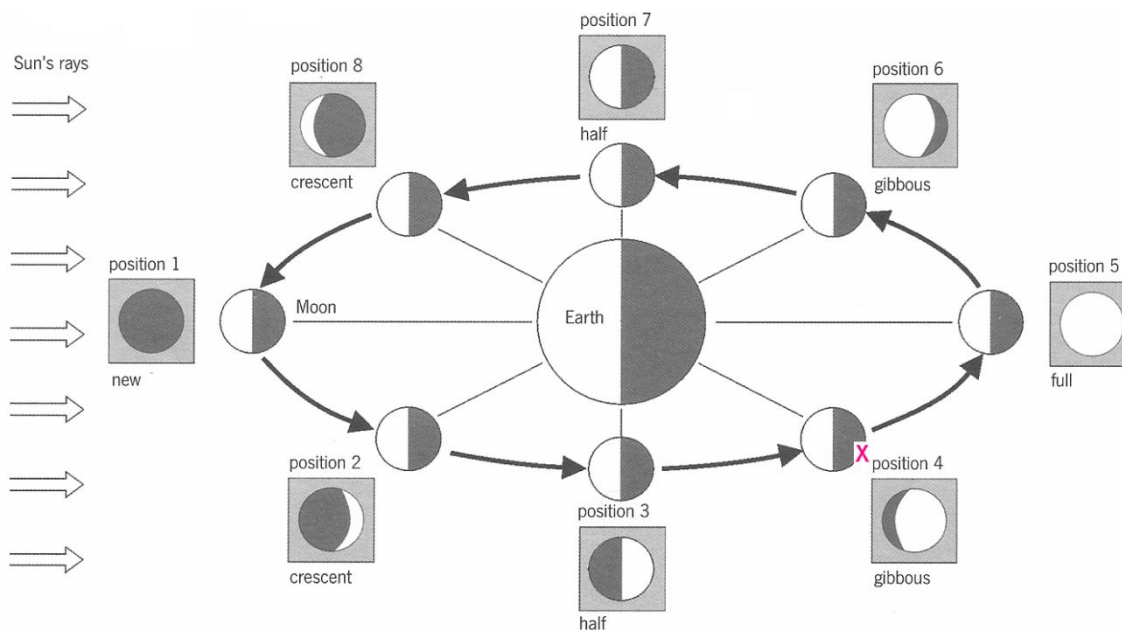
Motena: it would be bright

earth as two-dimensional

Responses obtained in this section indicate that only two learners (Makalo and 'Mamosa) interpreted the earth shape as representing a three-dimensional object. Interpreting the Earth as a spherical object would help learners understand why the Moon is visible to people on one side of the Earth at a given point in time.

8.3.2 Perceiving beyond the Moon

This section investigated whether learners interpreted the moon shapes as representing a two-or a three-dimensional object. Learners were asked to imagine being at Point X on a Waxing Gibbous moon shape in the inner oval (see the red X in the diagram below).



They were asked whether they could see the Earth, and to describe the shape of the Earth (if the Earth could be visible at all). Learners who interpreted the Moon as a three-dimensional object would realize that the Moon would obscure viewers from seeing the Earth. The following results were obtained.

- Two learners (Lehana and Karabo) said that the illuminated surface of the Moon would prevent them from seeing the Earth. The following extract illustrates their responses.

R: okay, I'm going to ask you to imagine being on the Moon. So this is the Moon (*pointing at Waxing Gibbous moon shape in the orbital path*), imagine standing here (*making a cross at the 4 o'clock position*) in that part of the Moon, looking at the Earth

Karabo: okay, standing here

R: yes, at the cross

Karabo: I think you wouldn't see anything

R: please explain to me. What do you mean?

Karabo: like you wouldn't see anything. Here (*pointing at Full Moon in the orbital path*) I would have seen that it was light there (*pointing at the white half of the Moon*) because of light rays, but here (*pointing at the right hand side of the page*) there aren't any light rays

moon as two-dimensional

R: okay

Karabo: so it would be dark

R: oh, you'd see darkness

Karabo: yes, but there's a bit of light there (*pointing at the white half of the Waxing Gibbous moon in the orbital path*) so I probably think I wouldn't see through it to earth

moon as two-dimensional

R: pardon, you would see that light but

Karabo: this light over here (*pointing at the white half of the moon*)

R: mmmm

Karabo: but I wouldn't see through it to earth

moon as two-dimensional

This response suggests that Karabo thought that she could see the white section of the Moon, which implies that that she interpreted the moon shape as representing a flat object so that she could see the white colour on the other side of the black colour.

- Seven learners gave responses indicating that they could see the Earth. Two of these learners (Masilo and Motena) gave responses suggesting that they would see the black side of the earth shape. The extract from Masilo's response illustrates these responses.

R: okay, and here, you come to the Moon in Position 4, you stand here where I've made a cross (*cross at the 4 o'clock position of the Waxing Gibbous moon shape*) you are looking at the Earth this time. The Sun is still here (*pointing at the arrows representing the Sun's rays*). What do you think you would see? Can you see the Earth?

Masilo: I think, because it's indicated as black (*pointing at the black part of the earth shape*) and usually on the drawing it shows that the black parts are non-visible I don't think you would be able to see it.

R: oh because of the black part?

Masilo: yes

moon as two-dimensional

One learner said that the Earth would appear to be banana-shaped.

R: alright, let's come to the Moon now. Imagine yourself standing here on the Moon (*4 o'clock position of the Moon in Waxing Gibbous position*) looking at the Earth

'Mamosa: on the Moon

R: mmm, you're standing at this very position on the cross looking at the Earth

'Mamosa: I'd see a banana of the Earth, a small piece of the Earth

moon as two-dimensional

Four learners (Lisebo, Makalo, Selomo and Seboka) made drawings to illustrate the shape of the Earth which they thought they would see. The following extract is an example of their responses.

R: okay, I want you to imagine standing here again (*4 o'clock position on the Moon in Waxing Gibbous position*). Now you're standing on the Moon,

Seboka: on the Moon?

R: yes and you are looking at the Earth

Seboka: must I draw what I would see?

R: oh yes

Seboka: (*he drew the Earth, shaded a fraction, and labelled the non-shaded portion as "visible"*)



moon as two-dimensional

- The remaining learner said that she would see nothing, but changed to say that the Earth is always visible from space.

R: alright. And then I'm going to ask you to imagine, this time, standing on the Moon here, where I'm making a cross (*making a cross at the 4 o'clock position on the Waxing Gibbous moon shape in the orbital path*) and you're looking at the Earth

Fumane: (*silent*)

R: what are you thinking?

Fumane: I don't know what I'm thinking because I'm thinking if I'm on the Moon (*pointing the 4 o'clock position on the moon shape*) and I'm looking at the dark side of the Earth

R: mmmh

Fumane: then I'm thinking that I won't be able to see it but Earth is always visible, like if you're in space it would always be visible

R: okay.

Fumane: I think I'd still see the Earth as light, but not like bright, you know what I'm saying, I'd see the Earth like fully, but not as bright as I would when the Sun was shining.

moon as two-dimensional

It appears that she had a scientifically unacceptable idea of thinking that the Earth is always visible from space. This seems to have interfered with her interpretation of the diagram, making her say that she would see the Earth. This response supports results of Khanyane (2002) who found that incorrect use of prior knowledge results in misinterpretation of diagrams.

The responses given in the above extracts indicate that all learners thought that they would see the Earth from the 4 o'clock position of the Moon in Waxing Gibbous position. This suggests that all learners interpreted the moon shape as representing a flat object beyond which they could see the Earth.

Interpreting the Moon shapes as representing a spherical object is the only condition under which viewers on earth would see the Moon as (i) circular when the entire illuminated surface faces the Earth, (ii) crescent-shaped when less than half of this surface faces the Earth, and (iii) gibbous-shaped when more than half of this surface is visible from the Earth. The fact that learners interpreted the moon shape as representing a flat rather than a spherical object might explain why they struggled to determine the phase of the Moon visible from earth (discussed in Section 7.6). That is, it is possible that the learners interpreted the Moon as a flat object, and as a result, struggled to determine accurate shapes of the Moon seen from the earth shape, particularly crescent and gibbous phases which require the Moon to be perceived as a spherical object.

Previous research shows that learners have inaccurate conceptions about the shape of the Earth (e.g. Diakidoy et al., 1997; Klein, 1982; Nobes, Moore, Martin, Clifford, Butterworth, Panagiotaki & Siegal, 2003). However, none of these studies investigated learners' interpretation of conventions used in diagrams illustrating phases of the Moon. The current study investigated not the conceptual understanding about the shape of the Earth, but whether learners interpret the Earth (in diagrams) as a two-or three-dimensional object.

8.3.3 Selection of Objects

Learners were shown two objects of the same diameter (a ball and a circular paper), each half-shaded black and white as discussed in Section 3.6.2 (p 77). Learners' attention was drawn to the Moon in the inner oval, and they were asked to select a shape which they thought the artists intended viewers to see when looking at the Moon. Learner who interpreted the moon shapes as representing a three-dimensional object would select the ball. On the contrary, learners who interpreted the moon shapes as representing a flat object would select the circular paper. The following results were obtained.

- Four learners selected the ball as representing the Moon. Three of these learners (Motena, Fumane and 'Mamosa) said that the Moon is round like a ball. The following extract gives an example of their responses.

R: Here is the Moon (*Waxing Gibbous in the Moon's orbit*). Which of these shapes (*the ball and the circular paper*) do you think the artist has drawn?

Motena: which one?

R: here (*pointing at Waxing Gibbous in the Moon's orbital path*). What do you think the artist wanted us to see, this (*the circular paper*) or that (*the ball*)?

Motena: this (*touching the ball*)

R: why do you select that?

Motena: because my mind tells me that the Earth is, the Moon is round, so I don't think he would want us to get confused by showing us something like that (*pointing at the circular paper*)

moon as three-dimensional

The other learner could not explain his reasons for selecting the ball.

R: alright this is what I want you to do. I want you to look at this shape (*New Moon in the Moon's orbital path*), and tell me what you think the artist has drawn between these two (*the half-shaded sphere and the half-shaded circular paper*), choose one of them.

Makalo: (*silent*)

R: tell me what you are thinking

Makalo: I'm just thinking of which one could it be

R: alright

Makalo: because I don't really understand what do they mean. What do you mean?

R: you see this shape (*pointing at the Moon in the inner oval*), you have one half not shaded, another shaded.

Makalo: yes

R: the artist wants to, has drawn something here, so I want to know if it's a flat object like that one (*circular paper*) with half not shaded and the other half shaded, or if it is a ball like that

Makalo: I think it's this one (*pointing at the ball*)

moon as three-dimensional

R: what makes you think that?

Makalo: because there is no such thing

R: pardon, there is no?

Makalo: there is no, if I call it a planet there is nothing that, that (*pointing at the circular paper*), you know, I can't explain it

These results indicate that the four learners interpreted the moon shapes as representing a spherical object. However, all the four learners had indicated earlier in the interview that they could see the Earth from the 4 o'clock position of the Moon in waning gibbous position. This gives contradiction on the responses given by the learners.

The responses given by the four learners support the findings of Vosniadou and her colleagues who argue that exposing learners to spherical objects during questioning helps learners to imagine a spherical Earth, which would have not necessarily been the case if the model was not presented (Vosniadou et al., 2004, 2005). Learners who participated in research conducted by Vosniadou and her colleagues gave more scientifically acceptable responses when asked forced-choice questions (which included presentation of models) than when asked open-ended questions. Vosniadou and her colleagues interpreted this result as indicating that the learners gave scientifically acceptable responses because of the type of questioning, not necessarily because they had scientifically acceptable responses.

- Six learners selected a circular paper as representing the Moon. Five of these learners said that the paper looked like the moon shapes in the diagram. It appears that these learners interpreted the moon shapes as representing a two dimensional object. The following extract illustrates an example of their responses.

R: alright. Now I want you to look at one of these shapes (*moon shapes in the inner oval*), just any one of them, you can take this one (*Position 5*). What do you think the artist wanted to show, which object, I have two examples of objects here; you see this one (*circular paper*) and this one (*ball*), which of these two do you think the artist wanted to draw here?

Lisebo: this one (*circular paper*)

R: why do you think so?

Lisebo: because it's the same as that one (*pointing at the moon shape*) it's shaded in one side

R: and that (*the ball*) is not shaded on one side?

Lisebo: it is, but that's more of a three-D shape (*pointing at the ball*) than a two-D (*pointing at the Moon in the diagram*) because you can see a flat part (*pointing at the diagram*) but that's the whole round side (*the ball*)

R: this (*Moon on the diagram*) is two-D

Lisebo: yes

R: so you are choosing another two-D

Lisebo: yes

moon as two-dimensional

The remaining learner gave a response suggesting that the terminator line would be curved if the half-shaded circle represented a sphere.

R: Here are our two shapes (*the ball and the circular paper*), and I want you to look at this moon (*Full Moon in the orbital path*) or any of these moons in the inner circle. Which of these do you think the artist intended to draw, this (*circular paper*) or that (*ball*)? What does each of these (*pointing at the moon shapes in the inner oval*), what do you think the artist wanted to show us here? This kind of shape (*circular paper*), or that kind of shape (*sphere*)?

Selomo: that kind of shape (*pointing at the circular paper*)

moon as two-dimensional

R: what gives you the clue from the diagram?

Selomo: because it's complete circle, it's just a straight line coming through (*moving his hand along the terminator line*)

R: what do you mean straight line?

Selomo: it's completely straight (*pointing at the terminator line*) so

R: okay, what would happen if it were this one (*the sphere*)?

Selomo: (*he drew a circle with a curved terminator line*)

R: is that not straight

Selomo: no

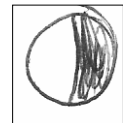
R: it's kind of

Selomo: it's like slanted or curved

R: and because it's not like that (*pointing at the learner's drawing*), the diagram indicates to you that it is this one (*pointing at the circular paper*)

Selomo: yes

moon as two-dimensional



It appears as though he selected the paper because the diagram lacked visual cues to make the Moon to appear to be spherical.

8.3.4 Summary

Table 8.3 summarizes results indicating the extent to which the learners interpreted the earth and the moon shapes as representing three-dimensional objects.

Table 8.3 Summary of learners' perception of the earth and the moon shapes on Diagram 24

Learners	Perceiving beyond Earth		Perceiving beyond Moon		Object representing Moon	
	Yes	No	Yes	No	Paper	Ball
Lisebo	✓		✓		✓	
Lehana	✓		✓		✓	
Motena	✓		✓			✓
Makalo		✓	✓			✓
Karabo	✓		✓		✓	
Seboka	✓		✓		✓	
Fumane	✓		✓			✓
Masilo	✓		✓		✓	
'Mamosa		✓	✓			✓
Selomo	✓		✓		✓	

The following trends are observable from the table.

- Six learners indicated that they could see the Earth from the 4 o'clock position of the Waxing Gibbous moon shape, and further indicated that they could see the Moon from the 9 o'clock position of the earth shape. In addition, these learners selected paper to represent the Moon. These responses suggest that the six learners interpreted the earth and the moon shapes as representing two-dimensional objects.
- Two learners (Motena and Fumane) indicated that they could see the Earth from 4 o'clock position of the Moon in Waxing Gibbous position, and further indicated that they could see the Moon from 9 o'clock position of the earth shape. These responses suggest that they interpreted both the earth shape and the moon shapes as representing two-dimensional objects. However, these two learners selected a ball as representing the Moon, suggesting that they interpreted the Moon as a three-dimensional object. This result shows inconsistency in learners' interpretation of the diagram, similar to inconsistencies reported by Vosniadou et al. (2004, 2005).

The remaining two learners (Makalo and 'Mamosa) indicated that they could not see the Moon from 9 o'clock position of the earth shape. However, they indicated that they could see the Earth from 4 o'clock position of the Waning Gibbous moon shape in the inner oval. These responses suggest that they interpreted the earth shape as representing a three-dimensional object but interpreted the moon shapes as representing a two-dimensional object. Despite this interpretation, these learners selected a ball to represent the Moon. These responses show inconsistency in their responses, again similar to inconsistencies reported by Vosniadou et al. (2004, 2005).

Overall, there appear to be no link between learners' spatial ability skills and interpretation of the three-dimensional nature of the Earth and the Moon in Diagram 24. That is, high spatial-ability

learners were not necessarily better than low spatial-ability learners at interpreting the Earth and the Moon as spherical objects (i.e. in assigning three-dimensional interpretations to two-dimensional drawings).

8.4 Interpreting shape of the Moon's orbital path

I used Diagrams 24 and 19 to investigate learners' interpretation of circular and oval shapes of the Moon's orbital path. Diagram 24 (Figure 8.1, p 209) illustrates the Moon's orbital path as oval in shape while Diagram 19 (Figure 8.2, p 234) illustrates this orbital path as circular in shape. No explanations have been given to explain the reason for the shape of the Moon's orbital path in each diagram. Two possible explanations can be attributed to the difference in the shapes of the Moon's orbital path. First, artists of Diagram 24 might have conceived of the Moon's orbital path as oval in shape, while artists of Diagram 19 might have conceived of the Moon's orbital path as circular in shape. Secondly, artists of both diagrams might have conceived of the Moon's orbital path as circular in shape, but used circular and oval shapes as depth cues indicating perspective. The artists of Diagram 24 might have drawn the Earth-Moon-Sun system as seen at some angle from above the Earth and the Moon so that the Moon's orbit appears to be oval in shape. On the other hand, the artists of Diagram 19 might have drawn the Earth-Moon-Sun system as seen from above the Earth and the Moon so that the Moon's orbital path appears to be circular in shape. This would be scientifically incorrect because the trace of Africa is shown on the earth shape, suggesting that the Earth has been drawn as seen from the side not from one of the poles. The following sections discuss learners' interpretation of these orbital paths in Diagrams 19 and 24.

8.4.1 Radiating Lines

The purpose of this section of the interview was to investigate learners' interpretation of lines between the Earth and each of the eight moon shapes in the inner oval in Diagram 24. Artists of the diagram provided no information explaining the purpose of these lines. Two possible interpretations can be attributed to these lines, depending on learners' interpretation of the shape of the Moon's orbital path. Learners who interpret the oval shape as suggesting that the Moon's orbital path is oval in shape are likely interpret the lines as indicating the distance of the Moon from the Earth. These learners might interpret the Moon as being closest to the Earth during First and Last Quarter phases, and being furthest from the Earth during Full Moon and New Moon phases. On the contrary, learners who interpret the oval shape as indicating perspective are likely to relate length difference of the radiating lines to position of diagram viewers relative to the Earth and the Moon. The following discussion presents learners' interpretation of these lines.

Meaning of the lines

Each learner was asked to describe what they thought the radiating lines represented.

- Six said that the lines help viewers to look at specific positions of the Moon using the earth shape as a reference point. The following extracts illustrate these responses.

R: now, we have these lines (*radiating lines*). See them?

Lisebo: yes

R: what do you think they mean? What do you think the artist is trying to tell us?

Lisebo: they're indicating, okay, once the Moon reaches that side of the Earth (*pointing at First Quarter in the inner oval*) it will take that form (*First Quarter in the outer oval*)

Radiating lines: visual aids for looking at moon from earth

Another example

R: okay, what do you think are these lines (*radiating lines*)? We've talked about the Earth; we've talked about the moons. What do you think are these lines?

'Mamosa: I think it's as we look at the Moon (*short pause caused by noise from outside*)

R: sorry you were saying?

'Mamosa: these lines are when you look, I think these lines are, If they were labelled they would be labelled as our view point or something, something about looking at the Moon.

R: what do you mean?

'Mamosa: it's as we look at the Moon, if you're on earth and you want to see this moon (*pointing at Waning Crescent in the inner oval*), follow this line (*pointing at the line between the earth shape and the Waning Crescent moon shape*).

Radiating lines: visual aids for looking at moon from earth

- ✦ Three learners (Lehana, Makalo and Masilo) associated the lines with compass directions. The following extract gives an example of these responses.

R: alright, we are generally done with this diagram. You see, because I wanted to know what the entire diagram shows, we have these lines here (*referring to lines between the earth and the moon shapes in the inner oval*), you see them

Lehana: mmm

R: what do you think they mean?

Lehana: I don't know

R: you don't know?

Lehana: maybe it's the directions of the moon

R: directions of the Moon? Please explain further

Lehana: like, this is when the Moon is north (*pointing at the line between the Earth and Last Quarter shape in the inner oval*) and south (*pointing at the line between the Earth and the First Quarter shape in the inner oval*) I don't know.

R: oh this is when the Moon is north and this is when the Moon is south

Lehana: maybe

Radiating lines: indicators of compass directions

- ✦ One learner said that the lines indicate dates.

R: ... You see there're lines here (*pointing at radiating lines*)

Karabo: mmmh

R: what do you think they mean? What do you think the artist wanted us to get out of the lines?

Karabo: I think it's just to show (*pause*)

R: to show?

Karabo: I don't know, okay, like if there were dates (*pointing at the lunar shapes in the inner oval*), to show like which date it would be, it's just a line pointing to where

R: line pointing to where?

Karabo: yes

Indicators of date

None of the learners thought that these lines indicated perspective. It appears as if all the learners interpreted the lines as cues helping viewers to focus at the Moon in a particular position using the earth shape as a reference point.

Reason for length difference between the lines

Learners were asked to explain why the lines were drawn to be different in length, i.e. why the artist drew some lines to be longer than others. All learners said that the longer lines indicated that the Moon would be further from the Earth, while the shorter lines indicated that the Moon would be closer to the Earth. The following extracts illustrate these responses.

R: okay, why do you think the artist drew this line (*between the Earth and First Quarter*) as shorter than this line (*between the Earth and Full Moon*)?

Seboka: because the Moon doesn't make round circle, it makes an oval circle

R: oh the Moon makes an oval circle

Seboka: yes

Oval orbit: distance between earth and moon

Another example

R: okay, I'd like you to look at this line (*between the Earth and First Quarter*) and that line (*between the Earth and Full Moon*) and tell me about them.

Selomo: (*not audible*)

R: this one is shorter you see?

Selomo: ja

R: that one is longer

Selomo: ja

R: what do you think could be the reason behind?

Selomo: this one is shorter because the Moon would be closer to the Earth and this one is longer because the Moon would be further from the Earth

R: alright, why do you think so?

Selomo: I'm not sure because as far as I know the Moon does not move in a complete circle, it's like, spins like, almost like an oval shape

R: oh the Moon spins like an oval

Selomo: like an oval ja

Oval orbit: distance between earth and moon

These responses suggest that none of the learners interpreted the length difference between the lines as indicating that the plane of the Moon's orbital path differs from the plane of the paper. The responses indicate that all learners interpreted the Moon's orbit as oval in shape, so that the Moon is closest the Earth during first and Last Quarter phases, and furthest from the Earth during New Moon and Full Moon phases.

The fact that the diagrams had no textual information explaining the purpose of the lines suggests that learners' verbal systems were not active in the beginning of information processing. The dual coding theory proposes that learners engaged in representational processing to perceive information illustrated on the diagram, and then engaged in referential processing when explaining what the lines represented. However, none of the learners interpreted the lines as depth cues indicating perspective. It is possible that learners could have performed better if textual information was provided to explain the purpose of the lines (interpretation of Diagrams 21a and 21b shows that the presence of verbal information helps the learners to better interpret diagrams). That is, the representational processing would have involved both the verbal and the nonverbal systems, which might help the learners to better understand the purpose of the lines.

8.4.2 Interpretation of circular and oval orbital paths

Table 8.4 illustrates design problems identified on Diagram 19 (Figure 8.2, p 234), and further shows that the interview was designed to minimize impact of the design weaknesses on interpretation of the diagram.

Table 8.4 Impact of design problems on interpretation of Diagram 19

Principle	Nature of violation	Implication on interpretation
Harmony	Darkness of the unlit part of the Moon differs from the darkness of the night sky.	None of these violations has to do with the shape of the Moon's orbital path. As a result, the violations would have no impact on learners' interpretation of the shape of the Moon's orbital path.
	Symbols representing the Moon in the orbital path are much larger than symbols representing phases of the Moon	
Non ambiguity	The invisible part of the Moon can be seen (as black) on the diagram.	
Scientific accuracy	The Moon's orbital path is incorrectly drawn as circular	The circular orbital path creates avenue for the researcher to investigate learners' interpretation of this shape.
Audience compatibility	The Moon's orbit and phases are drawn as seen from the Northern hemisphere	The order of moon phases could not distract learners from interpreting the shapes of the Moon's orbital path.

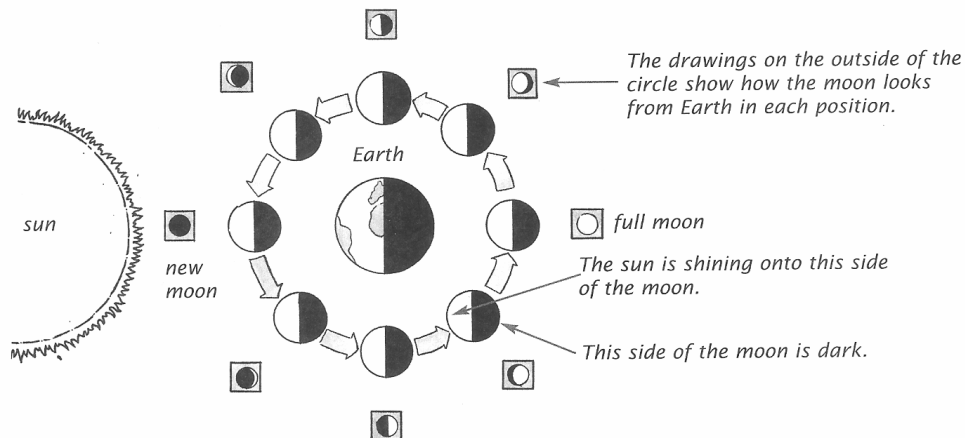
Sometimes the moon looks like a full circle of light, sometimes it is like a half circle and at other times it is not there at all. Why does the moon change shape?

We can see the moon in the sky because it reflects light from the sun. As the moon orbits the earth, different parts are lit up by the sun's light. When the moon is between the Earth and the sun, the side of the moon that faces the Earth does not get any sunlight. It is so dark that we cannot see it. We call this **new moon**. When the moon is on the other side of the Earth, it is fully lit and so looks like a round ball of light. We call this **full moon**. The amount of the moon that we can see from Earth slowly decreases between full moon and new moon and slowly increases between new moon and full moon. These different shapes of the moon are called the **phases of the moon**.

Important ideas!

The moon travels around, or orbits, the Earth once every 29 days and 13 hours, that is, about once a month

The shape of the moon that we see from Earth keeps changing because, as the moon orbits the Earth, we can only see the part of the moon that is in the sun's light.



The shape of the moon that we see from Earth keeps changing



Activity...

Keep a moon diary. Choose a way to record how the moon looks every night for one month. Show and explain your diary to the rest of your class after the moon has orbited once.

Show that you can!

Carry out an investigation, collect information, present your information and discuss your findings.

Figure 8.2 A page illustrating Diagram 19

Learners were shown both Diagrams 24 (Figure 8.1) and 19 (Figure 8.2) together. They were asked to explain why they thought the Moon's orbit was drawn as circular in one diagram and as oval in the other diagram. The following discussion presents their responses.

- Three interpreted the circular shape as representing view of the Moon's orbit from the top (bird-eye's view) and interpreted the oval orbit as representing view of the Moon's orbit from some angle from the top. The following extracts illustrate their responses.

R: ... Why do you think the artist drew this as a circle and this as an oval?

Lisebo: maybe it's the way they were looking at it. Say that (*Diagram 19*) is a bird eye's view and it's going in a circle. Say you're standing, you look (*she put the half-shaded ball on the table*); it will go that way (*she circled her right hand around ball*). If you're standing at the side it will go that way (*lifting the ball in space, and moving her hand around the ball*)

R: you see we have two diagrams here

Lisebo: yes

R: so which one do you think is which?

Lisebo: this one (*Diagram 19*) will be the one where you're standing (*she put the ball on the table*) and you're looking at it like that (*she moved her hand in a circular shape around the ball*), it's going in a circle, and that one (*Diagram 24*) will be an oval shape (*she lifted the ball in space, but the hand movement was not visible on the video*)

shape of moon's orbit: perspective

The second learner

R: why do you think the artist has drawn that one as circular and this one oval?

Fumane: I think maybe, because, ja, I think maybe he's drawn it from this angle for example (*putting her hand above Diagram 24*)

R: sorry

Fumane: maybe he's looking at it from this angle, like I'm looking at this (*pointing at the object in front of her on the table, indicating viewing the object at some angle from the vertical*)

R: sorry which diagram are you talking about?

Fumane: this one (*pointing at Diagram 24*). I'm looking at this thing (*top of the cylindrical object on the table*). When I look at this it doesn't look round it looks oval. So maybe he's looking at it from the angle that would actually look oval, or he just wants it to look that way.

R: and that diagram (*Diagram 19*)?

Fumane: and this one here I think maybe he's looking at it straight down; like this (*Diagram 19*) is the bird's eye view and this one (*Diagram 24*) is from the side but at an angle

shape of moon's orbit: perspective

The third learner

R: ... Let's take another diagram (*placing Diagram 19 next to Diagram 24*). You see this diagram (*Diagram 19*) differs from that one (*Diagram 24*)

Selomo: yes

R: what are the differences?

Selomo: this one (*Diagram 19*) looks like you're looking from the top

R: this one looks like you're looking from the top, and that one?

Selomo: is like you're looking from an angle (*using his hand to illustrate looking down at some angle, perhaps 45° from the horizontal*)

shape of moon's orbit: perspective

- Three other learners interpreted the oval and circular orbits as indicating the distance of the Moon from the Earth.

R: you said this one (*Diagram 24*) moves in an oblong way

Makalo: and this one (*Diagram 19*) moves in a circle

R: why do you think the artist has drawn this in an oblong way, and that one as a circle?

Makalo: I am not too sure about that

R: you're not too sure about that?

Makalo: I've not experienced it

R: you've not experienced it but maybe

Makalo: maybe because, maybe this (*Diagram 19*) is probably taken from a further point of view, than this one over here (*Diagram 24*)

R: alright, I want you to explain to me what you mean by further point of view. What could that mean?

Makalo: meaning that someone could have been here (*Earth in Diagram 24*) ... a near range and this one (*Diagram 19*) could have been from long range, that actually from long range looks like a circle and in near range it looks like that (*pointing at Diagram 24*)

shape of moon's orbit: distance between earth and moon

The second learner

R: alright, why do you think the artist has drawn this one as an oval and this one as circular, do you think that has any importance?

Karabo: no I don't

R: okay, it just happens to be?

Karabo: it could be, okay, it could be, using the lines again (*radiating lines on Diagram 24*), it could be this one (*Diagram 24*) from a far view and this one (*Diagram 19*) from a closer view

shape of moon's orbit: distance between earth and moon

The third learner

R: and why do you think the artist has drawn this (*Diagram 19*) as circular and that (*Diagram 24*) as oval?

Masilo: I think it's (*long pause*),

R: what are you thinking, tell me

Masilo: I think these are drawn by different people, and maybe with different ideas so I think it will be drawn differently, may be he (*pointing at Diagram 24*) had deeper meaning and wanted to express more understanding to people about the Moon so he has drawn it differently, and he (*pointing at Diagram 19*) was just may be talking about the basics

R: could there be deeper a meaning behind the circle, one being circular and another being an oval?

Masilo: yes

R: what could that be?

Masilo: I think this, the oval could be pointing the distance away from the Earth, and the circle would just show us that it goes around.

shape of moon's orbit: distance between earth and moon

- One learner said that the Moon's orbital path is oval in shape.

R: okay, why do you think the artist has drawn this as a circle and this as an oval?

Seboka: I think this artist (*pointing at Diagram 24*) was trying to be more specific

R: mmmm

Seboka: and this artist (*pointing at Diagram 19*) was trying to do this thing in general

R: more specific to what?

Seboka: to how the Moon rotates around the Earth

R: how does it rotate around the Earth?

Seboka: in an oval-like manner, because depending on whether the Moon is closer or further to Earth we get a high tide or a low tide

shape of moon's orbit: distance between earth and moon

- ✦ Three learners (Lehana, Motena and 'Mamosa) said that they did not know why the orbital path was drawn as circular in one diagram and as oval in another diagram.

The results indicate that only three learners interpreted circular and oval orbital paths as indicating the plane of the Moon's orbital path.

8.4.3 Summary

Table 8.5 summarizes learners' interpretation of the shape of the Moon's orbital path.

Table 8.5 Learners interpretation of the shape of the Moon's orbital path (on Diagrams 19 and 24)

Learners	Interpretation of radiating lines		Interpretation of circular and oval orbital paths	
	Perspective	Other	Perspective	Other
Lisebo		✓	✓	
Lehana		✓		✓
Motena		✓		✓
Makalo		✓		✓
Karabo		✓		✓
Seboka		✓		✓
Fumane		✓	✓	
Masilo		✓		✓
'Mamosa		✓		✓
Selomo		✓	✓	

The following results are observable from the table.

- None of the learners interpreted radiating lines as indicating perspective from which the Moon's orbit has been drawn. This suggests that all learners failed to interpret this convention, a situation different from that seen in Chapter 7 where learners were able to interpret three conventions used in Diagrams 21a and 21b. It has to be noted, however, that Diagrams 21a and 21b provided hints that helped the learners to interpret conventions, while Diagram 24 provided no hints to help learners to interpret the radiating lines. It is possible that learners failed to interpret this convention because there is no information helping them to interpret this convention.
- Only three learners interpreted the oval and circular orbital paths as indicating perspective from which the Moon's orbit has been drawn. It appears that only these learners have been able to interpret the depth cue. These results support observation made by Seddon and his associates, who found that some high school students have problem of interpreting depth cues (e.g. Nicholson & Seddon, 1977; Seddon et al., 1984). For example, the majority of high school students who participated in their research struggled to interpret depth cues needed to understand three-dimensional nature of molecular structures.
- Both low and high spatial-ability learners had problems of interpreting this convention. Thus, there appears to be no link between learners' spatial abilities and their interpretation of this convention. This result corroborates findings discussed in Section 7.7 (p 206), where only weak links were observed between spatial ability and learners' interpretation of conventions used in Diagrams 21a and 21b.

8.5 Summary: Interpretation of the three conventions

Table 8.6 summarizes learners' interpretation of conventions investigated in this chapter. The table shows some link between spatial ability and learners' interpretation of black and white colours in shapes in the outer oval in Diagram 24. That is, high spatial-ability learners correctly interpreted these colours while the majority of low spatial-ability learners encountered problems with these colours. As discussed in Section 8.2.3 (page 219), it is possible that the high spatial-ability learners were able to interpret these colours because earlier in the interview, they had correctly determined the shape of the Moon visible from earth when the Moon is in selected positions in its orbital path around the Earth.

The table shows no links between spatial ability and learners' interpretation of the last two conventions. That is, both low and high spatial-ability learners encountered problems of interpreting the earth and moon shapes as representing spherical objects. Furthermore, seven learners failed to interpret the shape of the Moon's orbital path as indicating perspective from which the Moon's orbit has been drawn, while the remaining three partly interpreted this convention.

Table 8.6 Summary of learners' interpretation of three conventions investigated in Chapter 8

Learner	colours on Moon phases	Earth and Moon as 3-dimensional						Interpreting shape of Moon's orbital path			
		Perceiving beyond Earth		Perceiving beyond Moon		Object representing Moon		Interpretation of radiating lines		Interpretation of circular and oval orbital paths	
		Yes	No	Yes	No	Paper	Ball	Perspective	Other	Perspective	other
Lisebo	✓ x	✓		✓		✓			✓	✓	
Lehana	✓ x	✓		✓		✓			✓		✓
Makalo	✓ x	✓		✓			✓		✓		✓
Motena	✓		✓	✓			✓		✓		✓
Karabo	✓ x	✓		✓		✓			✓		✓
Seboka	✓	✓		✓		✓			✓		✓
Fumane	✓	✓		✓			✓		✓	✓	
Masilo	✓	✓		✓		✓			✓		✓
'Mamosa	✓		✓	✓			✓		✓		✓
Selomo	✓	✓		✓		✓			✓	✓	

The last two conventions investigated learners' ability to interpret the earth and moon shapes as representing spherical objects, and the shape of the Moon's orbit as indicating perspective from which the orbit is seen. One would expect to find links between spatial ability and learners interpretation of these conventions (more so because clearer links were found between spatial ability and learners' ability to determine shape of the Moon seen from earth for selected configurations of the components of the Earth-Moon-Sun system). However, all learners generally struggled to interpret these two conventions. There are some possible explanations for this problem.

First, artists of the diagrams used two-dimensional shapes to represent the Earth and the Moon, but used no depth cues to help viewers interpret the shapes as representing spherical objects. It is possible that the learners misinterpreted this convention because of problems in design of the diagrams. The fact that one learner (Selomo) said that the terminator line would have to be slanted if the shapes were illustrating spherical objects helps to justify that flaws in design of diagrams might have resulted in interpretation problems.

Secondly, artists of the two diagrams provided no inscriptions to explain reasons for the shape of the Moon's orbit. Two possible interpretations might be ascribed to these shapes: either as indicating the actual shape of the orbit, or perspective from which the orbit has been drawn. The learners tended to interpret the shapes as indicating the shape of the orbit rather than perspective from which the orbit has been drawn. The fact that no inscriptions were provided to give the necessary explanation suggests that learners might have misinterpreted the convention because of diagram design flaws.

8.6 Evidence for poor background knowledge

A recent study shows that background knowledge affects learners' interpretation of diagrams (Schönborn & Anderson, 2009). The purpose of conducting interviews in my study was to investigate learners' interpretation of diagrams illustrating phases of the Moon, not to investigate learners' background knowledge on phases of the Moon. However, the following issues relating to poor background knowledge emerged during the interviews.

8.6.1 The cause of moon phases

In the course of interviews, four learners used statements suggesting that the shadow of the Earth causes phases of the Moon. Three of these learners gave these responses when interpreting Diagram 21b, as illustrated in the following extracts.

R: okay, why do you think the artist has drawn these shapes to be different?

Seboka: because the Moon doesn't stay one shape all the time

R: it doesn't stay one shape all the time, it?

Seboka: (*inaudible*)

R: please explain that to me

Seboka: because at different times

R: mmm

Seboka: the Earth might be in the way of, might be between the Sun and the Moon

R: mmmh

Seboka: so then the shadow of the world will be on the Moon, which will make the shape change because the dark part we can't see

The second learner

R: okay, let's take it one step further. I'm going to show you the second page. You see that is page 26, this is page 27; both are from the same book. So you see that page first and then this one. So I'd like you to look at this diagram (21b), and tell me what you think it's telling us.

Fumane: the different moons we get, like you get Full Moon, half moon, like all the different types of moons.

R: explain further

Fumane: (*silent*)

R: what do you mean types of moon? What are the types of moon?

Fumane: it's these here, the names (*pointing at the names*). Must I say the names?

R: you could say some of them maybe.

Fumane: okay, the Full Moon it's the Moon where it doesn't have a shadow over it, or something in the way of it to make it for example the Last Quarter.

R: okay

Fumane: it's one Moon but it's the different shadows that fall over that make it a different kind of shades and then it's a different name.

The third learner

R: alright. Now here is another diagram (Diagram 21b) you see these two are from the same book, actually this is Page 26 that is Page 27 so have a look at this (*Diagram 21b*) and tell me what you think it's telling us.

Selomo: it's telling us about different quarters of the Moon, when the Sun shine whether it's New Moon or Full Moon

R: if you can try to speak louder

Selomo: okay it shows, okay it shows the, the, the different way the Moon, the Sun catches the Moon's light, and it shows the way the Moon looks when the Sun is in different places and the Moon is in different places

R: the way the Moon looks?

Selomo: in different places around

R: around?

Selomo: around the Earth

R: can you tell me, why are they different in shape?

Selomo: because the Sun, sometimes the Earth blocks part of the Moon.

R: mmmh

Selomo: so the Sun only catches a little bit of the Moon so that's why it's different here so for the Full Moon, the Moon is out in the open there is nothing blocking it

The fourth learners gave this response when interpreting Diagram 24.

Lisebo: say like here (*Waxing Crescent in the inner oval*) this is the position and there (*Waxing Crescent in the outer oval*) they show you the shape when the Moon is in that position

R: okay. Let's take this very one that you've indicated (*pointing at Waxing Crescent*), or let's start with this one (*Waning Gibbous in the outer oval*). You said which one would be the position?

Lisebo: this here (*pointing at Waning Gibbous in the inner oval*)

R: and this one (*Waning Gibbous in the outer oval*) shows?

Lisebo: shape

R: please draw the shape that you would see

Lisebo: (*she drew a crescent-shaped moon*)

R: and tell me what is giving you a clue about that

Lisebo: the way it stands, and the Sun or maybe the shadow of the Earth would be cutting off that part of the Moon (*pointing at the white section of the Moon*) and you will only be able to see that part (*pointing at the black section of the Moon*)

R: okay let's start. You say the

Lisebo: maybe the shadow, when it's night time, the shadow of the Earth would be covering that part (*white section of the Moon*) and you'll see only the quarter part (*pointing at the black section of the Moon*)

These responses support results obtained in Question 5 of the diagnostic test, which showed that the majority of learners associated the Earth's shadow with phases of the Moon. In addition, the response supports the argument of Engeström (1991) who proposed that exaggeration of relative sizes and distances between the Earth, the Sun and the Moon might enhance a common misconception in which people consider the Earth's shadow as causing phases of the Moon.

8.6.2 Time lapse between phases of the Moon

Two learners appeared to have wrong ideas about the time lapse between phases of the Moon. For the first learner, this idea came during interpretation of Diagram 21a (Figure 7.1, p 157).

R: okay, and these circles, what are they (*pointing at the moon shapes in this diagram*)?

Selomo: they're supposed to be the Moon

R: the Moon?

Selomo: ja

R: alright, why has the artist drawn, you see there are about eight here, why do you think the artist has drawn eight of those shapes?

Selomo: to show the different places, the way the Sun can catch the Moon in different places, different times maybe.

R: please explain further

Selomo: like say for instance like here (*pointing at Last Quarter*) it's like ten o'clock, one o'clock (*pointing at Waning Crescent*), maybe the next day (*pointing at New Moon*), maybe the next day at ten o'clock (*pointing at Waxing Crescent*), maybe 12 o'clock (*pointing at First Quarter*)

R: is it the same moon?

Selomo: eeerrr, ja

For the second learner, this idea came during interpretation of Diagram 21b (Figure 7.2, p 174).

R: okay, now I want us to take it one step further. Look at this diagram (Diagram 21b), this is what happens, these two diagrams actually are from the same book. You see this is Page 26 and this is Page 27 of one book, so that diagram (Diagram 21b) follows this diagram (Diagram 21a) exactly, so I'd like you to look at this diagram (Diagram 21b) and tell me what you think is happening here.

Lehana: isn't this the different times (*pointing at different lunar phases*), how the Moon becomes during the day

R: what do you mean?

Lehana: I think maybe like now it's early, it's Full Moon now, may be by the end of the day it will be crescent

R: so you say it is early in the day now

Lehana: ja

R: it could be

Lehana: New Moon

R: it could be New Moon

Lehana: ja

R: and then

Lehana: then during the day the types of moon change

These two responses are consistent with results obtained in Question 1 of the diagnostic test which indicated that learners who participated in this study did not know the duration of a complete cycle of phases of the Moon (see details in Section 4.4.1, pp 88-89). In addition, these two responses support results obtained in Question 3 of the diagnostic test which show that the learners did not know time lapse between phases of the Moon.

8.6.3 Usage of non-scientific language

- Five learners used inaccurate phrases when describing phases of the Moon. Three learners referred to phases of the Moon as 'types of moon'. The following extracts illustrate this point.

R: alright, let's take it one step further. I'd like you to have a look at this one diagram (21b). What happens, check, this is Page 26, that is Page 27 the two are from the same book. Please look at this (*Diagram 21b*) and tell me what you think it's telling us, what the artist is trying to tell us here.

Makalo: different types of moons

The second learner

R: okay. Here is another page. In fact, if you look at this, this is page 26 that is page 27, so the two are actually from the same book, that page follows this one, so I'd like you to look at this diagram (21b) and tell me what you think is going on here.

Lisebo: these are the different types of moons

The third learner

R: okay, let's take it one step further. I'm going to show you the second page. You see that is Page 26, this is Page 27; both are from the same book. So you see that page first and then this one. So I'd like you to look at this diagram (21b), and tell me what you think it's telling us.

Fumane: the different moons we get, like you get Full Moon, half moon, like all the different types of moons.

Two learners referred to the phases of the Moon as 'quarters of the Moon' as indicated in the following extracts

R: alright. Now here is another diagram (*Diagram 21b*) you see these two are from the same book, actually this is Page 26 that is Page 27 so have a look at this (*Diagram 21b*) and tell me what you think it's telling us.

Selomo: it's telling us about different quarters of the Moon, when the Sun shine whether it's New Moon or Full Moon

The second learner

R: okay, this is one page from a science textbook (*Diagram 21a*). Here we have another page from the same book, this is Page 26, that is the very following page, 27, so I want you to look at this diagram (21b), and tell us what you think the diagram is telling us.

Seboka: by looking at it I think it tells us the quarters of the Moon

These results suggest that the learners did not read two captions available on the page; the first "The phases of the Moon" written in bold on top of the page, and the second "the eight phases of the Moon" written below the diagram.

- Three learners used inaccurate terms when describing individual phases of the Moon. Two of these learners used the term 'quarter moon' for crescent and/or gibbous phases.

R: okay, this is what I want you to do, as the second thing, I want you to look at this diagram, take your time, look at it, and tell me exactly what you think the artist is trying to show us, what the diagram is telling us.

Masilo: okay

R: everything that you think the diagram is telling us

Masilo: okay, I think the artist was trying to point out the Moon and how visible the Moon would be in each picture because here it says it's a New Moon (*pointing at the label 'New Moon'*), I think it's a quarter of

the Moon (*pointing at Waxing Crescent*), half (*pointing at First Quarter*) quarter (*pointing at Waxing Gibbous*) and we have Full Moon (*pointing at Full Moon*)

Another learner

R: okay, here is another issue; you see we have dots inside there (*dots inside the moons in Diagram 21a*)

Lisebo: yes

R: what do you think they are telling us? What's the artist telling us?

Lisebo: maybe it's for quarter part that's light (*pointing at the Waxing Gibbous*), maybe it's the arrows going

The extract from Masilo's response suggests that he used 'quarter' as a name for moon phases. This in turn suggests that he did not read names of moon phases written below each phase. It is possible that he thought that the crescent showed quarter of the Moon. However it is difficult to understand why he used 'quarter' to describe the gibbous shape.

The third learner referred to Waning Crescent as one third of the Moon, as indicated in the following extract.

R: alright, let's look at this diagram (*Diagram 24*). Have a look at the diagram and tell me what you think it's showing.

Makalo: it shows the phases of the Moon

R: where are they? What gives you that clue?

Makalo: because of, we do get quarter moon, Full Moon, and so on, so whenever it's like this (*Waning Gibbous in the outer oval*) it's one phase of the Moon and this is half moon (*Last Quarter in the outer oval*), this (*Waning Crescent in the outer oval*) is maybe one third of the Moon

Referring to the Waning Crescent phase as one third of the Moon suggests that he did not read the label 'crescent' written below the Moon. In addition, this response suggests that he considered the crescent as one third of the Moon, or that he possibly confused 'third' with 'quarter'.

- Six learners (Lehana, Masilo, Makalo, Lisebo, Karabo and Motena) used the terms 'rotate' and 'rotation' to describe the Moon's orbiting of the Earth. The following two extracts illustrate these responses. The first extract is taken from Lisebo's interpretation of Diagram 21a.

R: alright, I want you to look carefully at the diagram, and tell me exactly, the message that the diagram is conveying to us. What is it saying, what does the artist want us to understand from this diagram? Study it carefully and then tell me.

Lisebo: (*silence*)

R: what are you thinking?

Lisebo: it's telling us about the rotation of the Moon (*moving her hand along the Moon's orbit*), how it moves around the Earth, and how it gets Full Moon, half a moon, quarter moon and all that.

The second is taken from Karabo's interpretation of Diagram 24.

R: okay. Here's another diagram (*Diagram 24*). Have a look at the diagram and tell me what you think the diagram is showing.

Karabo: I think again this is the Earth (*at the centre*) and this is the circle of the Moon (*pointing at the inner oval*)

R: that's all?

Karabo: [*not audible*]

R: can you tell me everything that you think is here, you've talked about the Earth

Karabo: okay, these pictures (*pointing at the outer oval*) tell me something different

R: from?

Karabo: from these (*pointing at the inner oval*)

R: alright, what does each of those tell you? Start with any of the two

Karabo: okay, obviously these ones (*outer oval*) it's half moon (*pointing at Last Quarter*), crescent ... and crescent again, half moon, you know, it's Full Moon

R: alright, and this one? (*referring to the inner oval*)

Karabo: these ones?

R: mmm

Karabo: just rotation

R: of

Karabo: the Moon

These results are consistent with previous research which shows that people use the terms 'rotate' and 'revolve' interchangeably (e.g. Parker & Heywood, 1998 and Stahly et al., 1999). Interestingly, Lelliott and Rollnick (2010) observed while reviewing astronomy education research, that even researchers sometimes use these terms interchangeably.

The results obtained in this study are consistent with findings reported in literature, which show that poor background knowledge interferes with interpretation of diagrams. For example, Colin et al. (2002) showed high school students a diagram illustrating an object, a converging lens, and an image of the object formed on a screen, and asked the students to explain what would happen to the image if the screen was moved away from an object. The majority of students said that the image would move with the screen, but would be blurred and bigger. This response indicates that the learners had poor background knowledge on the topic (in fact, the image appears to be large and blurred because of being in front of the screen).

In another study (Khanyane, 2002), ten learners were asked to interpret a ball and stick model of atoms making an ozone molecule. Two of these learners said that the 'balls' represented oxygen molecules while another learners said that the balls represented ozone molecule (the balls actually represented oxygen atoms).

8.7 Answers to Research questions 4 and 5

This section provides answers to Research questions 4 and 5.

8.7.1 Research question 4

The fourth research question has been phrased as follows:

What interpretations do learners assign to components of diagrams illustrating phases of the Moon, and what does this imply about learners' interpretation of conventions used in these diagrams?

This study investigated learners' interpretation of the following six conventions:

1. *The same symbol appears more than once, representing different entities. That is, (a) half-shaded circles represent the Earth and the Moon, and (b) arrows represent the directions of the Moon's orbit and the Sun's rays.*

The discussion in Section 7.5.1 (p 181) shows that eight learners correctly interpreted the Earth and the Moon in Diagram 21a. This suggests that the eight learners correctly interpreted this convention when used to illustrate the Earth and the Moon.

The discussion further shows that nine learners correctly interpreted parallel arrows as representing the Sun's rays, and interpreted arrows in the Moon's orbital path as indicating the direction of the Moon's orbit. This suggests that the nine learners were able to interpret this convention when used to represent the Sun's rays and the Moon's orbital path.

2. *The same symbol appears more than once, representing the same entity as it changes position (i.e. eight circles represent one not many moons)*

The discussion in Section 7.5.2 (p 182) shows that nine learners correctly interpreted the Moon's orbital path in Diagram 21a. This suggests that the nine learners correctly interpreted this convention.

3. *Different symbols represent the same entity as it changes shape, i.e. phases of the Moon indicate one object (the Moon) changing shape.*

The discussion in Section 7.5.3 (p 183) shows that all learners correctly interpreted shapes in Diagram 21b as phases of the Moon. This suggests that all the learners were able to interpret this convention.

4. *Black and white colours indicate parts of the Moon visible and not visible from Earth.*

The discussion in Section 8.2 shows that six learners correctly interpreted the white colour as representing part of the Moon visible from Earth and the black colour as representing part of the Moon not visible from Earth (see Table 8.2, p 218). The discussion further shows that the

remaining four learners appeared to be uncertain as to what these colours represented. This suggests that only six learners correctly interpreted this convention.

5. *Circles (without depth cues) represent spherical objects.*

The discussion in Section 8.3 shows that learners tended to interpret the Earth and the Moon as two-dimensional objects (see Table 8.3, p 229). This suggests that in general, learners failed to interpret this convention.

6. *Shape of the Moon's orbit indicates perspective from which the Moon has been drawn.*

The discussion in Section 8.4 shows that three learners partly interpreted shape of the Moon's orbital path as indicating perspective from which the Moon has been drawn (see Table 8.5, p 237).

In general, the discussion shows that learners were able to interpret the first three conventions which required usage of information (e.g. hints) available on the diagram. The discussion further shows that learners generally failed to interpret the last two conventions which required usage of information (e.g. depth cues) which were not provided in the diagram.

8.7.2 Research question 5

The last research question has been phrased as follows:

What links (if any) exist between learners' spatial ability skills and interpretation of diagrams illustrating phases of the Moon?

Accurate interpretation of diagrams illustrating phases of the Moon requires viewers to accurately interpret conventions. Weak links were observed between learners' spatial abilities and interpretation of Conventions 1, 2, 3, 5, and 6. However, there appeared to be a stronger link between spatial ability and learners' interpretation of the 4th convention (see for example Table 8.2, p 218). That is, high spatial-ability learners correctly interpreted the black and white colours on the phases of the Moon, while most of the low spatial-ability learners appeared to be uncertain as to what these colours represented.

As discussed in Section 8.2.3, it is possible that the high spatial-ability learners correctly interpreted these colours because they had, earlier in the interview, correctly determined the shape of the Moon seen from Earth when the Moon is in selected positions in its orbital path around the Earth. Thus, the task of determining Moon phases for a given Earth-Moon-Sun alignment might have interfered with investigation of learners' interpretation of these colours. As a result, it becomes difficult to ascertain whether spatial ability (without interference of this activity) would have links with

learners' interpretation of these colours. In general, there appears to be weak links between spatial ability and learners' interpretation of conventions, except for the 4th convention.

In addition to conventions, accurate interpretation of diagrams illustrating phases of the Moon requires learners to understand why the Moon appears to take a particular shape for a given Earth-Moon-Sun alignment. The discussion in Section 7.6 reported learners' ability to determine the shape of the Moon visible from Earth for a given Earth-Moon-Sun alignment. This task required learners to mentally manipulate celestial objects in space (e.g. to imagine viewing objects from different perspectives). The discussion in Sections 7.6 shows links between spatial ability and learners' ability to determine the shape of the Moon visible from Earth for a given Earth-Moon-Sun alignment. That is, high spatial-ability learners were better able to perform this task than low spatial-ability learners.

The following answer can be provided to the research question: Results obtained in this study show weak links between spatial ability and learner's interpretation of conventions used in diagrams illustrating phases of the Moon. However, stronger links were observed between spatial ability and learners' manipulation of the components of the Earth-Moon-Sun system in space. That is, high spatial-ability learners were better able to mentally manipulate the Earth-Moon-Sun system in space than low spatial-ability learners.

8.8 Summary

This study investigated learners' interpretation of six conventions used in diagrams illustrating phases of the Moon, and further investigated learners' ability to mentally manipulate the Earth-Moon-Sun system in space. Chapter 7 presented learners' interpretation of the first three conventions, and further presented learners ability to mentally manipulate the Earth-Moon-Sun system in space. This chapter has presented learners' interpretation of the last three conventions. In addition, the chapter presented answers to the last two research questions. The next chapter summarizes findings of the study and provides answers to the research questions. Furthermore, the chapter discusses implication of the results on teaching and learning about phases of the Moon, suggesting ideas for further research concerning phases of the Moon.

Chapter 9 Summary and implications

9.1 Introduction

This study was motivated by the fact that many learners struggle to understand astronomy concepts associated with phases of the Moon, and as a result develop conceptual difficulties about these concepts. Several researchers propose that understanding these concepts requires people to mentally manipulate elements of the Earth-Moon-Sun system in space (e.g. Hans et al., 2008; Mulholland & Ginns, 2008; Wilhelm, 2009b). As a result, these researchers argue that learners need spatial ability skills to understand astronomy concepts.

Research shows that diagrams help learners to better understand science concepts (e.g. Braden, 1994; Mayer & Anderson, 1991). For this reason, many textbooks have diagrams illustrating these concepts. However, students sometimes struggle to interpret information illustrated in diagrams. Literature shows that people with good background knowledge on concepts illustrated in diagrams perform better on diagram interpretation, than people with poor background knowledge on these concepts. Additionally, this literature shows that composition of diagrams sometimes hinders learners from obtaining information intended by diagram illustrators. No research has been conducted to investigate learners' interpretation of diagrams illustrating concepts associated with the Earth-Moon-Sun system. The current study investigated issues associated with composition of diagrams illustrating phases of the Moon, and learners' interpretation of these diagrams.

9.1.1 Research Questions

The following research questions have been answered by the study.

1. *What is the level of Grade 9 Natural Science learners' understanding of astronomy concepts associated phases of the Moon?*
2. *What is the level of Grade 9 Natural Science learners' spatial ability skills?*
3. *To what extent does the composition of diagrams illustrating phases of the Moon (in South African school textbooks) comply with design principles recommended in literature?*
4. *What interpretations do learners assign to components of diagrams illustrating phases of the Moon, and what does this imply about learners' interpretation of conventions used in these diagrams?*
5. *What links (if any) exist between learners' spatial ability skills and interpretation of diagrams illustrating phases of the Moon?*

9.1.2 Methodology

I administered a diagnostic test to investigate learners' understanding of concepts associated with phases of the Moon, and to further investigate their ability to mentally manipulate celestial objects in space. Data obtained from the diagnostic test provided an answer to the first research question. In addition, I administered six tests to measure learners' spatial ability skills. Data obtained from these tests provided an answer to the second research question. Additionally, I analyzed textbook diagrams illustrating phases of the Moon to investigate the extent to which their composition complied with design principles recommended in literature. Data obtained from this analysis provided an answer to the third research question. I used spatial ability test scores to select learners who interpreted diagrams illustrating phases of the Moon. Furthermore, I used diagram-analysis results to select diagrams that I used during interviews. Having selected the diagrams and the learners, I conducted interviews to investigate learners' interpretation of diagrams illustrating phases of the Moon. Results of diagram interpretation provided answers to the last two research questions.

9.1.3 Theoretical framework

Three constructs formed a theoretical framework used to design the study and interpret results: (i) the spatial ability theory which helped me understand data obtained from the spatial ability tests, and to investigate links between spatial ability and learners' interpretation of diagrams illustrating phases of the Moon, (ii) the theory of models which helped me interpret results obtained from analysis of these diagrams, and (iii) the theory of diagrams which helped me interpret results obtained from analysis and interpretation of these diagrams.

In the following discussion, I present results obtained from analysis of data obtained from spatial ability tests, diagnostic test, analysis of diagrams illustrating phases of the Moon, and learners' interpretation of these diagrams.

9.2 Learners' understanding of phases of the Moon

I have already indicated that the bulk of research dealing with phases of the Moon investigated students' ideas about the cause of moon's phases, but paid less attention to students' understanding of other concepts associated with these phases. The current study investigated students' understanding of the cause of moon phases as well as their understanding of other concepts associated with these phases. The results extend the existing body of knowledge about students' understanding of the Earth-Moon-Sun system.

I administered a diagnostic test consisting of ten multiple-choice questions (Questions 1 to 10) and one question requiring learners to draw responses (Question 11). Seven of the ten multiple-choice

questions (Questions 1 to 7) investigated learners' understanding of the Earth-Moon-Sun system with specific focus on phases of the Moon. Question 8 investigated learners' ability to use the Earth-Moon-Sun alignment to determine appearance of the Earth as seen from the Moon. Question 9 investigated learners' ability to determine phases of the Moon from a given Earth-Moon-Sun alignment illustrated in a diagram. Question 10 consisted of a diagram illustrating the Sun illuminating Mars and its two moons. The question required learners to determine appearance of one moon (Phobos) as seen from the other (Deimos). Thus, Questions 8 and 10 investigated learners' ability to execute skills required to understand phases of the Moon from diagrams. Question 11 investigated learners' ability to execute simultaneous rotations and revolutions required to understand phases of the Moon. I have shown in the course of this thesis that Questions 1-7 investigated learners' understanding of content prescribed by the curriculum while Questions 8-11 investigated learners' mastery of skills needed to understand this content (see details in Section 3.4.1, pp 65-68). I have also shown that the tests required learners to perform functions at Piaget's formal operational stage, and assumed that learners were at this stage (on the basis of their age and grade level).

Each question had a confidence scale asking learners to indicate how sure they were about their responses. In addition, Questions 8 to 11 (which had diagrams) each had a visualization scale asking learners to indicate the extent to which they were able to envision what the diagrams illustrated.

9.2.1 Summary of results

Data from the diagnostic test provided an answer to the first research question phrased as follows: ***What is the level of Grade 9 Natural Science learners' understanding of astronomy concepts associated phases of the Moon?***

Learners obtained very low scores in all the questions. In addition, most learners indicated that they were uncertain and/or had guessed answers in multiple-choice questions. Furthermore, most indicated that it was difficult for them to envision what the diagrams illustrated. Low scores obtained in Question 5 suggest that the learners had poor understanding of the cause of moon phases (supporting results reported in literature). In addition, low scores obtained in Questions 1, 2, 3, 4, 6, and 7 indicate that learners had poor understanding of other concepts associated with phases of the Moon.

Some questions in the test could be answered by using daily experience of moon phases (e.g. Question 6 which asked learners about the moon phase that rises at sunset). Poor performance on these questions suggests that the learners lacked daily experience of moon phases. These results help to caution teachers not to assume that all learners have this experience (the experience might help the learners to better understand concept associated with phases of the Moon).

Low scores obtained in Questions 8-to-11, and the fact that the majority of learners indicated that they could not envision what the diagrams illustrated, suggest that the learners lacked spatial ability skills needed to obtain information illustrated in these diagrams. These results are particularly

important because they show that learners lack spatial ability skills applicable in the context of phases of the Moon. These results call for real concern as spatial ability is needed to understand astronomy concepts. Poor performance in these questions helps to explain why many learners struggle to understand these concepts. That is, the concepts require use of skills which learners appear to be deficient in.

It is worthy to note that teachers of the school where data was collected had claimed to have taught the section of the curriculum dealing with phases of the Moon. However, the majority of learners indicated that they had not learned about phases of the Moon in this school. Some of the learners who participated in interviews mentioned that they had learned about other astronomy concepts than phases of the Moon. It appears that the teachers had skipped phases of the Moon while teaching the relevant section of the curriculum. The reason for this is not clear, but it is possible that the teachers lacked background knowledge on phases of the Moon. This would support an observation I made in two workshops conducted to highlight problems of teaching about phases of the Moon, and to suggest strategies to overcome some of these problems (Mosoloane & Sanders, 2006; Sanders, Mosoloane & Stanton, 2006). Teachers who attended these workshops were interested in learning about phases of the Moon, rather than learning about problems associated with teaching this topic. This suggests that the teachers had low conceptual knowledge about this topic.

9.2.2 Background knowledge of learners who participated in interviews

The discussion in Section 2.2.3 (p 49) shows that people with good background knowledge of concepts illustrated in diagrams are better able to interpret the diagrams than people with poor background knowledge of these concepts. Results obtained from the diagnostic test show that all learners had poor background knowledge of concepts associated with phases of the Moon. As a result, none of the learners selected to participate in interviews was advantaged by good background knowledge in the topic when interpreting the diagrams.

9.3 *Spatial ability*

I administered the following tests to measure learners' spatial ability skills: Hidden Patterns Test (CF-2), Card Rotations Test (S-1), Cube Comparisons Test (S-2), Form Board Test (VZ-1), Paper Folding Test (VZ-2), and Surface Development Test (VZ-3). I used these tests because they measure spatial ability skills required to understand phases of the Moon. Three of these tests (CF-2, S-1 and VZ-1) measured learners' ability to manipulate two-dimensional objects on plane of the paper, while the other three (S-2, VZ-2 and VZ-3) measured learners' ability to manipulate three-dimensional objects in space. As mentioned before, designers of these tests indicate that the tests are suitable for persons who have reached Grade 9 and above, but can be administered to younger

participants if researchers read out instructions to these participants. These results helped me to select learners who interpreted diagrams illustrating phases of the Moon. In addition, information about students' spatial abilities extends the existing body of knowledge about spatial ability skills of learners in Africa (the bulk of the research involving spatial ability has been conducted in other parts of the world).

9.3.1 Summary of results

These results provided an answer to the second research question phrased as follows: ***What is the level of Grade 9 Natural Science learners' spatial ability skills?***

The learners obtained low scores for the S-1 test, much lower scores for the CF-2, VZ-1 and VZ-2 tests, and very low scores for the S-2 and VZ-3 tests. These results suggest that the learners had low spatial ability skills, particularly the skills requiring mental manipulation of three-dimensional objects in space. These results support findings of Sanders (2004), which show that some South African learners have low spatial ability skills. The results further support findings from other parts of the world, which show that high school students have low spatial ability skills, e.g. a USA study by Smalley et al. (1989), an Egyptian study by Abdel-Rahim et al. (1990), and an Australian study by Burton and Fogarty (2003).

Lack of spatial ability skills suggests that the learners would struggle to undertake tasks that require perception and manipulation of three dimensional objects in space. This finding has a number of implications. First, research conducted to date has focused on improving learners' conceptual understanding of astronomy concepts, but has not yet targeted learning of low spatial-ability learners. Researchers should investigate ways of helping low spatial-ability learners to better understand astronomy concepts. I have indicated earlier in the thesis that some research findings suggest that spatial ability can be improved, e.g. using two-dimensional objects, three-dimensional objects and/or computer simulations to help learners improve their ability to imagine rotating objects in space (see Section 2.2.1, p 30). I suggest that further research be conducted to investigate whether, and the extent to which these activities can help learners to better execute spatial ability in the context of astronomy concepts, and consequently, to understand astronomy concepts (e.g. to interpret diagrams illustrating these concepts).

I have also indicated that spatial ability is only one of the factors needed to understand science concepts (other factors include logical reasoning, memory span, verbal fluency, etc.). Results obtained from spatial ability tests give information about learners' ability to cope with activities requiring perception and manipulation of objects in space, but very little about learners overall ability to understand science concepts (and indeed, their ability to cope with other school subjects). Improving learners' spatial ability skills would likely enhance learners' ability to understand aspects of science concepts that require perception and manipulation of objects in space, which might, in turn, enhance learners' understanding of these concepts.

Finally, teacher trainers should be informed about these findings. This information can help them advise pre-service teachers about the need to use strategies that can enhance learners' spatial ability skills when teaching about phases of the Moon.

9.3.2 Spatial ability skills of learners who participated in interviews

I used results from the six spatial ability tests to select five learners with high spatial ability scores and five learners with low spatial ability scores to participate in interviews. Each of the high spatial-ability learners had obtained low scores in at least two of the six spatial ability tests. Poor performance of these learners on some spatial ability tests suggests that the learners were deficient in some spatial ability skills needed to understand phases of the Moon. It was reasonable to expect, therefore, that these learners would demonstrate weaknesses in some tasks requiring the use of spatial ability skills.

9.4 *Diagram analysis*

This thesis considers the Earth-Moon-Sun system conceptualized by scientists as a consensus model of the system, and considers diagrams illustrating this system as analogical models of the system (see Section 2.2.2, pp 40-41). The theory of models recommends that differences between consensus and analogical models be spelled out to help intended audiences match only relevant aspects of these models. It follows that textbook writers should provide information explicating differences between diagrams and the Earth-Moon-Sun system conceptualized by scientists.

I analyzed 28 diagrams illustrating phases of the Moon. The analysis instrument consisted of nine design principles classifiable into three levels: the syntactic level, the semantic level and the pragmatic level. The syntactic principles focused on perceptual issues on diagrams, the semantic principles focused on meanings obtainable from diagrams, while the pragmatic principles focused on suitability of diagrams to intended contexts and audiences. Findings extend our understanding of semantic problems found in these diagrams, and contribute new knowledge by making us understand syntactic and pragmatic problems found in the diagrams.

9.4.1 Summary of results

Diagrams from ten books illustrated phases of the Moon only, while diagrams from fourteen books illustrated the Earth, the Sun and the Moon. Diagrams from the fourteen books had two problems which have been identified in literature (e.g. Dove, 2002; Engeström, 1991; Subramaniam & Padalkar, 2009). First, relative sizes and distances between the Earth, the Sun and the Moon were not maintained in these diagrams, and no information was provided to clarify this issue. Second, the Moon's orbit was presented along the ecliptic so that Full Moon erroneously appeared to occupy

the position which results in a lunar eclipse, and again no information was provided to clarify this. The absence of this clarification suggests that learners using these diagrams might develop misconceptions about the Earth-Moon-Sun system.

In addition to the problems discussed above, the current study found several problems not reported in literature. The syntactic analysis shows that three diagrams lacked visual cues (e.g. numbering and labels) that would help viewers to perceive associated marks as linked. Furthermore, arrows representing the Sun's rays were not clearly visible in one of these diagrams. Thus, the three diagrams had design problems that might hinder viewers from accurate perception of information illustrated in the diagrams. The semantic analysis shows a number of problems. First, 12 diagrams used symbols inconsistently, so that one symbol represented different entities in a diagram. Secondly, 13 diagrams used symbols ambiguously. As a result, different viewers might ascribe different meanings to one symbol. Finally, 18 diagrams used symbols incorrectly, so that scientific concepts were not accurately represented in these diagrams. These problems suggest that the composition of several diagrams might hinder learners from obtaining the message intended by illustrators.

The pragmatic analysis shows that one diagram lacked information explaining the purpose of the diagram, three diagrams each provided inadequate amount of information needed to enable the diagrams to achieve their intended purposes, while 15 diagrams illustrated phases of the Moon as seen from the northern hemisphere, despite the fact that intended viewers live in the southern hemisphere. Thus, the design of these diagrams violated the pragmatic principles.

These results have a number of implications.

- Publishers should be informed about the types of problems found in the books. This might help them minimize these problems in books yet to be published. Furthermore, I recommend that publishers organise visual literacy training workshops for illustrators and editors. These workshops might help the illustrators and editors to realize the type of problems found in diagrams, and to be aware of design principles which can help them design better diagrams. This might reduce the number of problems found in the diagrams.
- Education officials should be informed about these problems. Their knowledge of these problems can help them recommend textbooks whose diagrams have fewer design problems. Also, the officials can work with publishers to ensure fewer design problems in textbook diagrams. Furthermore, the officials can work with teachers to help them minimize impact of these problems on learning.
- Teachers should be warned that diagrams do not always accurately illustrate the message intended by publishers. The presence of syntactic problems means that some information might be missed altogether. Teachers need to point out aspects of diagrams that are not clearly visible to viewers' eyes, to help overcome impact of the syntactic problems. The presence of semantic problems means that diagrams might convey incorrect information to the learners. Teachers need to correct this information. The presence of pragmatic problems means that diagrams might confuse learners, as the diagrams present information against context of intended learners (i.e. illustrating moon phases as seen from the northern hemisphere in the books designed for

learners living in the southern hemisphere). Teachers need to put ideas in context of learners, e.g. warning learners that diagrams illustrate phenomena as seen from the northern hemisphere, and then helping them to understand how the phenomena would be seen from the southern hemisphere. This might help the learners to make better sense of information learned in school and information perceived in their daily lives.

It is worthy to remember that the information I obtained from two workshops indicates that some South African teachers have poor background knowledge in this topic (Mosoloane & Sanders, 2006; Sanders, et al., 2006). It seems less likely then, that such teachers could realize and correct errors found in diagrams. This suggests that the misinformation might be passed on to students.

The third research question was phrased as follows: *To what extent does the composition of diagrams illustrating phases of the Moon (in South African school textbooks) comply with design principles recommended in literature?*

The analysis shows that very few diagrams violated syntactic principles, while the majority violated semantic and pragmatic principles.

9.4.2 Diagrams used during interviews

I used results obtained from diagram analysis to select diagrams for interviews. I selected four diagrams which had the fewest design problems (i.e. Diagrams 19, 21a, 21b and 24 in Appendix C). I designed the interview schedule so that the design problems identified in each diagram would have no impact on learners' interpretation of these diagrams (as discussed in Chapters 7 and 8).

9.5 Interviews

I used the four diagrams to investigate learners' interpretation of conventions used in the diagrams, and to further investigate learners' ability to determine the shape of the Moon visible from earth during selected configurations of the components of the Earth-Moon-Sun system. First I present results obtained from learners' interpretation of conventions. Then I present learners' ability to determine the shape of the Moon seen from earth during selected configurations of the components of the Earth-Moon-Sun system. Results discussed in this section provide new knowledge not reported in literature.

9.5.1 Interpretation of conventions

I used the four diagrams to investigate learners' interpretation of the following components of diagrams illustrating phases of the Moon: the Earth, the Sun's rays, phases of the Moon, and the Moon's orbital path around the Earth. In addition, I investigated whether learners would perceive

the earth and the moon shapes as representing three-dimensional objects, and further investigated whether learners would interpret the shape of the Moon's orbit as indicating perspective from which the Moon has been drawn. Results allowed me to make inferences about learners' interpretation of the following conventions:

- (1) The same symbol appears more than once, representing the same entity as it changes position
- (2) The same symbol appears more than once, representing different entities
- (3) Different symbols represent the same entity as it changes shape
- (4) Black and white colours represent parts of the Moon visible and invisible from Earth
- (5) Two-dimensional shapes represent three-dimensional objects
- (6) Shape of the Moon's orbital path indicates perspective from which the Moon is perceived

The diagrams had hints that might help learners to interpret the first three conventions, but had no hints to help learners interpret the last three conventions. The results show that the learners were generally able to interpret the Earth, the Sun's rays, the Moon orbiting the Earth, and phases of the Moon. These results suggest that both high and low spatial-ability learners were generally able to interpret the first three conventions. However, the results show that high spatial-ability learners correctly interpreted the black and white colours on phases of the Moon while the majority of low spatial-ability learners appeared to be uncertain about the meaning of these colours. As a result, I conclude that mostly high spatial ability learners have been able to interpret the fourth convention.

When asked to interpret these colours (on Diagram 24, Figure 8.1), all learners had determined appearance of the Moon from the Earth for selected configurations of the components of the Earth-Moon-Sun system using Diagrams 21a and 21b (Figures 7.1 and 7.2). High spatial-ability learners had demonstrated superior performance in this task. I speculate that lunar phase determination might have enabled the high spatial-ability learners to perform better on interpretation of these colours. I recommend that further research conducted to investigate learners' interpretation of these colours without prior lunar phase determination. Such research might indicate whether high spatial-ability learners are, indeed, better able to interpret these colours than their low spatial-ability counterparts. Results of such a study might determine the nature of interventions needed to help learners to interpret these colours.

The results further show that learners generally interpreted the earth and the moon shapes as representing two-dimensional objects. In addition, only three partially interpreted the shape of the Moon's orbit as indicating perspective from which the Moon is seen. These results imply that both the high and the low spatial ability learners generally failed to correctly interpret the last two conventions for which no hints were available on diagrams (no depth cues were used to show the earth and moon shapes as representing spherical objects, and no captions were given to help people interpret the oval orbit as indicating the perspective).

The dual coding theory helps to explain these results. Learners' ability to interpret conventions for which artists provided (mostly verbal) hints suggests that the learners were able to use both verbal

and nonverbal information while interpreting the diagrams. Learners' inability to interpret the last two conventions suggests that artists should provide verbal information that might help interpretation of diagrams.

Results obtained in the current study have a number of implications.

- *Teachers:* The results show that the learners were able to interpret the Earth, the Sun's rays, the Moon orbiting Earth, and phases of the Moon. The learners gave correct interpretation despite the fact that they had not learned about phases of the Moon in secondary school. These results suggest that the learners had visual literacy skills (discussed in Section 2.2.3, p 50) needed to interpret these aspects of the diagrams. However, learners failed to interpret the earth and the moon shapes as representing three-dimensional objects, and also failed to interpret the shape of the Moon's orbit as indicating perspective from which the Moon had been drawn. These results show that learners correctly interpreted the conventions requiring two-dimensional perception of diagrams, but struggled to interpret three-dimensional aspects of these diagrams. These results imply that diagrams might easily convey information about two-dimensional nature of moon phases, but might not be the most appropriate tool to use when teaching about three-dimensional aspects of these diagrams. These results suggest that in addition to diagrams, teachers should use resources known to help learners understand three-dimensional phenomena. For example, several researchers have found that the use of physical models and/or computer software helps learners to better understand concepts associated with phases of the Moon (e.g. Hans et al., 2008; Hobson et al., 2010; Sherrod & Wilhelm, 2009).

I would also suggest that teachers ask learners to say what they see when looking at diagrams. This might help teachers to get a sense of whether learners see information intended for the lesson, and to further help teachers to realise how much help they need to provide to the learners to help them appropriately interpret diagrams.

- *Publishers:* The results show that when moon phase diagrams are well designed, learners can generally interpret conventions used in these diagrams. I advise illustrators to design diagrams that have no design problems, as learners would likely interpret conventions used in such diagrams. In addition, I suggest that illustrators provide inscriptions to enable viewers to correctly interpret all the conventions used in these diagrams (e.g. explaining what the black and white colours represent, and also explaining reasons for the shape of the Moon's orbital path). Furthermore, I suggest that depth cues be used in moon phase diagrams, as these are likely to help learners to interpret the earth and moon shapes as representing spherical not flat objects. This might help learners to make better sense of diagrams.

These results can be used to answer Research Question 4 phrased as follows: ***What interpretations do learners assign to components of diagrams illustrating phases of the Moon, and what does this imply about learners' interpretation of conventions used in these diagrams?***

The results show that learners correctly interpreted the Earth, the Sun's rays, the Moon (in its orbital path around the Earth), and phases of the Moon. As a result, the learners are considered to have

been able to interpret Conventions 1, 2, and 3. The results also show that all the high spatial-ability learners correctly interpreted black and white colours on shapes representing phases of the Moon while only one of the low spatial-ability learners correctly interpreted these colours. As a result, only six learners are considered to have been able to interpret Convention 4. Finally, the results show that all learners failed to interpret the earth and the moon shapes as representing three-dimensional objects, meaning that all the learners failed to interpret Convention 5. Furthermore, the results show that only three learners partially interpreted the shape of the Moon's orbital path as indicating perspective from which the Moon is seen, meaning that the learners generally failed to interpret Convention 6.

9.5.2 Determination of moon phases from selected configurations of the Earth-Moon-Sun system

This part of the interview investigated learners' ability to determine the shape of the Moon seen from earth when the Moon is in selected positions on its orbital path around the Earth. In these positions, earth viewers would see Waning Gibbous, First Quarter, Waning Crescent, New Moon (nothing visible) and Full Moon. First, I asked the learners to draw the shape of the Moon visible from earth for each of these positions. Each of the high spatial-ability learners drew a half-moon shape and at least one circular shape. Four of these learners each drew a crescent shape, and one of the four learners drew a gibbous shape. On the other hand, the low spatial-ability learners drew half-moon shapes and unclassifiable shapes. That is, none of them drew a crescent shape, a complete circle or a gibbous shape. These results show that the high spatial-ability learners drew more expected shapes than their low spatial-ability counterparts. Furthermore, the results show that the learners encountered more problems with crescent and gibbous phases than other phases of the Moon.

After drawing moon phases, learners were shown shapes representing phases of the Moon and were asked to select shapes that would be seen from Earth during the selected configurations of the components of the Earth-Moon-Sun system. Low spatial-ability learners selected mostly wrong shapes while high spatial-ability learners selected mostly correct shapes. In actual fact, low spatial-ability learners tended to select a shape more than once: three selected half-moon shapes more than once while two selected a gibbous moon more than once. On the other hand, only two high spatial-ability learners selected a shape more than once. Selecting a shape more than once suggests that the learners failed to make a one-to-one correspondence between the eight cut-out moon shapes and the appearance of the Moon in the eight positions around the Earth.

These results have the some implications in education. The fact that high spatial-ability learners were better able to cope with three-dimensional interpretation of diagrams than their low spatial-ability counter parts suggests that researchers should investigate strategies that can help low spatial-ability learners to understand three-dimensional aspects of moon phases. Research involving phases of the moon, conducted to date, investigated ways of helping learners to understand these concepts. No research has been done to find difference between high and low spatial-ability

learners' ability to understand this topic, and to devise strategies that can help the low spatial-ability learners to understand these concepts. It is only after such research has been conducted, that recommendations can be suggested as to how low spatial-ability learners can be helped to better understand three-dimensional aspects of moon phases.

Another finding of the study is that diagrams are good at helping learners to understand two-dimensional but not three-dimensional phenomena associated with phases of the Moon. Teacher trainers should help pre-service teachers to realise this problem. Furthermore, they should ensure that pre-service teachers understand the value of other strategies used to help learners to understand astronomy concepts (e.g. the use of models and computer software). This might prepare the teachers to use other strategies in addition to diagrams when teaching about phases of the Moon.

These results can be used to answer Research Question 5 phrases as follows: ***What links (if any) exist between learners' spatial ability skills and interpretation of diagrams illustrating phases of the Moon?***

Results obtained in this study show no links between spatial ability and learner's interpretation of five conventions used in diagrams illustrating phases of the Moon. However, the results show that high spatial-ability learners were better than their low spatial-ability counterparts in determining the shape of the Moon seen from Earth for a given alignment of the Earth, the Sun and the Moon. Thus, high spatial-ability learners outperformed low spatial-ability learners in this aspect of diagrams interpretation.

9.6 Reflections

This PhD journey has enabled me to learn a number of things about doing a study of this magnitude. First, while it is important to keep the study as focused as possible, it is not always easy to proceed with the study as originally conceptualised, because of pragmatic factors (some of which are usually unforeseen in the beginning). For example, one of the original aims of the current study was to investigate teachers' awareness of problems encountered by students learning about astronomy concepts, and to investigate strategies used by these teachers to address these problems. However, data I obtained from two workshops indicated that the teachers actually lacked conceptual understanding of these concepts; they attended the workshops to learn about the topic, not to learn about teaching the topic. Poor results obtained from the workshops led me to drop this aspect of the study.

Another original aim of the study was to conduct research involving a wider range of astronomy concepts including day and night, seasons, eclipses, and moon phases. However, textbook publishers provided so many books for this study, that it became impossible to include all the concepts originally intended for the study. Thus, it became important to refocus the study to deal with one concept in detail. I selected phases of the Moon because I found many diagrams illustrating this concept.

Having refocused the study to dealing with phases of the Moon, I have a number of issues to discuss about the methods used in the study. First, I intended to use the diagnostic test for two purposes: (i) to investigate the extent to which participants understood phases of the Moon in order to minimize impact of subject matter knowledge during interpretation of diagrams (as has been the case in the thesis), and (ii) to investigate correlations between diagnostic test scores and spatial ability tests scores. The latter purpose was motivated by the fact that very few studies have investigated correlations between spatial ability and learners understanding of astronomy concepts (see Section 2.1.3, p 20). The correlation would add to the body of knowledge by clarifying links between spatial ability and understanding of astronomy concepts. However, the performance of learners in the diagnostic test was so low that it became impossible to investigate the correlations.

Secondly, I note the following methodological issues which emerged from the study. I administered the diagnostic and spatial ability tests to two groups of learners (96 learners in total) in two sittings for each group. Twenty one learners completed only some of these tests. As a result, their responses were not included during analysis of results. Some of the 21 learners had obtained very high scores in the few spatial ability tests that they answered. This suggests that some learners who might have been suitable for interviews were missed because of not answering all the tests. Closely related to this, I conducted interviews a year after learners had answered the diagnostic and spatial ability tests. As a result, some learners suitable for interviews were no longer in the school where data was collected (and could not participate in interviews). This shows that some potential learners were not available for interviews.

Furthermore, I conducted all the interviews in one school, involving learners who knew each other. It was possible for the first learners who participated in the interviews to inform their schoolmates about contents of the interview. This might help other learners to prepare for the interviews in case they were asked to participate. If learners passed information to others, then validity of the results obtained in the study might be threatened. However, the following points suggest that this is less likely to have been the case.

- The results show that almost all learners correctly interpreted the first three conventions and struggled to interpret the last two conventions. Thus, the order of interviews appears to have had no impact on this section of the interview.
- Analysis of responses in Tables 7.17 (p 194), 7.18 (p 196) and 7.21 (p 205) shows links between spatial ability and learners' determination of moon phases. On the contrary, these tables show no links between moon phase determination and the order in which learners participated in interviews. That is, high performance in moon phase determination was associated with learners' spatial ability skills and not the order in which learners were interviewed.

If the learners shared contents of the interviews, then the results show that the sharing had no impact on diagram interpretation.

9.7 Limitations of the study

- Many researchers acknowledge that spatial ability is needed to understand astronomy concepts. However, very few have measured spatial ability and investigated its relationship with learners' understanding of these concepts (see Section 2.1.3, p 20). Good performance on the diagnostic test would have enabled the current study to add to this body of knowledge by investigating correlations between spatial ability and learners' understanding of concepts associated with phases of the Moon.
- The current study employed convenience and purposive sampling procedures, involving only a small number of participants. As a result, findings of the study enable understanding of characteristics of the participants, but may not be generalized to other high school learners. Involvement of large samples would enable results to be generalised to other high school learners. However, that would be beyond the scope of the current study.

In addition, the study focused on diagrams illustrating only one aspect of the Earth-Moon-Sun system, i.e. phases of the Moon. As a result, the findings may not help understanding of problems associated with diagrams illustrating other aspects of this system.

- The current study was diagnostic in nature, investigating possible problems associated with composition and interpretation of diagrams illustrating phases of the Moon. The results help to caution people about existence of these problems, but not to suggest ways of helping learners to better understand information presented in these diagrams. Further research should investigate ways of helping learners to better interpret diagrams illustrating phases of the Moon. It is only after such research has been conducted, that teachers and learners can be helped to make better use of diagrams illustrating moon phases.

9.8 Suggestions for further research

The results obtained from this study enable me to make the following suggestions for further research:

- Teachers of the school where data was collected appeared to have skipped phases of the Moon while teaching about astronomy concepts. The reason for this is not clear, but it is possible that they lacked background knowledge on phases of the Moon. I recommend that research be conducted to investigate an extent to which South African 'Natural Science' teachers understand this topic and challenges associated with teaching the topic. Such a study might provide ideas about the nature of intervention to be undertaken to help the teachers better understand and teach the topic.
- Literature shows that some textbooks contain textual information that might hinder learners' understanding of concepts associated with the Earth-Moon-Sun system (e.g., Sebastia and Torregrosa, 2005; Vosniadou, 1991). I recommend that research be conducted to investigate

accuracy of textual information dealing with phases of the Moon in South African textbooks. Furthermore, I recommend that research be conducted to investigate the extent to which activities prescribed in these books might enhance learners' understanding of the Earth-Moon-Sun system (the presence of these activities does not necessarily mean that the activities would achieve their intended purposes). Such research might help evaluate the extent to which information in the books could help to explain the Earth-Moon-Sun system to the learners.

- The current study has been the first to investigate learners' interpretation of diagrams illustrating the Earth-Moon-Sun system. The study focused on phases of the Moon, which is only one aspect of this system. I recommend that research be conducted to investigate learners' interpretation of diagrams illustrating other concepts associated with this system (e.g. day and night, seasons and eclipses). Findings would indicate an extent to which the diagrams could help learners understand concepts associated with this system. Failure to obtain this information from diagrams would indicate, for example, that teachers need to use other resources in addition to diagrams when teaching this topic.

9.9 Conclusion

This study was carried out to investigate the following four issues: learners' understanding of concepts associated with phases of the Moon, the extent to which textbook diagrams illustrating phases of the Moon comply with design principles recommended in literature, learners' ability to obtain information illustrated in these diagrams, and links between spatial ability and learners' interpretation of the diagrams.

Results show that the learners had poor understanding of astronomy concepts associated with phases of the Moon. In addition, the results show that most diagrams complied with syntactic principles, but violated semantic and pragmatic principles recommended in literature. Furthermore, these results show that the learners were able to interpret the following components of diagrams illustrating phases of the Moon: the Sun's rays, the Earth, the Moon's orbit and the Moon's phases. However, the learners interpreted the earth and moon shapes as representing two-dimensional objects rather than spheres. In addition, the learners interpreted the shape of the Moon's orbital path as illustrating the distance between the Earth and the Moon, rather than the perspective from which the Moon has been drawn.

Finally, the results show that learners with high spatial ability skills were generally able to determine the shape of the Moon visible from Earth during selected configurations of the components of the Earth-Moon-Sun system while low spatial ability learners generally struggled to determine these shapes. Thus, the study provides additional information giving evidence about relationships between spatial ability and learners' performance in astronomy concepts.

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APPENDICES

Appendix A Spatial ability tests

Appendix B Diagnostic test

Appendix C Textbook diagrams

Appendix D Diagram analysis instrument

Appendix E Interview schedule

Appendix F Ethical and consent forms

Appendix G Summary of literature

Appendix H Learners' spatial ability scores

APPENDIX A: Spatial ability tests

Spatial Ability Tests

This appendix shows sample items from the six spatial ability tests administered in the study, but not the exact tests, as the license agreement indicates that the tests should not be included in research reports.

Name _____

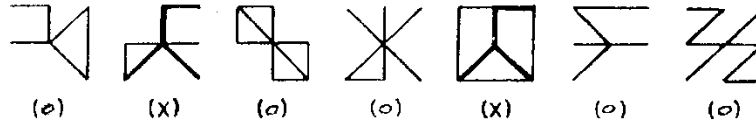
HIDDEN PATTERNS TEST -- CF-2 (Rev.)

How quickly can you recognize a figure that is hidden among other lines? This test contains many rows of patterns. In each pattern you are to look for the model shown below:

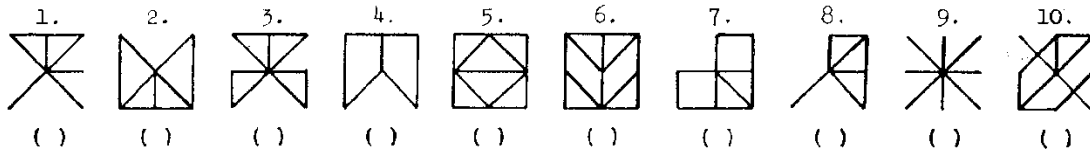


The model must always be in this position, not on its side or upside down.

In the next row, when the model appears, it is shown by heavy lines:



Your task will be to place an X in the space below each pattern in which the model appears and an O below the pattern where the model does not appear. Now, try this row:



You should have marked an X below patterns 1, 3, 4, 8, and 10, because they contain the model. You should have marked an O below patterns 2, 5, 6, 7, and 9 because they do not contain the model.

Your score on this test will be the number marked correctly minus the number marked incorrectly. Work as quickly as you can without sacrificing accuracy.

You will have 3 minutes for each of the two parts of this test. Each part has two pages. When you have finished Part 1, STOP. Please do not go on to Part 2 until you are asked to do so.

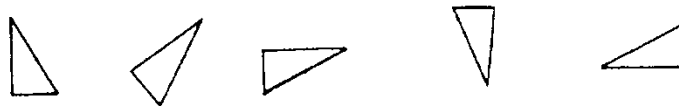
DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO

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Name _____

CARD ROTATIONS TEST — S-1 (Rev.)

This is a test of your ability to see differences in figures. Look at the 5 triangle-shaped cards drawn below.



All of these drawings are of the same card, which has been slid around into different positions on the page.

Now look at the 2 cards below:



These two cards are not alike. The first cannot be made to look like the second by sliding it around on the page. It would have to be flipped over or made differently.

Each problem in this test consists of one card on the left of a vertical line and eight cards on the right. You are to decide whether each of the eight cards on the right is the same as or different from the card at the left. Mark the box beside the S if it is the same as the one at the beginning of the row. Mark the box beside the D if it is different from the one at the beginning of the row.

Practice on the following rows. The first row has been correctly marked for you.

B									
		S ☒ D ☐	S ☐ D ☒	S ☒ D ☐	S ☒ D ☐	S ☐ D ☒	S ☐ D ☒	S ☐ D ☒	S ☐ D ☒
C									
		S ☐ D ☐	S ☐ D ☐	S ☐ D ☐	S ☐ D ☐	S ☐ D ☐	S ☐ D ☐	S ☐ D ☐	S ☐ D ☐
B									
		S ☐ D ☐	S ☐ D ☐	S ☐ D ☐	S ☐ D ☐	S ☐ D ☐	S ☐ D ☐	S ☐ D ☐	S ☐ D ☐

Your score on this test will be the number of items answered correctly minus the number answered incorrectly. Therefore, it will not be to your advantage to guess, unless you have some idea whether the card is the same or different. Work as quickly as you can without sacrificing accuracy.

You will have 3 minutes for each of the two parts of this test. Each part has 1 page. When you have finished Part 1, STOP. Please do not go on to Part 2 until you are asked to do so.

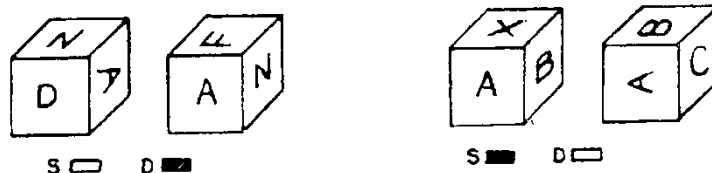
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Name _____

CUBE COMPARISONS TEST -- S-2 (Rev.)

Wooden blocks such as children play with are often cubical with a different letter, number, or symbol on each of the six faces (top, bottom, four sides). Each problem in this test consists of drawings of pairs of cubes or blocks of this kind. Remember, there is a different design, number, or letter on each face of a given cube or block. Compare the two cubes in each pair below.

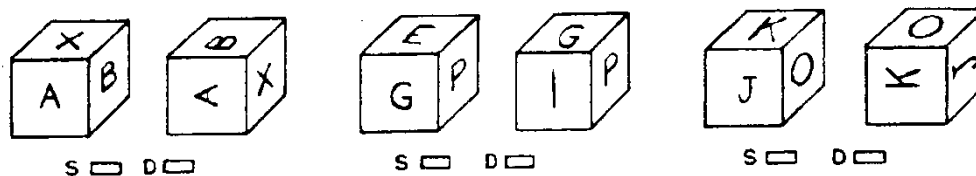


The first pair is marked D because they must be drawings of different cubes. If the left cube is turned so that the A is upright and facing you, the N would be to the left of the A and hidden, not to the right of the A as is shown on the right hand member of the pair. Thus, the drawings must be of different cubes.

The second pair is marked S because they could be drawings of the same cube. That is, if the A is turned on its side the X becomes hidden, the B is now on top, and the C (which was hidden) now appears. Thus the two drawings could be of the same cube.

Note: No letters, numbers, or symbols appear on more than one face of a given cube. Except for that, any letter, number or symbol can be on the hidden faces of a cube.

Work the three examples below.



The first pair immediately above should be marked D because the X cannot be at the peak of the A on the left hand drawing and at the base of the A on the right hand drawing. The second pair is "different" because P has its side next to G on the left hand cube but its top next to G on the right hand cube. The blocks in the third pair are the same, the J and K are just turned on their side, moving the O to the top.

Your score on this test will be the number marked correctly minus the number marked incorrectly. Therefore, it will not be to your advantage to guess unless you have some idea which choice is correct. Work as quickly as you can without sacrificing accuracy.

You will have 3 minutes for each of the two parts of this test. Each part has one page. When you have finished Part 1, STOP.

DO NOT TURN THE PAGE UNTIL YOU ARE ASKED TO DO SO.

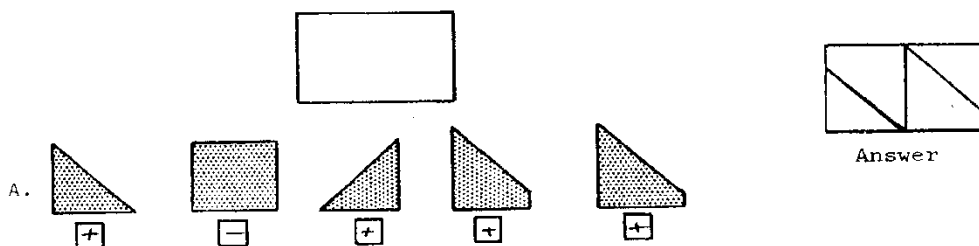
Copyright (c) 1962, 1976 by Educational Testing Service. All rights reserved.

Name _____

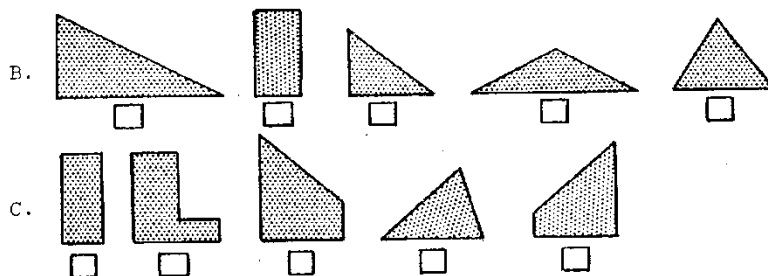
FORM BOARD TEST — VZ-1

This is a test of your ability to tell what pieces can be put together to make a certain figure. Each test page is divided into two columns. At the top of each column is a geometrical figure. Beneath each figure are several problems. Each problem consists of a row of five shaded pieces. Your task is to decide which of the five shaded pieces will make the complete figure when put together. Any number of shaded pieces, from two to five, may be used to make the complete figure. Each piece may be turned around to any position but it cannot be turned over. It may help you to sketch the way the pieces fit together. You may use any blank space for doing this. When you know which pieces make the complete figure, mark a plus (+) in the box under ones that are used and a minus (-) in the box under ones that are not used.

In Example A, below, the rectangle can be made from the first, third, fourth, and fifth pieces. A plus has been marked in the box under these pieces. The second piece is not needed to make the rectangle. A minus has been marked in the box under it. The rectangle drawn to the right of the problem shows one way in which the four pieces could be put together.



Now try to decide which pieces in Examples B and C will make the rectangle.



In Example B, the first, fourth, and fifth pieces are needed. You should have marked a plus under these three pieces and a minus under the other two pieces. In Example C, the second, third, and fifth pieces should be marked with a plus and the first and fourth with a minus.

Your score on this test will be the number marked correctly minus the number marked incorrectly. Therefore, it will not be to your advantage to guess unless you have some idea whether or not the piece is correct.

You will have 8 minutes for each of the two parts of this test. Each part has 2 pages. When you have finished Part 1 (pages 2 and 3), STOP. Please do not go on to Part 2 until you are asked to do so.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

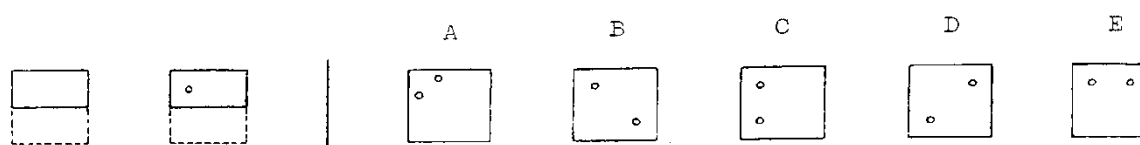
Copyright © 1962 by Educational Testing Service. All rights reserved.

Name _____

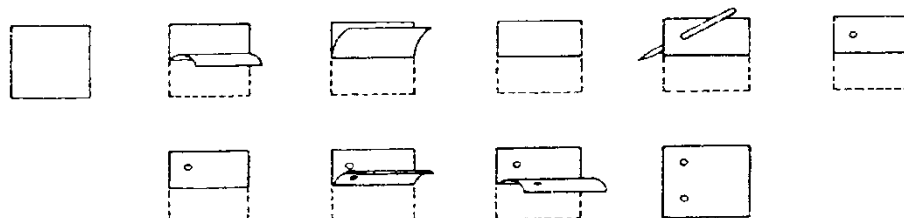
PAPER FOLDING TEST — VZ-2

In this test you are to imagine the folding and unfolding of pieces of paper. In each problem in the test there are some figures drawn at the left of a vertical line and there are others drawn at the right of the line. The figures at the left represent a square piece of paper being folded, and the last of these figures has one or two small circles drawn on it to show where the paper has been punched. Each hole is punched through all the thicknesses of paper at that point. One of the five figures at the right of the vertical line shows where the holes will be when the paper is completely unfolded. You are to decide which one of these figures is correct and draw an X through that figure.

Now try the sample problem below. (In this problem only one hole was punched in the folded paper.)



The correct answer to the sample problem above is C and so it should have been marked with an X. The figures below show how the paper was folded and why C is the correct answer.



In these problems all of the folds that are made are shown in the figures at the left of the line, and the paper is not turned or moved in any way except to make the folds shown in the figures. Remember, the answer is the figure that shows the positions of the holes when the paper is completely unfolded.

Your score on this test will be the number marked correctly minus a fraction of the number marked incorrectly. Therefore, it will not be to your advantage to guess unless you are able to eliminate one or more of the answer choices as wrong.

You will have 3 minutes for each of the two parts of this test. Each part has 1 page. When you have finished Part 1, STOP. Please do not go on to Part 2 until you are asked to do so.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

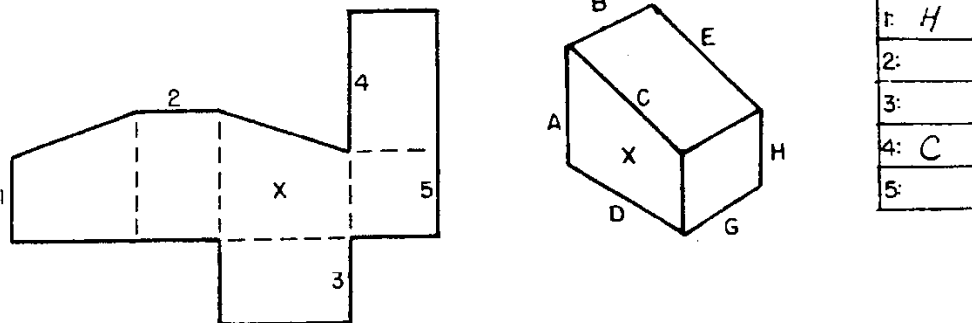
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Name _____

SURFACE DEVELOPMENT TEST -- VZ-3

In this test you are to try to imagine or visualize how a piece of paper can be folded to form some kind of object. Look at the two drawings below. The drawing on the left is of a piece of paper which can be folded on the dotted lines to form the object drawn at the right. You are to imagine the folding and are to figure out which of the lettered edges on the object are the same as the numbered edges on the piece of paper at the left. Write the letters of the answers in the numbered spaces at the far right.

Now try the practice problem below. Numbers 1 and 4 are already correctly marked for you.



NOTE: The side of the flat piece marked with the X will always be the same as the side of the object marked with the X. Therefore, the paper must always be folded so that the X will be on the outside of the object.

In the above problem, if the side with edge 1 is folded around to form the back of the object, then edge 1 will be the same as edge H. If the side with edge 5 is folded back, then the side with edge 4 may be folded down so that edge 4 is the same as edge C. The other answers are as follows: 2 is B; 3 is G; and 5 is H. Notice that two of the answers can be the same.

Your score on this test will be the number of correct letters minus a fraction of the number of incorrect letters. Therefore, it will not be to your advantage to guess unless you are able to eliminate one or more of the answer choices as wrong.

You will have 6 minutes for each of the two parts of this test. Each part has 2 pages. When you have finished Part 1 (pages 2 and 3), STOP. Please do not go on to Part 2 until you are asked to do so.

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APPENDIX B: The diagnostic test

APPENDIX B: The Diagnostic test

NAME _____

Have you ever learned about **phases of the Moon**? Write YES or NO _____

If your answer is “yes”, in which grade did you learn about **phases of the Moon**? _____

IMPORTANCE OF THE STUDY

- Your participation in the study will provide information that can help to increase teachers' awareness about difficulties encountered by learners when trying to understand **phases of the Moon**.
- This information can help teachers to change the way they teach about phases of the Moon.
- Improving teaching methods could help learners to better understand phases of the Moon.

HOW TO ANSWER

How many official languages do we have in South Africa? ☐ 5 ☐ 7 ☐ 9 ☒ 11 ☐ 13	How sure are you that your answer is correct? ☐ I am sure ☐ I think so ☐ I am guessing
For multiple-choice questions, choose your answer by Placing a tick (✓) in the box next to the answer that you think is correct.	Tell us how sure you are that your answer is correct: • If you are <u>absolutely sure</u> that your answer is correct, then place a tick (✓) in the box “I am sure”. • If you are <u>not sure, but think that your answer is correct</u>, then place a tick (✓) in the box “I think so”. • If you <u>do not know, but you are just guessing</u> the answer, place a tick (✓) in the box “I am guessing”.

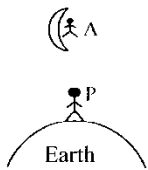
1. A complete cycle of phase of the Moon occurs once in ☐ 27.3 days ☐ 28.0 days ☐ 29.5 days ☐ 30.0 days ☐ 31.0 days	How sure are you that your answer is correct? ☐ I am sure ☐ I think so ☐ I am guessing
2. When viewed from the Earth, the Moon appears to rise in the east and set in the west daily. This is because ☐ the Moon revolves (circles) around the Earth ☐ the Earth rotates (turns) on its axis ☐ the Earth revolves (moves) around the Sun ☐ the Moon rotates (turns) on its axis ☐ the Moon revolves (circles) around the Sun	How sure are you that your answer is correct? ☐ I am sure ☐ I think so ☐ I am guessing
3. If the Moon is in the last quarter phase on the 7th of November, on what day (approximately) will the Moon be full? ☐ November 14 ☐ November 21 ☐ November 28 ☐ December 7 ☐ December 14	How sure are you that your answer is correct? ☐ I am sure ☐ I think so ☐ I am guessing
4. If the Moon rises at 21h00 (9 o'clock) tonight, tomorrow night it will rise at about ☐ 19h00 (7 o'clock) ☐ 20h00 (8 o'clock) ☐ 21h00 (9 o'clock) ☐ 22h00 (10 o'clock) ☐ 23h00 (11 o'clock)	How sure are you that your answer is correct? ☐ I am sure ☐ I think so ☐ I am guessing
5. As seen from the Earth, the Moon seems to change shape during the month because of ☐ the turning of the Earth on its own axis ☐ the shadow of the Earth falling on the Moon ☐ the changing positions of the Earth, Sun and Moon ☐ the turning of the Moon on its own axis ☐ the Earth moving around the Sun	How sure are you that your answer is correct? ☐ I am sure ☐ I think so ☐ I am guessing
6. If the Moon rises in the east as the Sun is setting in the west, then the phase of the Moon must be ☐ new Moon ☐ waxing crescent ☐ first quarter ☐ full Moon ☐ waning gibbous	How sure are you that your answer is correct? ☐ I am sure ☐ I think so ☐ I am guessing

7. If we see the first quarter Moon tonight, which phase of the Moon will people on the other side of the Earth see when night arrives for them? ☐ a crescent Moon ☐ a first quarter Moon ☐ a gibbous Moon ☐ a last quarter Moon ☐ a full Moon	How sure are you that your answer is correct? ☐ I am sure ☐ I think so ☐ I am guessing

Did you understand what you had to do in questions 1 to 7?	Write YES or NO
If you did not understand what you were supposed to do, please explain any problems you had.	

8. The following diagram shows a person (P) standing on the Earth, looking at the crescent Moon. An astronaut (A) is standing on the Moon looking back towards the Earth. This question requires you to work out what **phase of the Earth** the astronaut will see.

The answer may not be as obvious as you think. To help you work out the answer, draw a diagram (in the space below) to show the positions of the Earth, the Sun and the Moon. Use your diagram to help you work out the answer.

	Draw your diagram here

What **phase of the Earth** will the astronaut (A) see? Circle the correct diagram/answer.

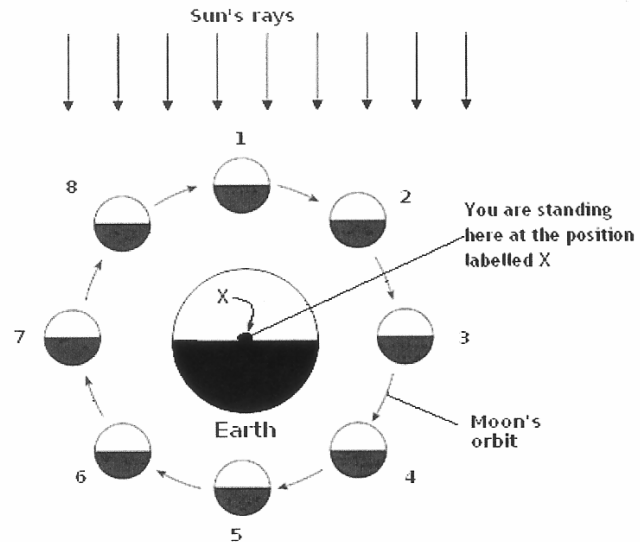
				
full Earth	gibbous Earth	quarter Earth	crescent Earth	new Earth

How sure are you that your answer is correct? ☐ I am sure ☐ I think so ☐ I am guessing	How difficult did you find it to imagine what was happening in the picture? ☐ It was easy ☐ I could imagine only after thinking hard ☐ I could not imagine what was happening

Did you understand what you had to do in question 8?	Write YES or NO
If you did not understand what you were supposed to do, please explain any problems you had.	

9. The diagram on the right shows sunlight shining on the Earth and the Moon. The Moon is shown in eight positions as it revolves around the Earth.

To help you to work out answers to the following questions, you might like to draw lines (on the diagram) showing what a viewer on Earth would see when the Moon is in each position.



Imagine that you are standing at point X on Earth, looking at the Moon.

If the Moon is in position 1, what would you see? **Circle the correct diagram/answer.**



If the Moon moves to position 4, what would you see? **Circle the correct diagram/answer.**



If the Moon moves to position 5, what would you see? **Circle the correct diagram/answer.**



If the Moon moves to position 7, what would you see? **Circle the correct diagram/answer.**



If the Moon moves to position 8, what would you see? **Circle the correct diagram/answer.**



How sure are you that your answers for question 9 are correct?

- ☐ I am sure
☐ I think so
☐ I am guessing

How difficult did you find it to imagine what was happening in the picture?

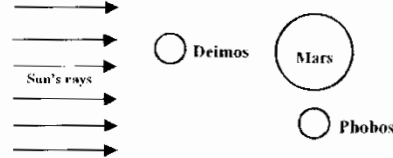
- ☐ It was easy
☐ I could imagine only after hard thinking
☐ I could not imagine what was happening

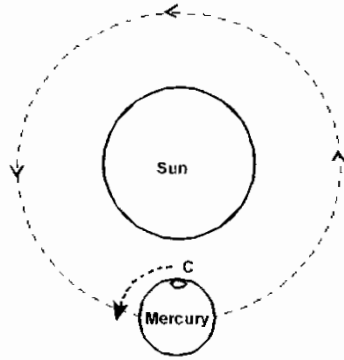
Did you understand what you had to do in question 9?

Write YES or NO

If you did not understand what you were supposed to do, please explain any problems you had

Questions 10 and 11 deal with planets (and their moons) which you have probably not learned about. However, by thinking carefully you should be able to work out the correct answers even if the planets and their Moons are unfamiliar to you.

10. Carefully examine the diagram on the right, which shows the positions of the Sun, Mars, and Mars's two moons (Phobos and Deimos). This question requires you to work out the phase of Phobos that a person on Deimos would see. <i>You might like to draw lines on the diagram to help you work out the answer to this question.</i>					
If you stood on Deimos and looked at Phobos, which 'phase of Phobos' would you see? Circle the correct answer.     					
How sure are you that your answer is correct? ☐ I am sure ☐ I think so ☐ I am guessing	How difficult did you find it to imagine what was happening in the picture? ☐ It was easy ☐ I could imagine only after hard thinking ☐ I could not imagine what was happening				
<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 60%; padding: 2px;">Did you understand what you had to do in question 10?</td> <td style="width: 40%; padding: 2px;">Write YES or NO</td> </tr> <tr> <td colspan="2" style="padding: 2px;">If you did not understand what you were supposed to do, please explain any problems you had.</td> </tr> </table>		Did you understand what you had to do in question 10?	Write YES or NO	If you did not understand what you were supposed to do, please explain any problems you had.	
Did you understand what you had to do in question 10?	Write YES or NO				
If you did not understand what you were supposed to do, please explain any problems you had.					

11. Mercury turns on its own axis in about 60 days, and moves around the Sun in 88 days. The diagram on the right shows the path of Mercury (imagine it moving on the surface of the page). The diagram shows a crater (labelled "C") on Mercury, directly facing the Sun. If Mercury now continues to move around the sun from the position given, draw <u>on the diagram</u> a circle to show - The approximate position of Mercury after 22 days, with the new position of crater C clearly marked. Label your diagram (a). - The position of Mercury after 30 days, with the new position of crater C clearly marked. Label your diagram (b).					
How sure are you that your answers are correct? ☐ I am sure ☐ I think so ☐ I am guessing	How difficult did you find it to imagine what was happening in the picture? ☐ It was easy ☐ I could imagine only after hard thinking ☐ I could not imagine what was happening				
<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 60%; padding: 2px;">Did you understand what you had to do in question 11?</td> <td style="width: 40%; padding: 2px;">Write YES or NO</td> </tr> <tr> <td colspan="2" style="padding: 2px;">If you did not understand what you were supposed to do, please explain any problems you had.</td> </tr> </table>		Did you understand what you had to do in question 11?	Write YES or NO	If you did not understand what you were supposed to do, please explain any problems you had.	
Did you understand what you had to do in question 11?	Write YES or NO				
If you did not understand what you were supposed to do, please explain any problems you had.					

Sources of items

The following table indicates sources of items used in the test

Item number	Source
1	My creation
2	Examination 1: June 2006 (Regents High School Examination) http://regentsprep.org/Regents/core/questions/questions.cfm?Course=ESCI&TopicCode=08
3	http://www.astro.umd.edu/cgi-bin/PracticeExam?subject=moon
4	http://people.brandeis.edu/~wardle/questions/exam1-review-used.doc
5	Examination 1: June 2006 (Regents High School; Examination) http://regentsprep.org/Regents/core/questions/questions.cfm?Course=ESCI&TopicCode=08
6	http://people.brandeis.edu/~wardle/questions/exam1-review-used.doc
7	http://people.brandeis.edu/~wardle/questions/exam1-review-used.doc
8	Rochford, K. (1984). An investigation into the attainment of spatial concepts by university science students. Unpublished PhD thesis. University of Cape Town, Cape Town.
9	Regents High School Examination: June 2001 http://regentsprep.org/Regents/core/questions/questions.cfm?Course=ESCI&TopicCode=08
10	Rochford (1984), from his PhD Thesis.
11	Rochford (1984), from his PhD Thesis.

APPENDIX C: Textbook diagrams

APPENDIX C: Textbook Diagrams

Diagram 1

Pictures of the moon taken from space show that the surface of the moon has many holes in it. These holes are called **craters**. Scientists believe that **meteorites** hitting the moon formed these craters.

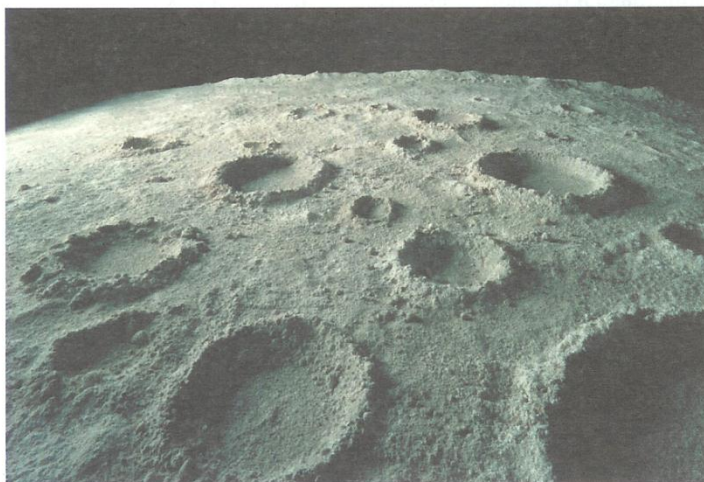


Figure 3: *The surface of the moon. Can you see the craters?*

The moon is about 284 000 km from the earth. It circles the earth every 27.3 days. While it is moving around the earth, it is also turning on its own axis. The moon turns around completely every time it circles the earth.

Phases of the moon

You will have noticed that the moon is not a full circular shape every night. It has a different shape on different nights. These different shapes are called **phases of the moon**. When we cannot see the moon at all, we call it a new moon. A few nights later we can see that the moon is crescent shaped. The moon slowly gets bigger until it is a circle. We call this a full moon. Then the moon starts to get smaller again until we cannot see it any more. The Moon goes through all its phases every month.

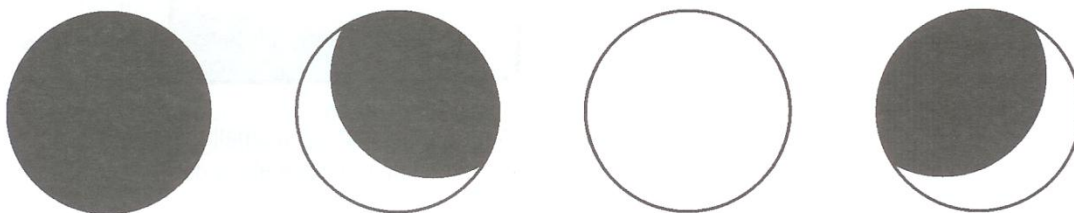
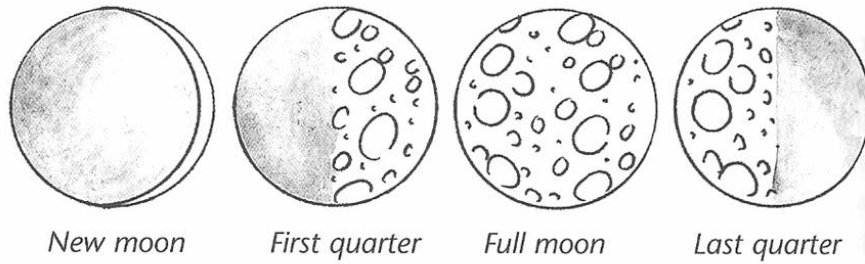


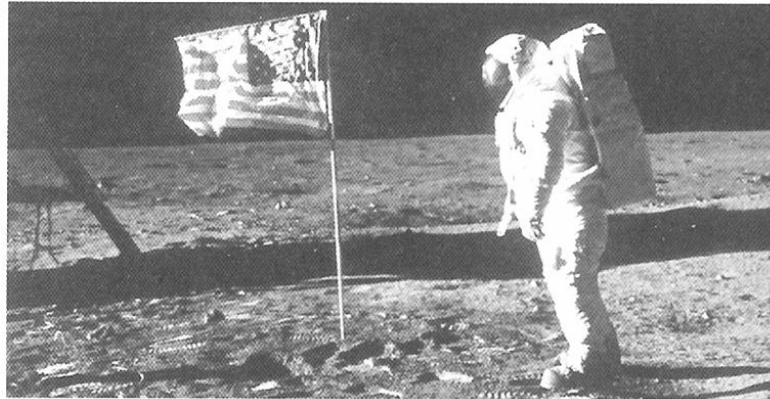
Figure 4: *The four phases of the moon.*

Diagram 2

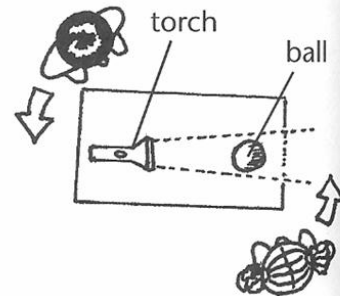
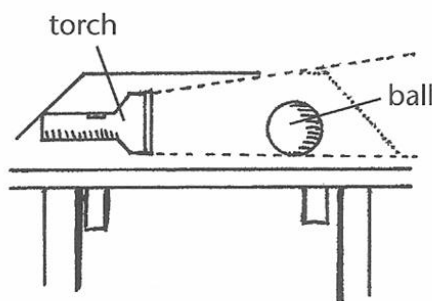


► Did you know?

Neil Armstrong was the first man to walk on the moon. On 20 July 1969, he stepped off the spacecraft *Apollo 11*. Edward ('Buzz') Aldrin and Michael Collins also went with him to the moon. A person who travels in a spacecraft is called an astronaut.



Ishtiak and Thandi took a torch and a ball, and placed them on a table so that the light of the torch shone on one side of the ball. They then walked around the table to look at the ball from all sides. By doing this they were able to see all the phases of the moon.



1. Write down the answers to the following questions in your exercise book.
 - a. What do we call the turning of the Earth?
 - b. How long does it take for the Earth to move around the sun?
 - c. Name the satellite of Earth.

Diagram 3

Unit 7.12 Why does the Moon change its shape? NB See Teacher's Book

In Unit 7.11 we read about the ways people observed the Moon and looked for patterns in its movement. In Unit 7.2 you looked at the Moon and recorded its changing positions on one night. Its **position** changed over a few hours, but you could not see any change in its **shape** on that night.

But a few nights later, the Moon's shape looked different. The Moon's shape changes as night follows night. Sometimes the Moon looks round and full, at other times it looks like a thin **crescent** (say KRES-int), as you see in **Figure 1**.

Figure 1 Sometimes the Moon is a thin crescent like this, and it goes down soon after sunset.

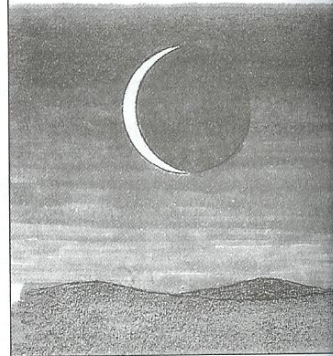


Figure 2 The Moon may look like this on the first day of the month.

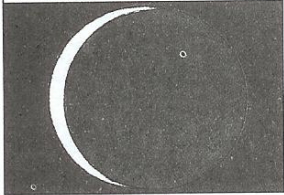


Figure 3 The Moon may look like this after 7 days.

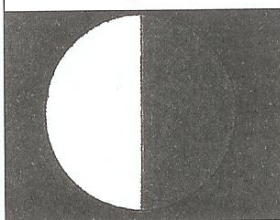


Figure 4 Then the Moon looks like this after 14 days.

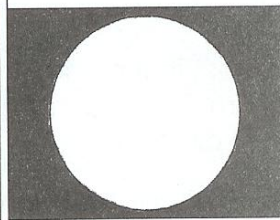
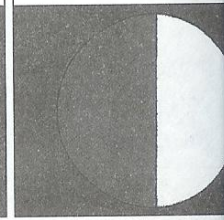


Figure 5 Then the Moon looks like this after 21 days.



Phases of the Moon.

The shapes we see in these four Figures are called **phases** of the Moon (say FAY-ziz). A **phase** is a period of time. For example, you are in the Intermediate Phase at school. Next year, you will change Grades and you will go into the Senior Phase.

Why does the Moon look different as the nights pass?

If you look carefully at the Moon when it is like **Figure 3**, you can see where the light part of the Moon meets the dark part. With a telescope, you can see the edges of the shadow more clearly – the edge looks like **Figure 6**.

Figure 6 This photo was taken through a telescope. Look at the edge between the light and the dark area.



So when a part of the Moon seems to be missing, it is not really missing. It is in shadow and we can see only the part of the Moon that is in the light.

Diagram 4

You will have the opportunity to:

- Collect information about the shape of the Moon.
- Demonstrate why the Moon appears to change its shape.

The Moon

When we look up at the Moon, we notice that at times it appears to have different shapes. Sometimes it seems big and round, sometimes it looks like a tiny sliver and sometimes it appears not to be there at all.

Activity 1

1. Copy the chart below.

Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14

2. Go outside each night at the same time. Look for the Moon and draw its shape in one half of the block. In the other half of the block draw a symbol to show what the weather was like.

Why does the Moon seem to change shape?

The Moon does not have any light of its own – it reflects the light of the Sun. The Moon moves around the Earth. The same side of the Moon always faces the Earth but the part of the Moon that is lighted up is not always the same. This makes the Moon appear as if it is changing shape. The different shapes of the Moon are called phases. These phases can be divided into waxing (growing bigger) phases or waning (growing smaller) phases.

New word: **PHASES**
Particular stages in the development or progress of something.

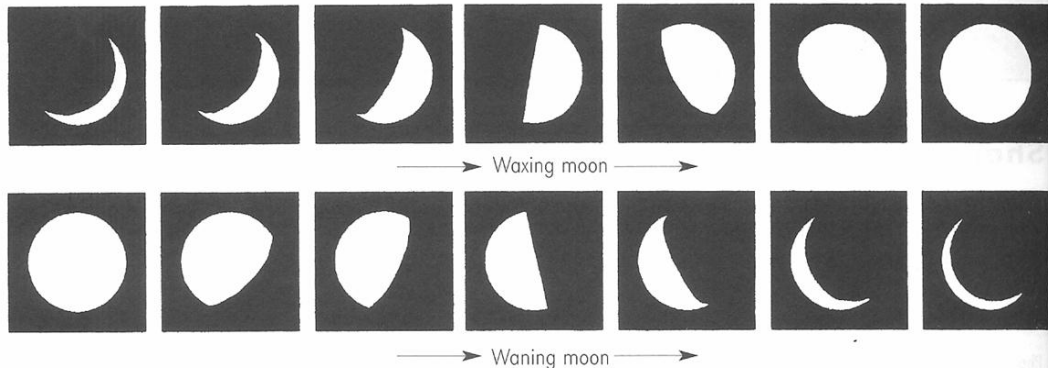


Diagram 5

Topic 4: Line up

In Topic 3 you learned that the motions of the earth cause day and night as well as the seasons to occur. These are not the only phenomena that happen as a result of these motions. In this topic you are going to learn about eclipses and the phases of the moon caused by the earth's motions around the sun and the moon's motion around the earth.

Phases of the moon

The moon revolves around the earth once every month. As it revolves around the earth, the sun lights up parts of it. We only see the parts that face the sun. During the times when the moon does not look completely round to us, there are parts that face away from the sun and are not lit up. It seems as if the moon changes shape when in fact all we see are the parts that are lit up by the sun. The different shapes we see of the moon throughout the month are known as the **phases of the moon**.

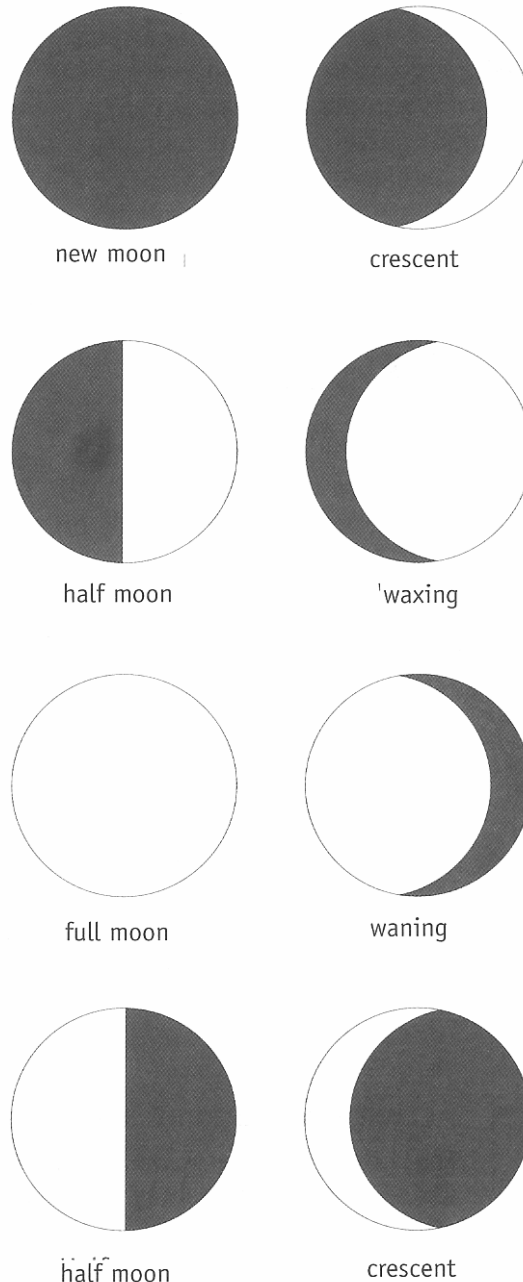
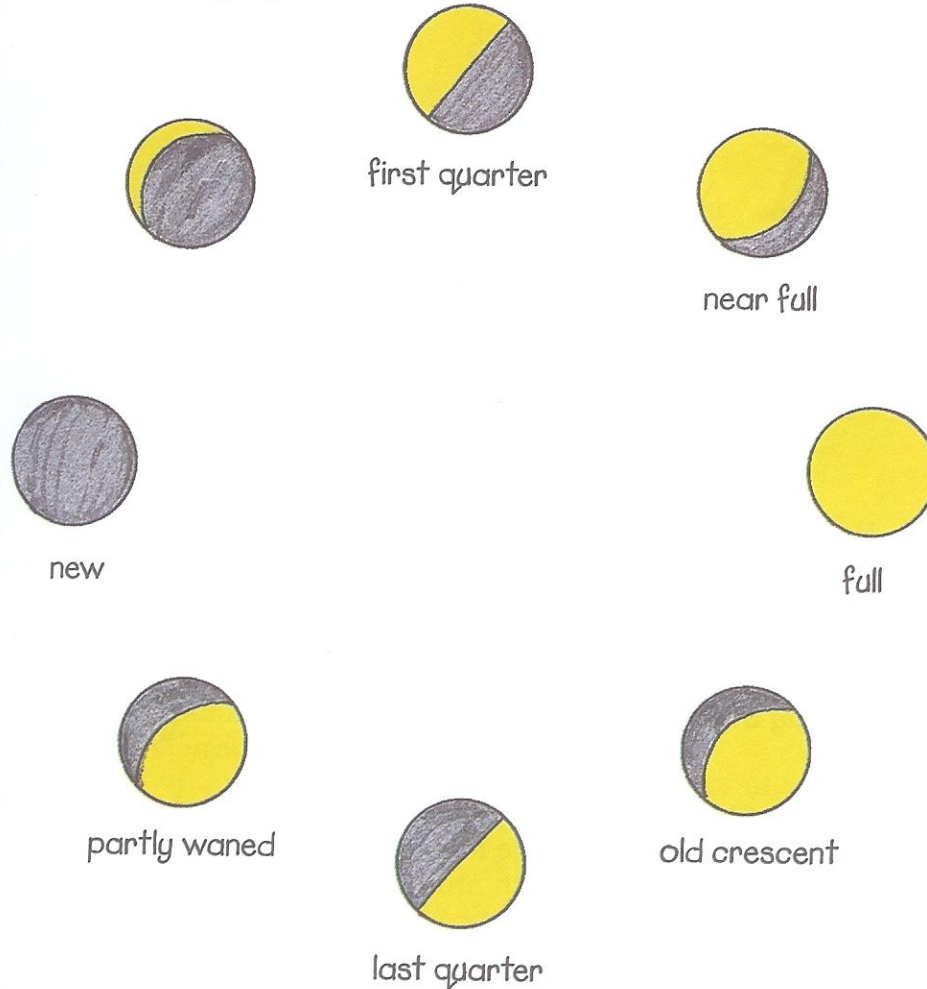


Figure 10: The phases of the moon.

Diagram 6

The phases of the Moon

The Moon does not make its own light. It looks bright to us because it **reflects** light from the Sun. The shape of the Moon seems to change as it moves around the Earth. That is because we can only see the part of the Moon that is lit up by the Sun. We see the light part of the Moon.



know

As the Moon moves around the Earth, the same side of the moon always faces the Earth. We never see the other side of the Moon from the Earth.

The Moon is always moving around the Earth.

The Earth is always moving around the Sun.

So the Sun does not always light up the same parts of the Moon.

You only see the parts that the sunlight reaches.

Diagram 7

All about the Moon

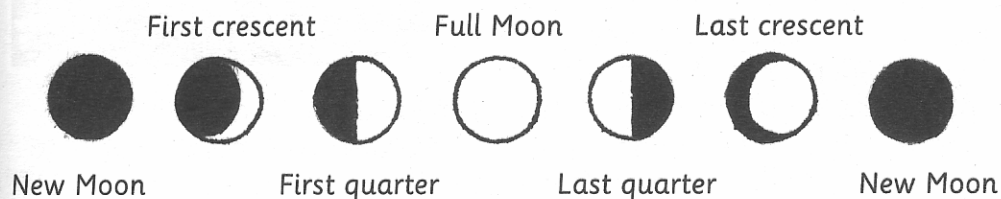
The Moon is a small world that moves around the Earth. It has no light of its own. It shines because it is reflecting light from the Sun. There is no air on the Moon and no water. The Moon is made of a type of rock that is almost the same as that which the Earth is made of. The Moon is 3 476 km across, which is about one quarter of the distance across the Earth.

The Moon has three main kinds of features on it. The rougher, lighter-coloured parts are highlands or mountains. They have been battered by meteorites and asteroids for millions of years. The largest punched through the surface rocks to the liquid interior. Warm lava gushed out to cover large lowland areas of the surface and then solidified.

The darker, smoother parts are the lowlands. These large dark areas are sometimes called seas, because early astronomers believed they were made of water.

The small marks are craters left by large space objects (meteorites) that hit the surface of the Moon very hard. If you look carefully you might even see that there are lines spreading out from the craters, which shows how hard the meteorites must have hit.

Shapes of the Moon



This diagram shows the shapes of the Moon you might have drawn in Activity 4. As the Moon moves around the Earth, the Sun shines on different parts of it. We can only see those parts of the Moon that are in the sunshine. This is why the Moon seems to change its shape. It is because the parts we can't see are in shadow.

Diagram 8

Why does the Moon shine?

When you look at the Moon at night, it looks like it shines with light. However, the Moon does not produce its own light. So where does the light come from? The light we see from the Moon is light from the Sun that is reflected or bounced off the Moon's surface. We can see the Moon because it is like a big white ball that reflects the light of the Sun (Figure 7).

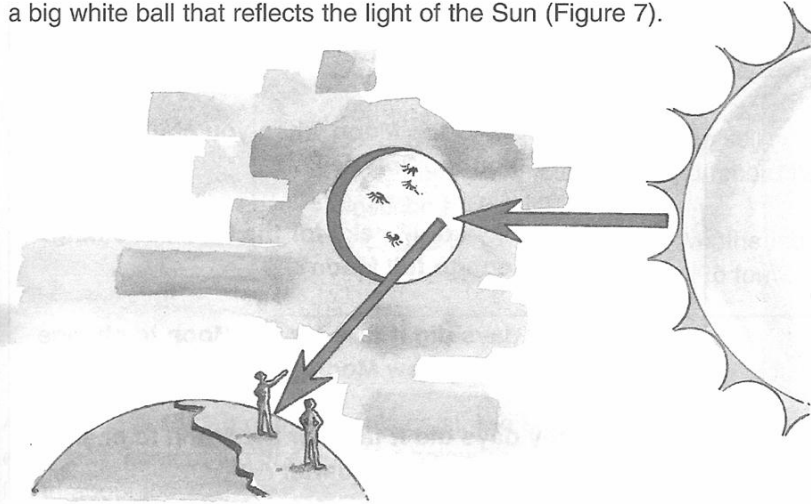
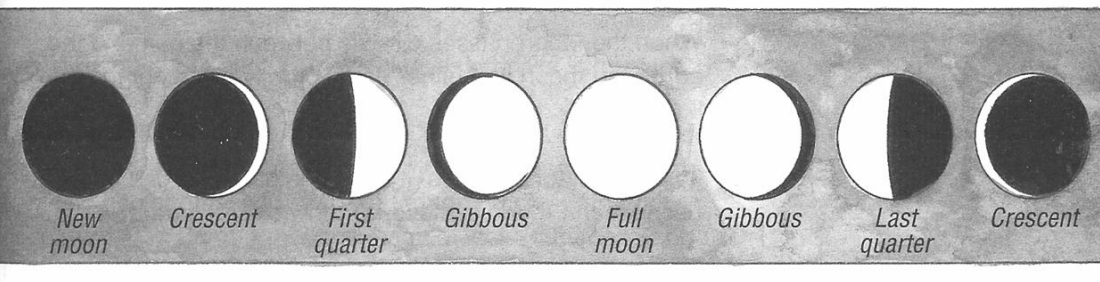


Figure 5: *The Moon reflects the light from the Sun.*

The phases of the Moon

The Moon appears to be a different shape in the sky from night to night. We call the different shapes of the Moon the phases of the Moon. The Moon appears to change shape because it moves in relation to the Sun as it revolves around the Earth. As the Moon revolves around the Earth, the Sun shines on the same side of the Moon. From the Earth we see the bright part from different angles (Figure 6).

Figure 6: *The phases of the Moon. The white part is what we see from the Earth at different times of the month.*



Notes concerning Diagram 8

The page has two diagrams

The first diagram has three unlabelled shapes representing half of the Sun, a gibbous Moon, and about one third of the Earth. The diagram shows two human figures on Earth, looking at the Moon. Furthermore, two broad dark arrows are drawn, showing the path of light from the Sun being reflected off the Moon to reach viewers on Earth.

This diagram has not been analyzed in the study.

The second diagram is linearly laid out, showing eight phases of the Moon against a grey background (indicating the night sky). *This diagram has been analyzed in the study.*

Diagram 9

EXPLANATION

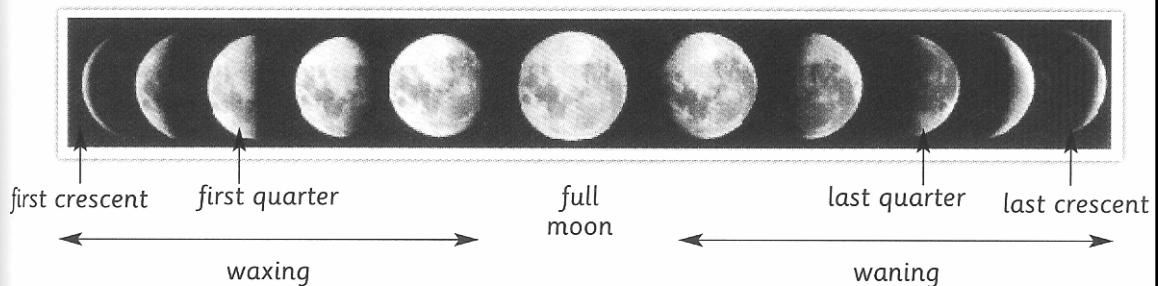
Phases of the Moon

As you will see from your Moon watch table, the Moon changes its shape slightly each night. The different shapes of the Moon are called the Moon's phases. The actual shape of the Moon does not change. Remember, you only see the part that is being lit up by the Sun.

The Moon takes one month to orbit the Earth. The Sun lights up the half of the Moon that faces it. As the Moon moves around the Earth, you see a different amount of the lit-up half of the Moon.

As you saw in Activity 7, in position A, when the Sun illuminated the side of the Moon facing away from the Earth, you could not see the Moon. This is called the New Moon phase. In position B, the Sun was illuminating the same side of the Moon that was facing the Earth, so you could see all of the Moon as it was brightly lit up. This phase is called 'Full Moon'.

The in-between positions of the Moon are shown below. Note that this diagram shows all the phases of the Moon as we see them in the Southern Hemisphere. 



MORE ABOUT THE MOON

The Moon is the only natural satellite of Earth. It was first visited by the Soviet spacecraft Luna 2 in 1959. The first time humans landed on the Moon was on 20 July 1969 and the last time was in December 1972. The Moon was extensively mapped by the spacecraft Clementine in 1994 and by Lunar Prospector in 1999.

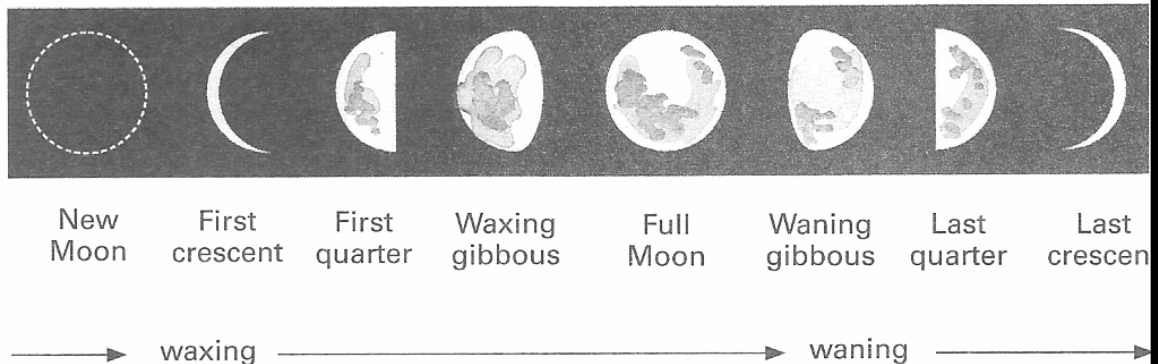
The Moon has no atmosphere, but evidence from Clementine suggested that there might be water ice in some deep craters near the Moon's south pole, which are permanently shaded. Lunar Prospector confirmed this. There is apparently ice at the north pole as well.

The Moon's crust averages 68 km thick. Below the crust is a mantle and probably a small core. Unlike the Earth's mantle, however, the Moon's is only partially molten. A total of 382 kg of rock samples were returned to Earth by the Apollo and Luna explorations. These provide most of our detailed knowledge about the Moon and are particularly valuable as they can be dated. Most rocks on the surface of the moon seem to be between 4,6 and 3 billion years old.

Diagram 10

So you could see all of the Moon as it was brightly lit up. This phase is called Full Moon.

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More about the Moon

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Diagram 11

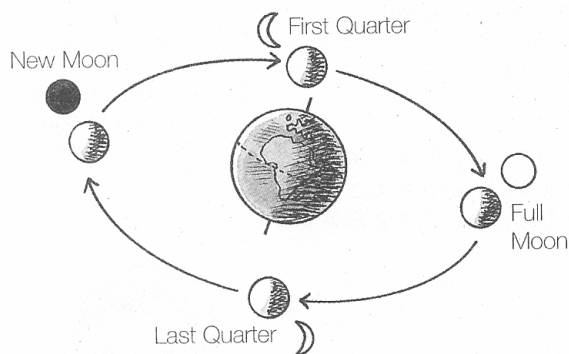
Does the Moon change shape?

If you observe the Moon you will notice that sometimes it looks like a whole round cheese and sometimes it looks like a slice of the cheese. Although it looks as if the actual shape changes, this is not true. What changes is the amount of the Moon that is in sunlight. When the side of the Moon that is facing the Earth has no sunlight on it, we cannot see it at all.

Just like the Earth, the Moon moves in two different ways: it takes 27 days to turn around or rotate on its own axis and it revolves around the Earth from east to west in an orbit that is shaped like an ellipse.

As the Moon moves around the Earth, it moves between the Earth and the Sun. When this happens, we cannot see the half of the Moon that is in sunlight. As the Moon moves around the

Earth, more and more of the lighted half can be seen. After about two weeks, the Moon is on one side of Earth and the Sun is on the other. This means that from Earth we can see all of the lighted half of the moon. After that the Moon seems to get smaller and smaller again. We call these changes the phases of the Moon. Each phase has a special name that comes from the shape of the moon at that phase. For example, when the Moon looks like a round ball, we call it a Full Moon.



As the Moon travels around the Earth, we can see different amounts of its sunlit face.

Activity

The phases of the Moon

Use an almanac or calendar to answer the following questions.

- ◆ 1. a. Find the date of a New Moon. Then find the date of the First Quarter, the Full Moon, the Last Quarter and the New Moon in that same month. Write them down.
b. Count the days from one New Moon to the next New Moon.
- ◆ 2. a. Which is the shortest month and how many days does it have?
b. Which are the longest months and how many days do they have?
- ◆ 3. What do you notice about the phases of the moon and the months in a year? Have a class discussion.

Think about

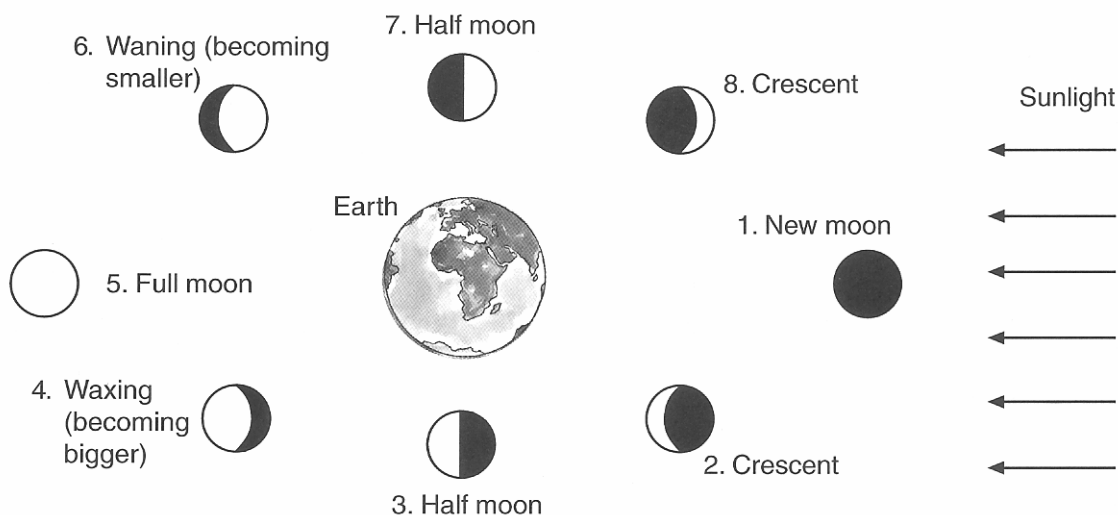
- There is less gravity on the Moon because it is much smaller than the Earth. Think about what would happen if you dropped something on the Moon.

Diagram 12

Topic 2: It's just a phase

When you look up into the sky at night, it looks as if the moon is glowing. Have you ever wondered where the light comes from? The moon cannot make its own light. It only reflects the light from the sun. As the moon travels around the Earth, it can only reflect the sunlight that shines directly onto it. Some parts of the moon are in the Earth's shadow for parts of the journey around the Earth. To us here on Earth, it looks as if the moon's shape is changing. The changing shape of the moon is called the **phases of the moon**.

Here's how it happens

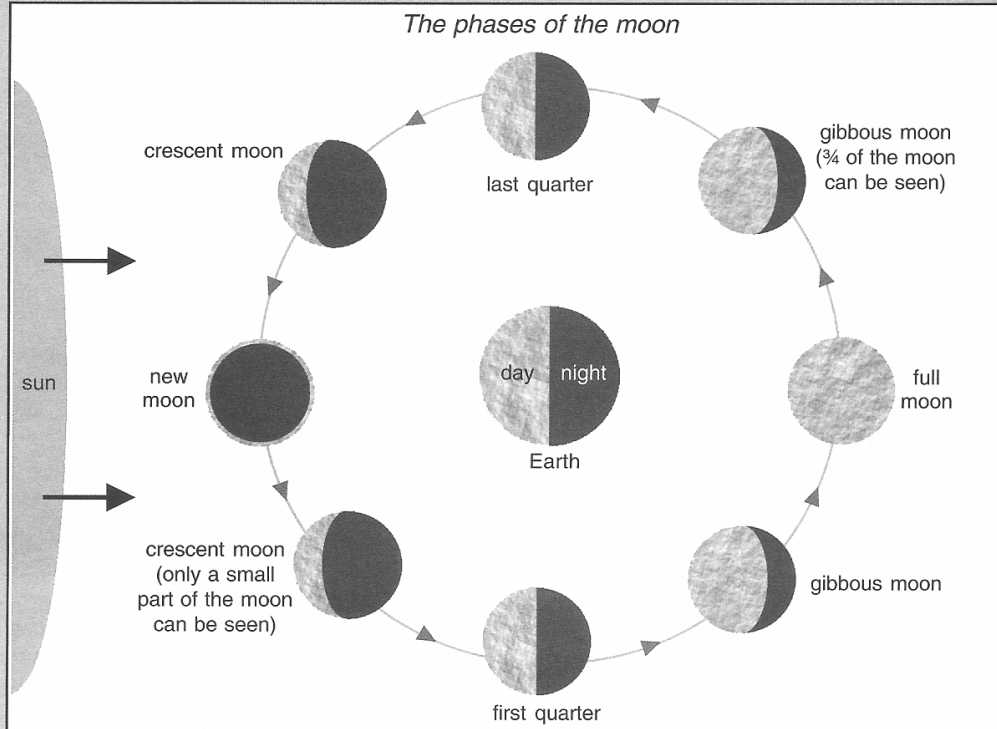


The moon takes about 28 days to travel around the Earth. In this time, its shape changes eight times. These changes depend on the position of the moon at the time. When the moon is directly between the Earth and the sun, we cannot see it, because the side that is turned away from the Earth is lit up. This is called the **new moon**. As it travels around the Earth, part of it becomes visible to us because the facing the Earth side (near side) catches the rays of the sun and reflects them. This is when we begin to see a **crescent moon** taking shape. This crescent grows bigger and bigger (waxing) because more and more of the near side faces the sun directly. When the moon reaches the other side of the Earth, the sun's rays shine onto the whole of the near side. This is called **full moon**. As the moon continues on its



Diagram 13

3. Light a candle and put your model of the Earth about 15cm from the candle.
4. Move the moon around the Earth to see how it reflects the light of the sun.
5. Use the diagram below to identify and name the phases of the moon as you move it around the Earth.



6. Record your answers to the following questions:
 - (a) What does the moon look like when it is a full moon?
 - (b) What does the moon look like when it is a new moon?
 - (c) How many phases of the moon are shown in the diagram?
 - (d) What does the moon need to be able to shine?
7. People have different feelings and beliefs about the moon. To some people, moonlight seems romantic; to other people it is frightening. Some people believe that moonlight can even make strange things happen.
 - (a) What do you feel or think about the moon?
 - (b) What do people in your culture or community think about the moon?
 - (c) Are any of the phases of the moon important to them?
 - (d) Was the moon important in the history of your culture?
 - (e) What do you call the moon and the phases of the moon in your home language?
8. Discuss your answers and ideas with another pair of learners or group.

Sometimes the Earth and the moon go into each other's shadows. When this happens, we say that there is an **eclipse**. A **solar eclipse** is when the moon blocks out the light of the sun. A **lunar eclipse** is when the Earth's shadow falls on and blocks out the light of the moon. Let's find out how eclipses can happen.

Key words

eclipse
lunar eclipse
solar eclipse

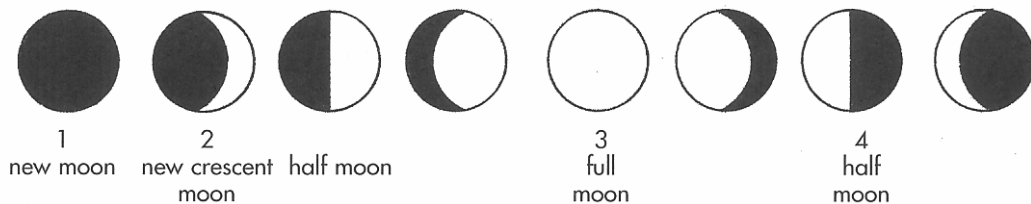
Diagram 14a

Why the moon seems to change shape



Shapes of the moon

The moon travels around the earth. It takes $29\frac{1}{2}$ days for the moon to travel once around the earth. This is called the **lunar** cycle.



Sometimes the moon looks like a huge ball in the sky. At other times it has a thin crescent shape, and at other times, a half-circle shape.

The moon doesn't really change shape! The moon has no light of its own, so all we can see of the moon is the part that is lit up by the sun. The moon 'catches' the light of the sun and reflects it to the earth. That light is what we see as moonlight.

New Word

Lunar means anything to do with the moon.

Diagram 14b

The drawing below shows the four phases. The phases follow the same pattern nearly every 28 days. When you see the half moon about a week after a full moon, the moon has travelled one quarter of the way around the earth. We see the new moon when the moon has travelled halfway around the earth.

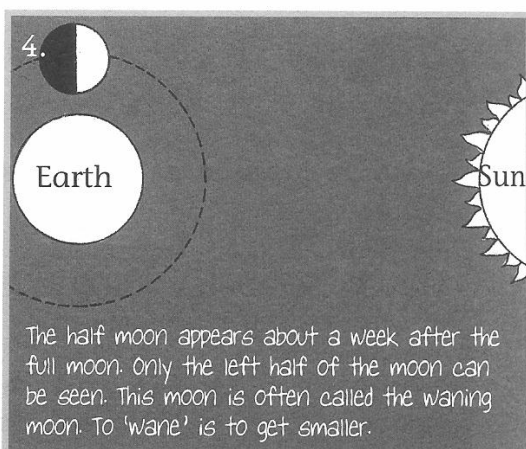
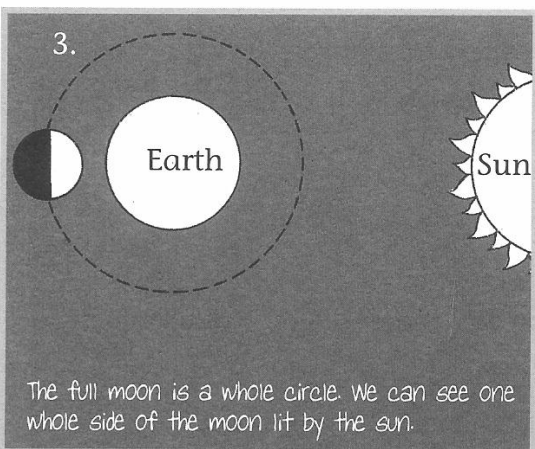
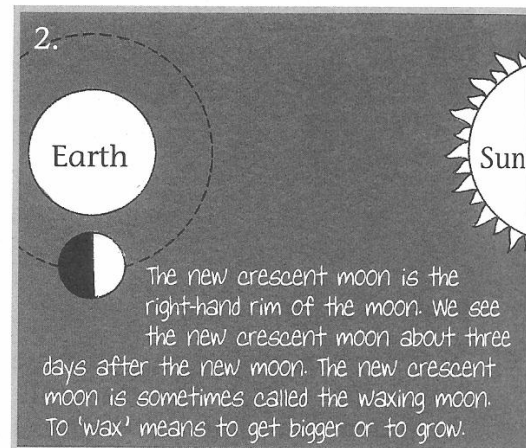
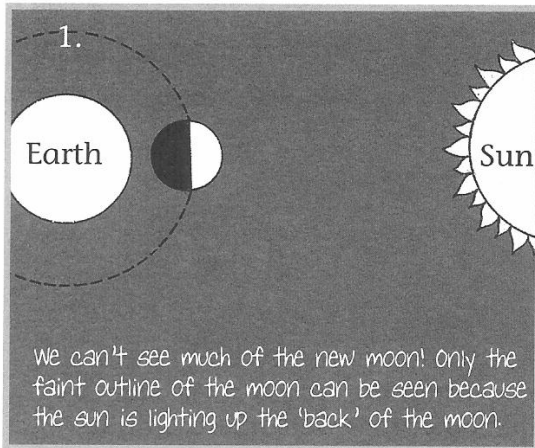


Diagram 15a

PLANET AND EARTH AND BEYOND

The phases of the moon

The shapes of the moon

Here are some pictures of the moon in its various phases. Notice how the diagram describes its shapes. How do these shapes compare with your observations?

A full moon: the whole face of the moon is lit up.	
A gibbous moon: the sunlit part becomes smaller.	
A last quarter moon: only half the moon's surface is lit up.	
A waning crescent: only a thin crescent of light is visible.	
A new moon: the part facing earth is all dark.	
A waxing crescent: a thin crescent of light becomes visible.	
A first quarter moon: half the surface is lit.	
A gibbous moon: the sunlit portion becomes much smaller.	

Diagram 15b

PLANET AND EARTH AND BEYOND

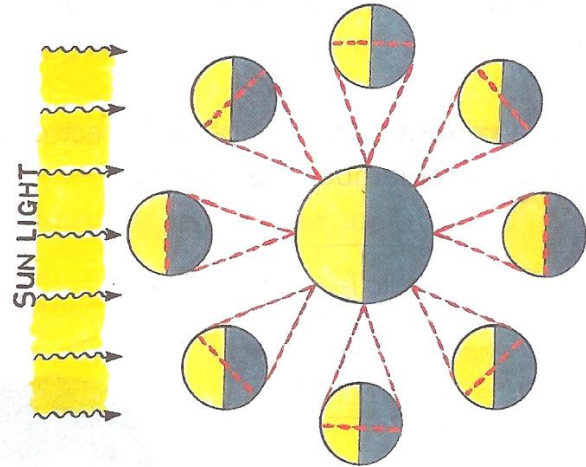
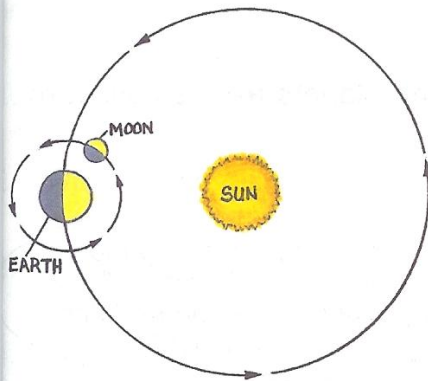
As you keep your moon diary for a month, answer the following questions:

- Does the shape of the moon differ each night?
- Does the moon rise and set at the same time each night?
- Does the earth circle the moon or does the moon circle the earth?

Did you know that the moon orbits around the earth every 28.25 days?

Seeing the moon in its different shapes is called 'The phases of the moon.'

Full moon occurs every 29.5 days.



The page has two diagrams presented side-by-side, one on the left and the other on the right-hand side.

Diagram on the left-hand side

This diagram shows that the Earth revolves around the Sun, and the Moon revolves around the Earth. The purpose of the diagram is not stated in the text, and there is no explanatory heading. One of the questions in the activity requires learners to answer the question: *Does the earth circle the moon or does the moon circle the earth?* The diagram can enable learners to correctly answer this question, as it shows the Moon orbiting the Earth. The diagram gives no information about phases of the Moon, and has not been analyzed in this study.

Diagram on the right-hand side

The coloured diagram shows information in the following three clusters:

- The Sun's rays, represented by seven parallel (wavy) arrows, drawn against a yellow background.
- The Earth, represented by an unlabelled, half-illuminated circle, centrally situated within a circles of moon shapes. The illuminated half of the Earth is shaded yellow, while the dark side of the Earth is shaded dark grey.
- The Moon, represented by unlabelled, half-shaded circles in eight positions around the Earth.
 - The half of the Moon that is illuminated by the Sun's rays is coloured yellow, while the half of the Moon that is in darkness is shaded dark grey.
 - There are red, dotted lines which connect the 8 lunar shapes to the Earth.

This diagram has been analysed.

Diagram 16

After about two weeks, the moon is on one side of the Earth and the sun is on the other. This means that from Earth we can see all of the lighted half of the moon. After that, the moon seems to get smaller and smaller again. When the side of the moon that is facing the Earth has no sunlight on it, we cannot see it at all.

We call these changes the phases of the moon. Each phase has a special name that comes from the shape of the moon at that phase. For example, when the moon looks like a round ball, we call it a Full moon.

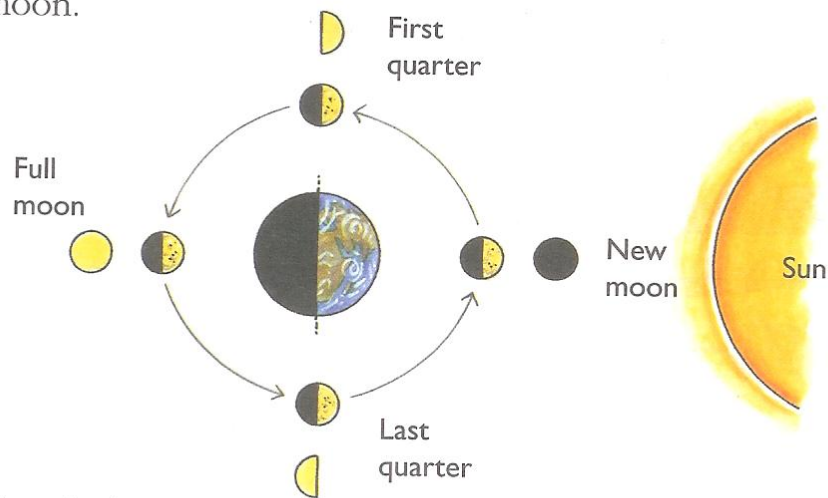


Figure 2 As the moon orbits the Earth, we can see different amounts of its sunlit face.

Activity I The phases of the moon

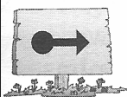
Use an **almanac** or calendar to answer the following questions.

- Find the date of a New moon. Then find the date of the First quarter, the Full moon, the Last quarter and the New moon in that same month. Write them down.
 - Count the days from one New moon to the next New moon.
- Which is the shortest month and how many days does it have?
 - Which are the longest months and how many days do they have?
- What do you notice about the phases of the moon and the months in a year? Have a class discussion.

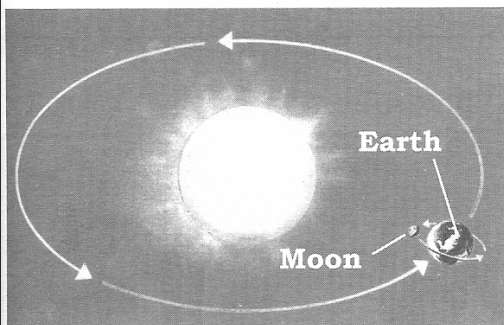
Word box

almanac – an old word for a calendar with phases of the moon

Diagram 17



The Earth moves around the Sun once every 365 days or one year in an **orbit**. This movement around the Sun is called a **revolution**. The Sun pulls on the



Earth so that the Earth always stays in the same **orbit** around the Sun. The Earth also turns around its own axis every 24 hours. This turning of the Earth is called a **rotation**. Day is when a part of the Earth is facing the Sun. Night is

when a part of the Earth is facing away from the Sun.

Orbit: The path an object follows when moving around another object.

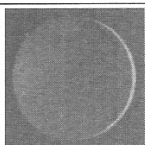
Axis: A line through the centre of the Earth around which the Earth rotates.

Satellite:

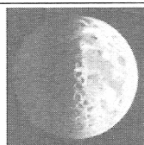
An object that moves around another object

The Moon also orbits around the Earth. The Moon is called a **satellite** of the Earth, because it moves around our planet. The Moon takes almost a month (27 days 8 hours) to orbit around the Earth. The Moon also rotates while moving around the Earth.

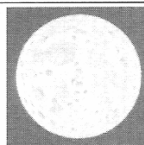
As the Moon moves around the Earth it looks as if it changes its form. These changes happen because the Moon doesn't make its own light. The light that we see shining from the Moon is actually the light from the Sun shining on the Moon. We say the Moon reflects the light of the Sun. The side of the Moon that shows to the Sun gets light. The other half of the Moon is dark. When we look at the Moon we only see the part of the Moon that is lit. At different times of the month we see different amounts of the Moon that are lit. These shapes of the Moon are called the **phases of the Moon**.



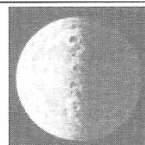
New Moon



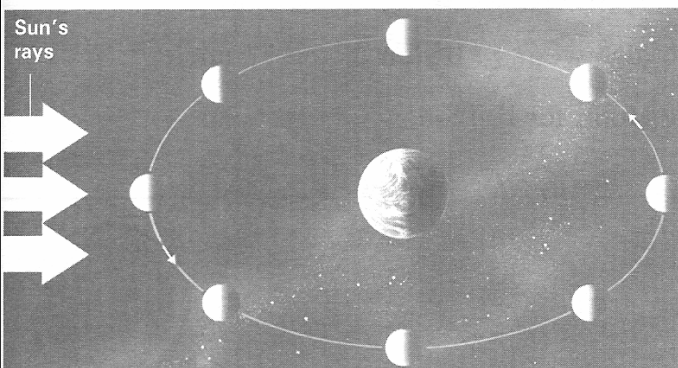
First Quarter



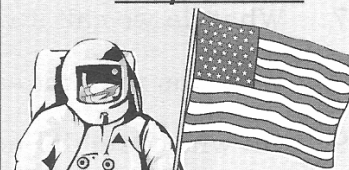
Full Moon



Last Quarter



Did you know?



○ Neil Armstrong was the first man to walk on the Moon. On 20 July 1969 he stepped off the spaceship Apollo 11. Edward Aldrin and Michael Collins also went with him to the Moon. A person who flies in a spaceship is called an astronaut.

Notes concerning Diagram 17

The page has two diagrams, one at the top and the other at the bottom. The diagram at the top shows the earth-Sun-Moon system, but not phases of the Moon. This diagram has not been analyzed in the study.

The bottom diagram shows visual information in the following four clusters:

- A linear arrangement of four shapes, representing phases of the Moon.
 - One shape is shaded black, but has a thin white crescent on one side (probably to make the Moon visible).
This shape is labelled *New Moon*.
 - Two shapes are half-shaded, and are labelled *First Quarter* and *Last Quarter*.
 - One shape has a white-coloured surface, and is labelled *Full Moon*.
- The Sun's rays, represented by three thick, parallel white arrows labelled *Sun's rays*. The Sun itself is not shown.
- The Earth, represented by an unlabelled half-illuminated shape, centrally located within an elliptical orbit of the Moon.
- An oval representing the Moon's orbital path, showing eight positions of the Moon during the lunar month, as viewed from space. The Moon is represented by unlabelled, half-shaded circles.

There is no visual information to indicate whether the Moon's orbital path around the Earth is drawn as it would be seen if looking down on Earth to one of the poles, or as it would be seen if looking sideways at the Earth, with the equator as a line across the middle.

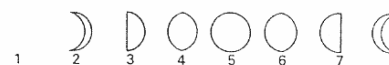
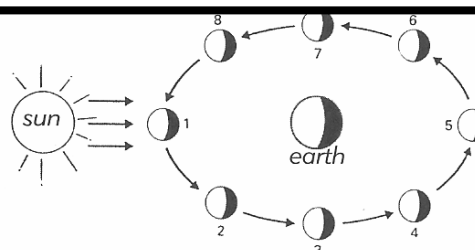
This diagram has been analyzed in the study.

Diagram 18

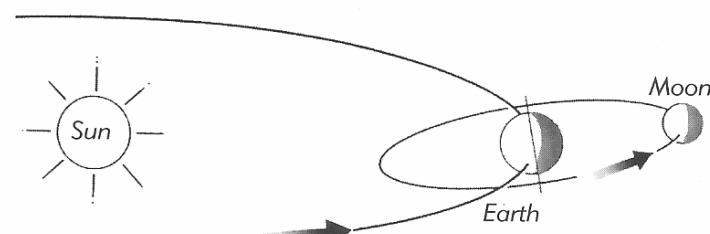
Activity 1.4

Eight phases or positions of the moon are shown.

1. Name the different phases of the moon (1–8). Most diaries and weather forecasts in newspapers also supply information in this regard.
2. How long does it take the moon to **orbit** the Earth once?
3. Why is it that phase 1 is less visible from the Earth than phase 5?



Phases of the moon

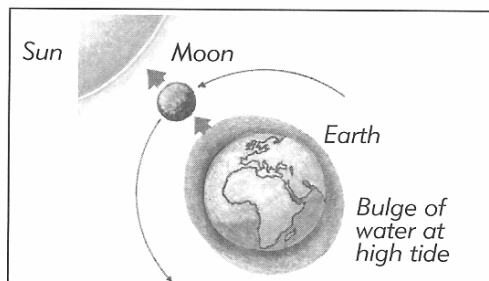


The orbit of the moon

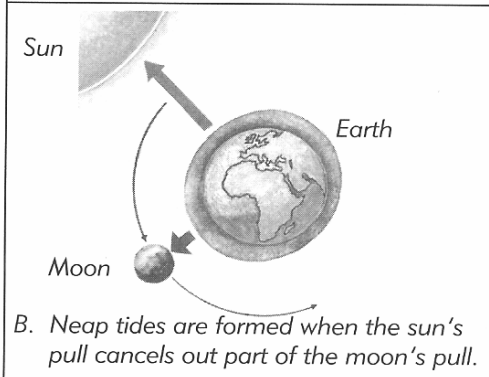
Word-wise

orbit: to move in an orbit, that is the curved path of, for example, the Earth going round the sun, or the moon going round the Earth

Activity 1.5 Problem-solving



A. Spring tides are formed when the sun's pull helps the moon's pull.



B. Neap tides are formed when the sun's pull cancels out part of the moon's pull.

Drawings A and B show the sun and the moon, which both influence tides on the Earth.

Discuss the following questions in your group. Some of the questions relate to the drawings. Other questions may require you to gather information from an encyclopaedia, tide tables and weather forecasts over the radio or in the newspaper.

1. What is a "tide"?
2. What different tides are there?
3. What is a "tide table"?
4. About how many tides take place every 24 hours?
5. Does it take exactly 24 hours to complete a cycle of tides? Explain in detail.
6. How do tides influence the decisions made by people on holiday at seaside resorts, sea fishermen, etc.?
7. Refer to the drawings to write a definition of spring tide and neap tide.

Notes concerning Diagram 18

The page has four diagrams. The first shows visual information in the following four clusters:

- The Sun, represented by a circle labelled *sun* surrounded by radial lines, and the Sun's rays approaching the Earth and the Moon, represented by three parallel arrows.
- The Earth, represented by a circular shape labelled *earth*, with a gibbous-shaped area of illuminated surface and a crescent-shaped area of non-illuminated surface.
- An oval representing the Moon's orbital path, showing eight positions of the Moon during the lunar month, as viewed from space. In each position, the Moon is represented by a circle with a gibbous-shaped area of illuminated surface and a crescent-shaped area of non-illuminated surface. The circles are numbered one to eight.
- The phases of the Moon as seen from the Earth, represented by seven shapes (and a blank space) numbered one to eight, linearly arranged below the Sun, the Earth, and the Moon's orbit around the Earth.

There is no visual information to indicate whether the Moon's orbital path around the Earth is drawn as it would be seen if looking down on Earth to one of the poles, or as it would be seen if looking sideways at the Earth, with the equator as a line across the middle.

The diagram is placed next to an activity which requires learners to (1) name the numbered phases of the Moon, (2) state the duration of the Moon's orbit around the Earth, and (3) explain why one phase (New Moon) is 'less visible' from Earth than another phase (Full Moon). The names of these phases of the Moon, however, are not provided in the diagram.

This diagram has been analyzed in the study.

The second diagram illustrated the Earth-Sun-Moon system but not phases of the Moon. The third and fourth diagrams illustrate tides. These three diagrams have not been analyzed in the study.

Diagram 19

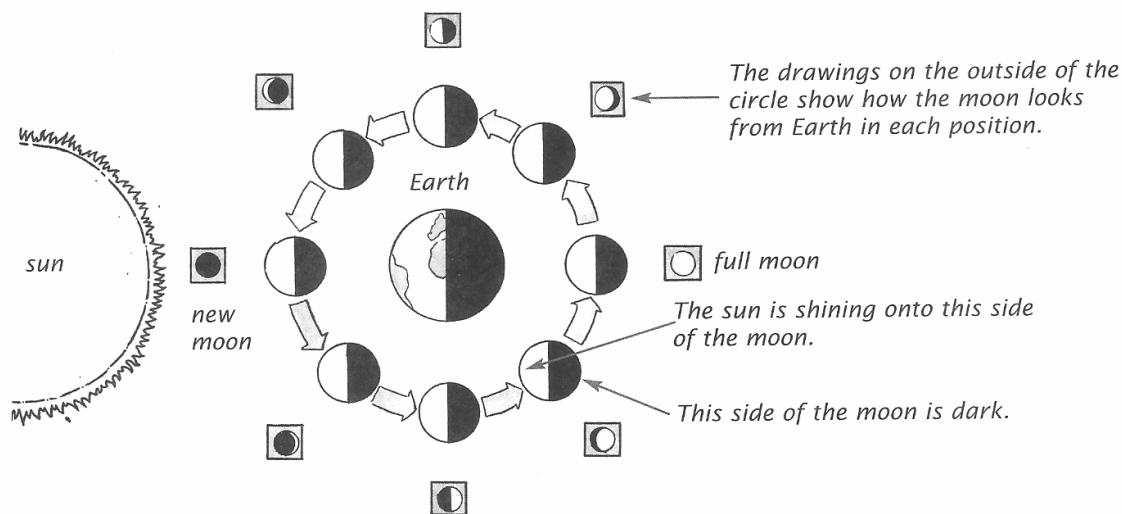
Sometimes the moon looks like a full circle of light, sometimes it is like a half circle and at other times it is not there at all. Why does the moon change shape?

We can see the moon in the sky because it reflects light from the sun. As the moon orbits the earth, different parts are lit up by the sun's light. When the moon is between the Earth and the sun, the side of the moon that faces the Earth does not get any sunlight. It is so dark that we cannot see it. We call this **new moon**. When the moon is on the other side of the Earth, it is fully lit and so looks like a round ball of light. We call this **full moon**. The amount of the moon that we can see from Earth slowly decreases between full moon and new moon and slowly increases between new moon and full moon. These different shapes of the moon are called the **phases of the moon**.

Important ideas!

The moon travels around, or orbits, the Earth once every 29 days and 13 hours, that is, about once a month.

The shape of the moon that we see from Earth keeps changing because, as the moon orbits the Earth, we can only see the part of the moon that is in the sun's light.



The shape of the moon that we see from Earth keeps changing



Activity...

Keep a moon diary. Choose a way to record how the moon looks every night for one month. Show and explain your diary to the rest of your class after the moon has orbited once.

Show that you can!

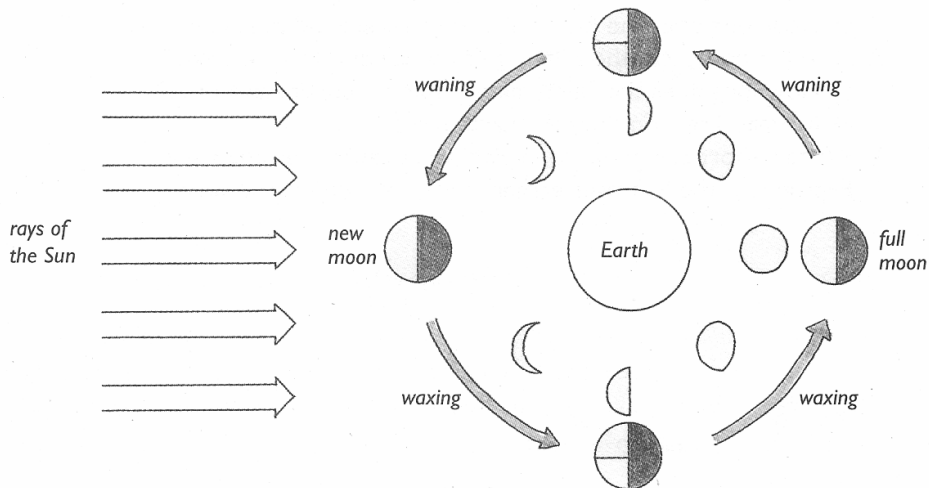
Carry out an investigation, collect information, present your information and discuss your findings.

Diagram 20

3. Phases of the Moon

Have you noticed that over a period of a month the shape of the Moon changes? The Moon is the Earth's only natural satellite. This means that the Moon orbits the Earth. As the Moon moves around the Earth, different parts of it are lit up by the Sun. The part of the Moon that is dark is turned away from the Sun. We see the part of the Moon that is lit up. It seems to grow and shrink depending on its position or phase. When the Moon is growing, we say it is waxing. When it is shrinking, we say it is waning.

This diagram shows the phases of the Moon and what the Moon would look like from Earth.



Discuss Moon phases

1. What is the Moon lit up by?
2. What is the shadow on the Moon made by?
3. What do we mean when we say the Moon is waxing?
4. What do we mean when we say the Moon is waning?
5. Explain how and why the shape of the Moon changes when you look at it from the Earth. Draw a diagram to explain your answer.

Extension

- Find out more about galaxies. Concentrate on the Milky Way, our own galaxy.

OR

- Keep a Moon diary for a month. Draw the correct symbols for the phases of the Moon next to each date. How long does it take the Moon to complete a full cycle?

Diagram 21a

Unit 3: The Earth and the Moon

In Unit 2 you saw that many of the planets in our Solar System have moons. Moons are **natural satellites** that move around the planets they are attached to. Astronomers are discovering new moons all the time. Our Moon is the closest space object to Earth. We can see the Moon in the night sky because it reflects light from the Sun. We normally cannot see the Moon during the day, because it is too light, but it is still there!



The full Moon

Moon movements

The Moon revolves around Earth in an **elliptical orbit** once every $29\frac{1}{2}$ days. At the same time, the Moon rotates on its own axis. The Moon's rotation means that the same side always faces Earth and that we only ever see one side of the Moon from Earth. The side of the Moon that we never see is called the 'dark side of the Moon'.

The diagram below shows the position of the Moon at different times in its orbit.

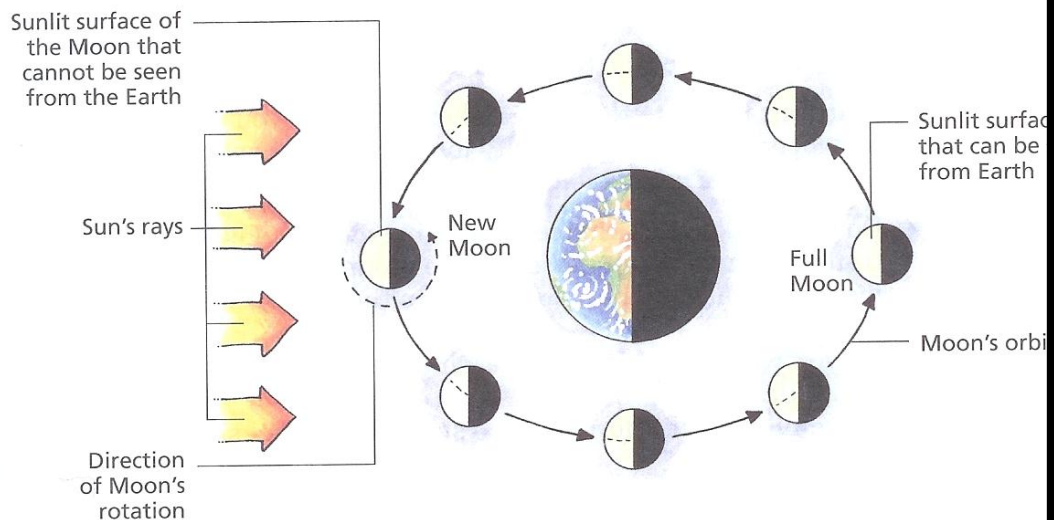


Diagram 21b

The phases of the Moon

As the Moon moves around Earth, it seems to change shape in the night sky. These changes are the result of the position of the Moon in its orbit around the Earth. One half of the Moon is always in sunlight but we cannot always see the entire sunlit section because of the Moon's position. The only time we do see the whole sunlit section is during full Moon. At new Moon the sunlit half of the Moon is facing away from Earth and we cannot see it at all.

The diagram on page 26 shows the eight main positions of the Moon during its orbit. The pictures below show you how the Moon appears in the sky at these eight points. We call these the **phases of the Moon**. The Moon goes through these phases every 29½ days. This is called a **lunar month**. The first stage is called **waxing** because the Moon seems to be getting bigger from new Moon to full Moon. The next stage is called **waning** because the Moon seems to get smaller from full Moon to the next new Moon phase.



The eight phases of the Moon

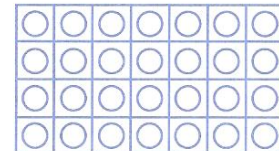


Observing and recording Moon phases

LO1 AS2; LO2 AS3

1. You are going to keep a record of Moon phases for 28 days. Start tonight!

- a) Draw a chart with a simple sketch like this one showing 28 days.
- b) Look at the shape of the Moon in the night sky each night and colour the part of the Moon you can see in yellow on your diagram.
- c) Write the date on each block.



2. At the end of the month, try to fill in on your chart the eight main phases of the Moon when they occurred .
3. Will the full Moon occur on the same date every month? Give reasons for your answer.
4. The start of the Muslim holy month of Ramadan is linked to the phases of the Moon. Find out how.

Diagram 22

WHERE DOES THE MOON FIT IN?

UNIT CHECKLIST

- How do we see the Sun and the Moon?
- What are the phases of the Moon?
- What is a solar eclipse?
- What is a lunar eclipse?

Our Earth has a smaller rocky body orbiting it just as the Earth itself orbits the Sun. This is called the Moon.

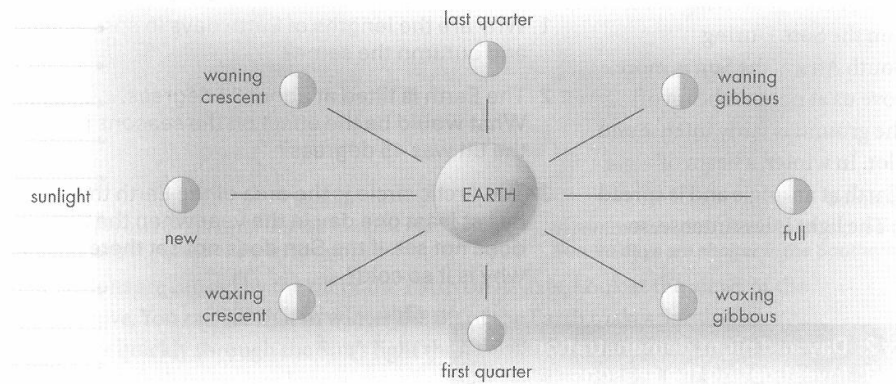
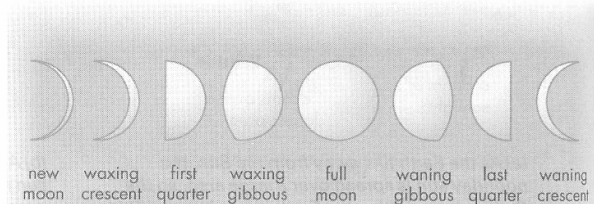
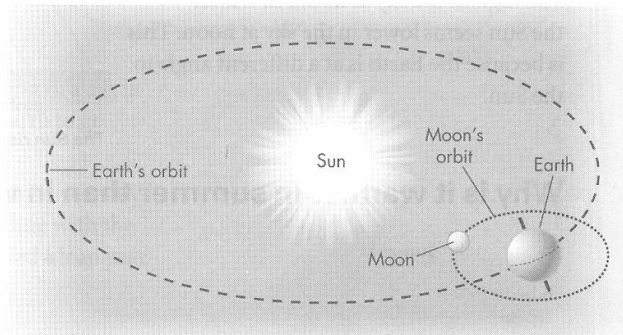
The Moon takes about 28 days to orbit the Earth. A month is roughly the time it takes the Moon to orbit the Earth. The Moon also spins on its axis about once every 28 Earth days.

How do we see the Sun and the Moon?

We see the Sun because it creates its own light. The Moon does not create its own light. We see it because it reflects the Sun's light. When something creates its own light we call it **luminous**. Objects which do not create their own light are **non-luminous**.

What are the phases of the Moon?

Because the Moon is orbiting the Earth, the amount of the Moon that reflects light towards the Earth changes, and this makes the **phases of the Moon**.



Notes about Diagrams 22a and 22b

The page has three diagrams. The first diagram shows information in two clusters

- The Sun, represented by a circular shape (with flares) labelled *Sun*, centrally located within an ellipse showing the Earth's orbital path.
- The Earth, represented by a spherical shape labelled *Earth*, shown on its elliptical orbit around the Sun. The Earth is centrally located within the orbit of the Moon. The Moon is represented by a spherical shape labelled *Moon*, shown on its elliptical orbit around the Earth.

This diagram has not been analyzed in the study (the diagram gives no information about phases of the Moon).

DIAGRAM 22a (middle diagram)

This diagram is linearly laid out, and uses photograph-like graphics to illustrate phases of the Moon. Because of the style, the diagram shows the Moon as a 3-D spherical object, in spite of the absence of obvious depth cues. This diagram has been analyzed.

DIAGRAM 22b (bottom diagram)

The diagram shows information in the following three clusters

- The Sun's rays, represented by very faint arrows labelled *sunlight*, pointing to the Earth-Moon configuration from the left of the diagram.
- The Earth, represented by a spherical shape labelled *Earth*, centrally located within an ellipse of eight moon shapes. Solid straight lines radiate between the Earth and each position of the Moon, not quite touching either.
- An ellipse representing the Moon's orbital path, showing eight positions of the Moon during the lunar month, as viewed from space.

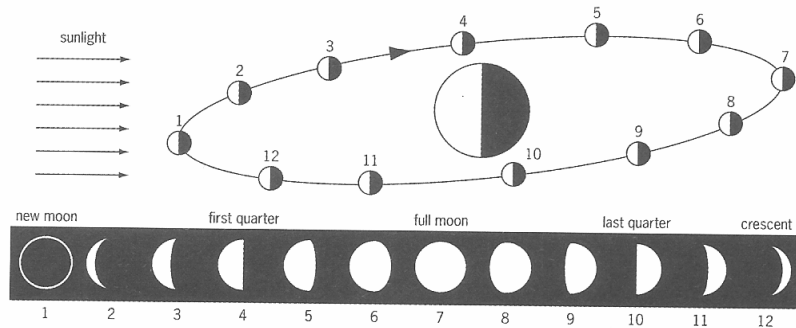
This diagram, has been analyzed in the study.

Diagram 23

9

Tides and the phases of the Moon

When you look into the sky at night you sometimes see the Moon. The Moon shines because it reflects sunlight. At different times, you will see that the Moon appears to be a different shape or in a different phase. This is because you see different parts of the Moon lit up by the Sun, as the Moon orbits the Earth. The Moon takes 29,5 days to orbit the Earth. As it moves, the Moon affects the level of the sea. These changes in the level of the sea are called tides.



The phases of the Moon

You can't see the Moon when it is between the Sun and the Earth. This is called the new Moon. About a day later, you can see the first crescent, a small, thin slice of the Moon. In the southern hemisphere this thin crescent is on the left hand side of the Moon. This crescent Moon is visible just after sunset.

The slice of the Moon waxes or grows bigger until it reaches the first quarter and is when the Moon appears half lit. When the Moon is between first quarter and full, it is called a gibbous Moon. Once it has reached full Moon, the Moon wanes or the sunlit part of it becomes less until it reaches the last quarter. Finally the Moon becomes a thin crescent again, lit up on the right-hand side and is visible just before sunrise.

ACTIVITY 1

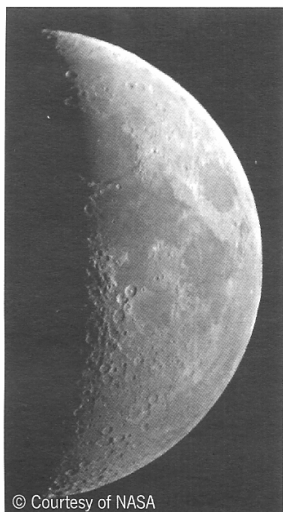
Groups / Use a model to experience the phases of the Moon (LO2 AS3)

You will need: an old cricket ball (or any other small ball), painted white; a small stick; Prestik; a bright light, such as an overhead projector light or desk lamp light.

1. Work in small groups to attach the ball to the short stick with the Prestik. Hold the stick at arm's length. Each group member must take a turn to do this.
2. Switch on the light and hold the ball between yourself and the light. The light represents the Sun, and the ball, which you cannot see clearly, the new Moon.

Diagram 24

UNIT 2: The Moon's phases



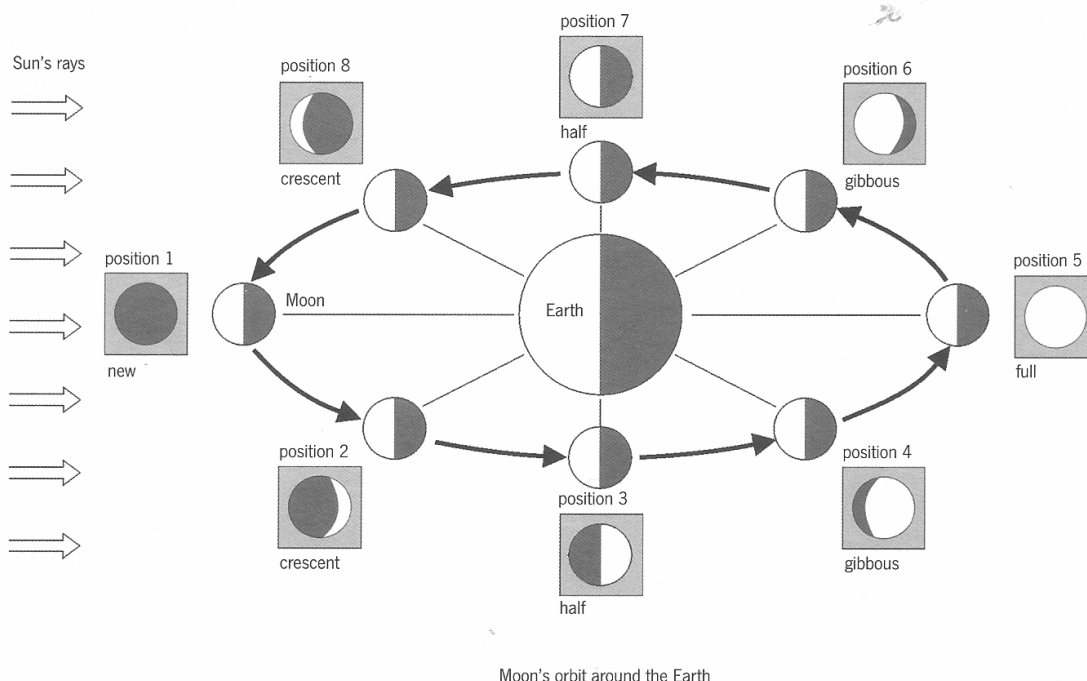
Look at the night sky and identify which phase the Moon is in at the moment.

As you know from earlier grades, many of the planets have smaller bodies that move in orbits around them. These bodies are called **moons**. For example, Jupiter has 16 moons. Like all the other bodies in the solar system, moons make regular motions. They revolve around planets in regular orbits.

Earth's moon

Earth has one moon. It takes $29\frac{1}{2}$ days for the Moon to complete its orbit around the Earth. During the month, we can sometimes see half the Moon, sometimes a whole circle of Moon and sometimes no Moon at all. This is because, like Earth, only half the Moon can be lit up by the Sun at any one time. The part of the lit half of the Moon that we can see from Earth is called the **phase** of the Moon. We see all the phases of the Moon in $29\frac{1}{2}$ days or one month. Look at the diagram of the Moon in its different phases below.

The phases of the Moon



APPENDIX D: Diagram analysis instrument

Diagram analysis instrument

Syntactic Principles

These principles focus on the way viewers perceive marks, and the way the marks are organized into perceptual units.

Principle	Guidelines	Source
1. Perceptual apprehension <i>(to do with how marks are discriminated by the viewers)</i>	Diagrams should be designed so that marks are easily perceived. This would allow viewers to see the visual message conveyed by each mark. This principle is violated for example if marks are not • big enough to be perceived by viewers • clearly printed, so that they are legible and can be perceived • perceivable against the background (figure-ground differentiation)	Kosslyn (1989), Thompson (1994)
2. Perceptual organization <i>(to do with how marks are grouped into perceptual units by viewers)</i>	Design of diagrams should enable viewers to perceive associated marks as linked. The following can help viewers to view marks as linked: <i>continuity (e.g. left-right and/or top-down arrangement used in the reading culture of learners), proximity, similarity [in colour, pattern, form, etc.] framing (e.g. empty spaces, lines, colour discontinuities, etc.)</i> (Arrows and numbers can be used to connect parts of a diagram.) The principle is violated for example if no mechanism is used to enable • 8 phases of the moon to be perceived as a unit • 8 positions of the Moon in its orbital path to be perceived as a unit • the Sun, the Earth, the Moon in its orbital path, and phases of the Moon to be linked together	Goldstein (1976), Kosslyn (1989), Thompson (1994), Rockman (2000)
3. Processing limitations <i>(to do with capacity limitations of working memory)</i>	Diagrams should be designed so that information can be processed without overloading working memory (only four perceptual units can be held in the mind at once). This principle is violated for example if • A diagram contains more than 4 perceptual units (<i>only 4 units can be held in the at mind once, although up to seven can be seen at a single glance</i>) • Perceptual units deal with more than one main message.	Kosslyn (1989)

Semantic Principles

These principles focus on the interpretation of marks and their configurations

Principle	Guideline	Source
4. Harmony <i>(to do with synchronization between messages conveyed by different parts of a diagram)</i>	Diagrams should be designed so that there is consistency in the meaning associated with each mark The principle is violated, for example, if • Size of the Moon (in its orbital path) differs from size of the Moon in the lunar phases • The number of moon shapes in the lunar circle differs from the number of lunar phases • Colour of the unlit part of the Earth (and/or Moon) differs from colour of the night sky (if this is represented). • Colours of the illuminated part of the Earth differ from colour of the illuminated part of the Moon, and either of these differs from colour of the sun's rays (if colour is used for these rays).	Thompson (1994)
5. Non-ambiguity <i>(to do with the certainty of messages conveyed by the marks in a diagram)</i>	Ambiguous use of marks should be avoided, as this might prevent viewers from understanding meanings of the marks This principle is violated for example if • The difference is not clear between the following phases: gibbous moon shapes and Full Moon, gibbous shapes and half moon shapes, and crescent moon and half moon shapes. • Readers cannot decide whether the black or the white colour represents the appearance of the Moon as seen from the Earth.	Kosslyn (1989), Thompson (1994)
		Kosslyn (1989) (identified the principle not the sub-principles)
6. Scientific accuracy: <i>(to do with scientific accuracy of marks making the diagram)</i>	Diagrams should be designed so that marks (e.g. symbols, keys, headings, captions, labels, etc.) accurately represent scientific concepts. This principle is violated for example if • Shapes representing phases of the Moon follow a wrong order (e.g. some phases have been misplaced) • Labels for phases of the Moon are inaccurate or incomplete • The Moon's orbit is drawn as circular, but a trace of Africa (or any country) is illustrated on the side. • The Moon's orbit is illustrated as an oval, but the North or South is indicated at the centre of the Earth.	

Pragmatic Principles

These principles focus on the appropriateness of diagrams for their intended purpose and specific target audience

Principle	Guidelines	Source
7. Purpose compatibility <i>(to do with appropriateness of diagrams for their intended purpose)</i>	Textual information should be provided to explain the purpose of each diagram. In addition, each diagram should have an appropriate amount of information needed to achieve its intended purpose This principle is violated for example if • No verbal elements are used to describe what the diagram is intended to show • Some information is lacking, which is needed to fulfill the intended purpose of the diagram • Irrelevant information is found in the diagram (<i>as this could cause visual and cognitive overload</i>).	Kosslyn (1989)
8. Textual compatibility <i>(to do with conformity between diagrams and the accompanying text)</i>	If diagrams are intended to illustrate concepts described in text, there must be correspondence between the diagram and the textual content This principle is violated for example if • Diagram and the text employ different terminology. • Diagram and text give contradictory messages.	Kosslyn (1989)
9. Audience compatibility <i>(to do with appropriateness of diagrams for the intended audience)</i>	Diagrams should be designed to comply with culture and context of intended viewers (e.g. left-right and top-down orientations in Western cultures, and for viewers in the southern hemisphere, diagrams should illustrate lunar phases as they would appear from the southern hemisphere). This principle is violated for example if • Diagrammatic information (or any part of the diagram) is against the top-down left-right reading convention used in schools. • A diagram illustrates phases of the moon as they would be seen from the northern hemisphere, when the intended audiences live in the southern hemisphere.	Kosslyn (1989)

APPENDIX E: Interview schedule

APPENDIX E: Interview Schedule

INTRODUCTION

Maybe you remember that last year we were here (in the hall) with some exercises that you completed. I told you that I would like you to talk to me about them. I am trying to find out how useful textbooks are in helping learners to understand different science topics. I can use this information to help textbook writers to improve their textbooks. This will make it easier for learners in the future, so by talking to me you are helping other learners. Your name will be kept confidential at all times. No one (including the teachers) will know what individual learners have said. I am very grateful that you agreed to help us with this research.

I am going to ask you questions about some information found in textbooks. If there is anything you do not understand, feel free to ask me about it. For example, if you do not understand what I am asking you to do, you do not understand my accent, or if I talk too fast.

I really need to know what you are thinking when you look at pages from textbooks. So I would like you to explain to me what you are thinking as you look at the diagrams. In other words, you need to 'think aloud'. I would like to record this interview so we have an accurate record. Would that be alright with you?

Probes to be used during the interviews

- ***If more explanation is needed:*** Tell me how you got that answer, What makes you think that? Explain further, Tell me more
- ***If they are quiet:*** Tell me what you are thinking, What are you thinking about? What are you looking at?

DIAGRAMS 21a and 21b

Aim	Main question	Probing questions
To find out if learners can work out the main message given by the diagram (and to see whether they use the text for this purpose).	Here is a page taken from one of the Natural Science textbooks. <i>(Give them a minute to look at the page that has Diagram 21a).</i> What do you think the main topic is that is being dealt with?	<i>All learners will be asked this question</i> What is it on the page that tells you what is being shown? <i>If necessary use probes (given on the introductory page)</i>
To find out how learners interpret the diagram, e.g. how they interpret the 8 moons and the arrows between them, and whether they associate the Sun's rays with illuminated parts of the Moon	I want you to study the diagram, and tell me what you think is happening in the diagram.	<i>If they can't answer, say</i> Look more carefully at the diagram. What clues can tell you what is happening?
	<i>If they do not talk about the Moon, ask</i> What do you think these circles show?	<i>Then ask the following questions</i> What is happening to the Moon? Why do you think the artist has drawn eight moons in the diagram? Why is half of each circle shaded grey? What do these arrows represent? <i>(pointing at arrows representing the Sun's rays)</i>
To find out how learners explain the (apparent) changing shapes of the Moon.	Now look at this diagram (21b showing lunar phases). What do you think is happening?	<i>If the question is not clear, rephrase as</i> What are these figures telling us? <i>Then ask</i> Why are the figures different in shape?
To investigate learners' spatial ability Orientation: imagining viewing the Moon from a different perspective (from the Earth instead of from space as the diagram viewer sees it). Perception: considering the Earth-Sun-Moon in a given perspective, ignoring everything else and imagine seeing only the relevant section. Visualization: mentally changing configurations of the components of the Earth-Sun-Moon system.	Now I want you to imagine that you are standing on the Earth shown in this diagram (referring to Diagram 21a) and you are looking at this Moon (pointing at Waning Gibbous in this diagram). What shape of the Moon would you see? Use this paper to draw what you would see. <i>(The following phases will be considered in turn: First Quarter, Waning Crescent, New Moon and Full Moon)</i>	<i>If learners do not know "where to stand on Earth", say</i> Imagine that you are standing here (pointing at the centre of the Earth, on the terminator line) and looking in this direction. What shape of the Moon would you see? <i>Use the following probe</i> Tell me how you got that answer. <i>If learners cannot work out the answer, show them shapes of lunar phases (without labels) and ask:</i> Here are some possible shapes. Which of these shapes do you think shows what the Moon will look like?

DIAGRAMS 24 and 19

Aim	Main question	Probing questions
To investigate how learners interpret a diagram showing both lunar phases as seen from Earth and the Moon as seen from space.	Here is a page from another textbook (<i>Diagram 24</i>). What do you think this diagram is showing?	<i>If they miss either circle of moons, ask them</i> What do you think this part of the diagram is showing us? <i>And probe with</i> Explain why you think so.
To find out how learners interpret the two dark colours (one representing the night sky and the other representing unlit part of the Moon) To investigate whether learners consider lunar phases to be represented by the black or the white section of the Moon in the diagram.	I want you to look at this part of the diagram (<i>pointing at the Waning Gibbous in the outer circle</i>) What do you think the artist is trying to show us? <i>(These questions will be repeated for Waxing crescent Moon)</i>	<i>If they can't answer, say</i> What do you think this shading (<i>pointing at the area surrounding New Moon</i>) shows? <i>Use probing questions listed in the introduction</i> <i>Then ask</i> What shape of the Moon would viewers on Earth see when the Moon is in this position? Use this paper to draw what you would see. <i>If they can't answer, say</i> Would the Moon look like this (<i>present them with a cut out crescent shape</i>) or like this (<i>present them with a cut out gibbous shape</i>)? <i>Then ask these questions to confirm answers given to the previous two questions</i> What do you think this part (<i>pointing at the shaded part of the Moon</i>) shows? <i>Use probing questions listed in the introduction</i> What do you think this part (<i>pointing at the illuminated part of the Moon</i>) shows? <i>Use probing questions listed in the introduction</i>
To find out how learners interpret the radiating lines, and to see if the lines help learners to interpret the 3-D spatial configuration of the celestial bodies.	What do you think these lines mean? (<i>pointing at the radiating lines between the Earth and the moons in Diagram 24</i>)	Why do you think this line is shorter than this one? (<i>Pointing at the shortest and the longest lines</i>).

Aim	Main question	Probing questions
To find out whether learners interpret the Earth and the Moon as 3-D objects.	If you were standing here (<i>pointing at the 9 o'clock position on the Earth</i>) would you be able to see the Moon? (<i>pointing at Full Moon</i>) If you were standing here (<i>pointing at 4 o'clock position on the waxing gibbous</i>) would you be able to see the Earth? Here are some shapes (<i>showing them a half-shaded circular paper and a half-shaded sphere</i>) that could show how these objects (<i>pointing at the moons</i>) look in real life. Which of these shapes shows what the artist is trying to draw?	Use probing questions listed in the introduction whenever necessary
To investigate how learners interpret the oval and circular orbital paths.	Here is another diagram (<i>showing them Diagram 19 next to Diagram 24</i>). You can see that it looks different from this diagram (<i>pointing at Diagram 19</i>). What is different about this diagram?	Allow them to talk until they have identified all the differences they can see. If necessary, use probes given in the introduction to get the learners talking.
	Can you think of any reason why the artist drew this orbit (<i>pointing at Diagram 19</i>) as a circle and this one (<i>pointing at Diagram 24</i>) as an oval?	Probe with Could the oval and the circular pathways tell us something about how the Moon moves in space? Use probes given in the introduction to get learners talking.

APPENDIX F: Ethical issues

APPENDIX F: Ethical Issues

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Prof

12/1/2006



Clearance from Gauteng Department of Education



UMnyango WezeMfundo
Department of Education

Lefapha la Thuto
Departement van Onderwys

Enquiries : Shadrack Phele MIRMSA

Tel. No. : [+2711] 355 0285

Friday, 29 August 2008

Mr. Mosoloane Retšelisitsoe
D11 West Campus Village
Private Bag 3
Wits
2050

Dear Mr. Mosoloane Retšelisitsoe

PERMISSION TO CONDUCT RESEARCH: PROJECT

The Gauteng Department of Education hereby grants permission to conduct research in its institutions as per application.

Topic of research : "Selected factors affecting students' understanding of concepts in astronomy: spatial ability, visual literacy and learning aids".

Nature of project : PhD [Science]

Name of university : University of the Witwatersrand.

Upon completion of the research project the researcher is obliged to furnish the Department with copy of the research report (electronic or hard copy).

The Department wishes you success in your academic pursuit.

Yours in Tirisano,

A handwritten signature in black ink, appearing to read "Shadrack Phele".

p.p. Shadrack Phele [MIRMSA]

TOM WASPE
CHIEF INFORMATION OFFICER
Gauteng Department of Education



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UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Division of the Deputy Registrar (Research)

HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)

R14/49 Mosoloane

CLEARANCE CERTIFICATE

PROTOCOL NUMBER H070204

PROJECT

Selected factors affecting students' understanding of concepts in astronomy; spatial ability, visual literacy and learning aids

INVESTIGATORS

Mr R Mosoloane

DEPARTMENT

School of Physics/Physics

DATE CONSIDERED

07.02.27

DECISION OF THE COMMITTEE*

Approved unconditionally

This ethical clearance is valid for 2 years and may be renewed upon application

DATE

07.03.26

CHAIRPERSON



(Professor M Vorster)

*Guidelines for written 'informed consent' attached where applicable

cc: Supervisor : Sanders/Stanton
APES/ Physics

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10005, 10th Floor, Senate House, University.

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to a completion of a yearly progress report.**

This ethical clearance will expire on 1 February 2009

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

Information sheet and consent form for learners

AN INVITATION TO PARTICIPATE IN OUR RESEARCH

WHAT THIS RESEARCH IS ABOUT

Many learners have problems when trying to understand day and night, lunar phases and eclipses. I am part of a research team which is trying to find the causes of these problems. The results of this research will be used to help teachers to help learners to better understand these topics.

WHY ARE YOU BEING INVITED TO PARTICIPATE?

Your teachers have shown an interest in the research. Your participation in the study will help to provide information that can help to improve teaching and learning of these concepts.

WHAT YOU WILL BE ASKED TO DO

- To take part in some written activities to help us to find how well you understand the topics, and to identify any difficulties you may have in understanding these topics. The activities will take about an hour.
- Some of you will be invited to take part in discussions in a few weeks time. These discussions are aimed at finding out more about these difficulties, and will take about 30-45 minutes. The discussions will be video-recorded if you give permission.

WHAT WE ARE PROMISING YOU

- Your participation is voluntary, and you will not be penalized if you refuse to participate in the research.
- You are free to withdraw from our study (should you wish to do so), and you will not be penalized for this.
- Your name will be kept confidential at all times. The teachers will not know what individual learners have said.
- This research study poses **no** risks to you.
- Getting involved in the study will help your teachers understand why some learners have problems, and will help teachers to teach these topics better.

If you would like to know more about the results of the research, please feel free to contact me

Retšelisitsoe Mosoloane

Email: Mosoloaner@science.pg.wits.ac.za

Tel no: 072-108-8643

Thank you for your interest.

CONSENT FORM

The project has been explained to me. I understand that:

- The study is being conducted for educational purposes.
- No harm will come to me if I participate in the study.
- My participation is voluntary; I can refuse to participate without facing any penalty.
- I can withdraw from the study at any time.
- If interviewed, I will be audio-and video-recorded only if I grant the researcher permission to do so.
- My identity will be kept secret.
- I am welcome to ask questions about the research, and the questions will be answered the researcher.

I agree to participate in the study

Participant's name
(please print)

Signature

Date

Information sheet and consent form for Parents

AN INVITATION FOR YOUR CHILD TO PARTICIPATE IN MY RESEARCH

WHAT THIS RESEARCH IS ABOUT

Many learners have problems when trying to understand day and night, lunar phases and eclipses. I am part of a research team which is trying to find the causes of these problems. The results of this research will be used to help teachers to help learners to better understand these topics.

WHY YOUR CHILD IS INVITED TO PARTICIPATE?

The teachers at your child's school have shown interest in the research. The participation of your child in the study will help to provide information that can help to improve teaching and learning of these concepts.

WHAT YOUR CHILD WILL BE ASKED TO DO

(S)he will complete

- some written activities to help us to find how well (s)he understands the topics, and to identify any difficulties (s)he may have in understanding these topics. The activities will take about an hour.
- Some learners will be invited to take part in discussions in a few weeks time. These discussions are aimed at finding out more about these difficulties, and will take about 30-45 minutes. The discussions will be video-recorded if learners give permission.

WHAT WE ARE PROMISSING YOUR CHILD

- Your child's participation is voluntary, and s/he will not be penalized if (s)he refuses to participate.
- Your child is free to withdraw from our study (should s/he wish to do so), and (s)he will not be penalized for this.
- His/her name will be kept confidential at all times.
- This research study poses **no** risks to him/her.
- Your child's participation in the study will help teachers understand why some learners have problems, and will help teachers to teach these topics better.

If you would like to know more about the results of the research, please feel free to contact me

Retšelisitsoe Mosoloane

Email: Mosoloaner@science.pg.wits.ac.za

Tel no: 072-108-8643

Thank you.

CONSENT FORM

The project has been explained to me.

- I understand that the study is being conducted for educational purposes.
- I realise that no harm will come to my child if (s)he participates in the study.
- I allow my child to participate voluntarily and understand that s/he can refuse to participate without facing any penalty.
- I understand that my child may withdraw from the study at any time.
- I further consent to my child being video-and audio-recorded if invited to do so.
- I understand that information obtained from my child may be used in the research report, but it will be reported so that his/her identity is anonymous.
- I am aware that my child is entitled to ask questions about the research, and the questions will be answered the researcher.

I allow my child to participate in the study

Parent/guardian's name (please print)

Signature

Date

APPENDIX G: Summary of literature

Summary of literature

This appendix presents a summary of conducted about phases of the Moon and spatial ability.

Appendix G(i): Misconceptions about the cause of Moon phases

Author	Country	Participants	Percentage of participants giving misconceptions				
			Obstacles in space	Earth's rotation	Earth's shadow	Sun's Shadow	Moon changes shape
Barnett & Moran (2002)	USA	14 Grade 5 students	13	21			
Baxter (1989)	England	120 pupils (9-16 year-olds)	* ¹⁴		*	*	
Bisard, Aron, , Francek & Nelson (1994)	USA	708 high school and university students	4		38		
Callison & Wright (1993)	USA	76 pre-service teachers	*		*		
Hermann & Lewis (2003)	USA	High school students (number not given)	18		61		
Hobson et al. (2010)	USA	21 Grades 2-to-3 students	*		*		
Kelfkens & Lelliott (2006)	South Africa	22 Pre-service teachers	*	*	*		
Kucukozer (2008)	Turkey	76 pre-service teachers	8		32		
Mant & Summers (1993)	UK	20 primary school teachers	40		40		
Mulholland & Ginns (2008)	Australia	±90 pre-service teachers	*		*	*	
Parker & Heywood (1998)	UK	89 pre-and-in service teachers			45		
Rider (2002)	USA	32 middle school students	*		*	*	*
Roald & Mikalsen (2001)	Norway	26 deaf and 13 hearing children	13		3		13
Schoon (1992)	Indiana	1213 young and adult students			48		
Sharp (1996)	UK	42 ten and eleven year-olds	24	7	5		
Stahly et al. (1999)	USA	Four Grade 3 students	25				
Trumper (2000)	Israel	76 university students			32		
Trumper (2001a)	Israel	448 junior high school students			19	25	
Trumper (2001b)	Israel	378 senior high school students			27	17	

¹³ Empty cells indicate that no misconceptions have been reported.¹⁴ The symbol * indicates that a misconception has been reported, but frequencies were not provided in the article.

Author	Country	Participants	Percentage of participants giving misconceptions				
			Obstacles in space	Earth's rotation	Earth's shadow	Sun's Shadow	Moon changes shape
Trundle et al. (2002)	USA	78 prospective teachers	4	11	32		
Trundle et al. (2010)	USA	20 Grade 8 students	*	*	*	*	
Wilhelm (2009a)	USA	Three children (6-to 8-year olds)	*				*

Appendix G(ii): Studies that conducted interventions to help learners understand the cause of Moon phases

Authors	Participants	Intervention		
		Moon observation	Use of models	Computer modelling
Abell, Martini & George (2001)	Pre-service teachers	✓	✓	
Barab et al. (2000)	Undergraduates			✓
Barnett & Moran (2002)	Grade 5 learners	✓		✓
Bell & Trundle (2008)	Pre-service teachers	✓		✓
Callison & Wright (1993)	Pre-service teachers	✓	✓	
Dove (2002)	Secondary school students		✓	
Hans et al. (2008)	Grade 6 to Grade 8 students		✓	✓
Hansen et al. (2004a)	Undergraduates			✓
Hansen et al. (2004b)	Undergraduates			✓
Herman & Lewis (2003)	High school students		✓	
Hobson et al. (2010)	Grade 2 to Grade 3 students	✓	✓	✓
Jones & Lynch (1987)	Grade 3 and Grade 6 learners		✓	
Kelfkens & Lelliott (2006)	Pre-service teachers		✓	
Kucukozer (2008)	Pre-service teachers			✓
Mulholland & Ginns (2008)	Pre-service teachers	✓	✓	
Ogan-Bekiroglu (2007)	Pre-service teachers	✓	✓	
Parker & Heywood (1998)	Pre-service and practicing teachers		✓	
Shen & Confrey (2007)	Practicing teachers		✓	
Sherrod & Wilhelm (2009)	Grade 7 students	✓	✓	
Stahly et al. (1999)	Grade 3 learners		✓	
Subramaniam & Padalkar (2009)	Masters' students in Engineering, and Physics researchers		✓	
Suzuki (2003)	Pre-service teachers	✓	✓	
Taylor, Baker & Jones (2003)	Year 7-8 pupils		✓	
Trumper (2006)	Pre-service teachers	✓	✓	
Trundle et al. (2002)	Pre-service teachers	✓	✓	
Trundle, Atwood, & Christopher (2006)	Pre-service teachers	✓	✓	
Trundle et al. (2007a)	Pre-service teachers	✓	✓	
Trundle et al. (2007b)	Grade 4 students	✓	✓	
Trundle et al. (2010)	Grade 8 students	✓	✓	
Wilhelm (2009b)	Grade 7 learners		✓	✓

Appendix G(iii): Studies which investigate links between spatial ability and astronomy education

Researcher	Sample	Content	Test	Skill measured	Purpose
Callison & Wright (1993)	76 pre-service teachers	The Earth, the Sun and the Moon	Purdue Rotation Abilities Test	Mental rotation	To investigate links between spatial ability and participants conceptual change in astronomy
			Test of Logical Thinking	Logical thinking	
			Astronomy Test	Understanding of astronomy concepts	
Rudmann (2002)	18 university students	The Earth, the Sun and the Moon	Cube Comparison Test	Mental rotation	Correlation of results between these tests
			Astronomy Based Geometry Test	Skills relevant to astronomy, e.g. rotation, revolution, tilt, light and shadow	
			Astronomy Questionnaire	Participants' basic knowledge in astronomy	
Kikas (2006)	176 children in Grade 1 and then in Grade 2	The Earth and the Sun	Contour Extraction Test	Not mentioned	Correlation between performance on astronomy test and spatial tests
			Mommies Test and a Hands Test	Mental rotation	
			Memory for Objects	Memory	
			Astronomy Test	Participants' knowledge in astronomy	
Black (2005)	97 university students	Earth Science concepts, e.g. the Earth-Sun-Moon configuration, geology structures, map projections, meteorology, etc	Earth Science Concepts Test	Participants' knowledge of Earth sciences	To investigate links between spatial ability and participants' understanding of Earth Science concepts
			Group Embedded Figures Test	Spatial perception	
			Purdue Visualization of Rotations Test	Mental rotation	
			Differential Aptitude Test (DAT)	Spatial visualization	
Wilhelm (2009b)	123 Grade 7 learners	Phases of the Moon	Lunar Phase Concept Inventory (LPCI)	Concepts associated with moon phases	To investigate links between gender differences and conceptual gains after a moon phase intervention
			Geometric Spatial Assessment (GSA)	Spatial skills needed to understand moon phases	

Appendix G(iv): Components of spatial ability

<i>Author</i>	<i>Perception of objects</i>		<i>Manipulation of objects</i>		<i>Manipulation of parts of objects</i>	
	Term	Definition	Term	Definition	Term	Definition
Anderson et al. (1954; cited by Eliot & Hauptman, 1981)	Relations	Ability to comprehend the arrangement of elements within a visual stimulus pattern	Visualization	Ability to imagine rotation of depicted forms of objects		
Bratt (1953; cited by Eliot, 1987)	Orientation	Ability of an observer to determine his spatial location in relationship to another object.	Relations	The ability to turn or rotate a given figure in one plane	Visualization	Ability to imagine spatial relationships of objects which change positions relative to each other.
Carroll (1993)	Closure Flexibility	Speed in finding, apprehending, and identifying a visual pattern, knowing in advance what is to be apprehended, when the pattern is disguised or obscured in some way.	Spatial Relations	Speed in manipulating relatively simple visual patterns, by whatever means (mental rotation, transformation, or otherwise).	Visualization	Ability in manipulating visual patterns, as indicated by level of difficulty and complexity in visual stimulus material that can be handled successfully, without regard to the speed of task solution.
Ekstrom et al. (1976)			Orientation	Requires only mental rotation of the configuration	Visualization	Requires both rotation and the performance of serial operations
French (1951; cited by Eliot & Smith 1983, and Smith 1964)	Spatial	Ability to perceive spatial patterns accurately and to compare them with each other.	Orientation	Ability to remain unconfused by the varying orientations in which a spatial pattern may be presented.	Visualization	Ability to comprehend imaginary movements in 3-D space, or to manipulate objects, in

<i>Author</i>	<i>Perception of objects</i>		<i>Manipulation of objects</i>		<i>Manipulation of parts of objects</i>	
	Term	Definition	Term	Definition	Term	Definition
						imagination.
Gulford and Lacey (1947; cited by Eliot & Smith, 1983)	Spatial relations	• Ability to determine relationships between different spatially-arranged stimuli and responses • Comprehension of the arrangement of elements within a visual stimulus pattern.			Visualization	Ability to imagine the rotation of depicted objects, the folding and unfolding of flat patterns, and relative changes of position of objects in space.
Linn & Petersen (1985)	Spatial perception	Ability to determine spatial relationships with respect to the orientation of their own bodies, in spite of distracting information	Mental rotation	Ability to rotate a 2-D or 3-D figure rapidly and accurately.	Visualization	May involve the processes required for spatial perception and mental rotations, with the possibility of multiple solution strategies.
Lohman (1979)	Minor factors		Relations	Requiring the mental rotation of figures or objects	Visualization	
			orientation	The ability to imagine a stimulus from different perspectives		
McGee (1979)			Orientation	• Comprehension of the arrangement of elements within a visual stimulus pattern • The aptitude to remain unconfused by the changing orientation of a stimulus	Visualization	The ability to mentally manipulate, rotate, twist, or invert a pictorially presented stimulus object.

<i>Author</i>	<i>Perception of objects</i>		<i>Manipulation of objects</i>		<i>Manipulation of parts of objects</i>	
	Term	Definition	Term	Definition	Term	Definition
				The ability to determine spatial orientation with respect to one's body		
Michael, Gulford, Fruchter & Zimmerman (1957)	Relations and Orientation	Comprehend the arrangement of elements within a visual stimulus pattern with respect to examinee's body			Visualization	Mental manipulation of visual objects involving a specified sequence of movements
Thurstone & Thurstone (1941,1949; cited by Eliot & Smith, 1983)	Perceptual processes	Require only the perception of detail in flat surface	Space factor S ₁	The ability to visualize a rigid configuration when it is moved to a different place	Space factor S ₂	The ability to visualize a configuration in which there is movement or displacement among parts of the configuration.
Werdnig (1961/2; cited by Elliot & Smith, 1983 and Eliot, 1987)	S ₁	Ability to see a whole configuration or gestalt.	S ₁ Factor	The ability to see a whole gestalt and to manipulate it as a whole.	S ₂ Factor	The ability first to break down a gestalt and then to manipulate the different parts.

Appendix G(v): Similarities and differences between spatial ability tests and skills required to understand phases of the Moon

Tests	Test demands	Similarities between test demands and skills needed to understand moon phases	Differences between test demands and skills needed to understand moon phases
Hidden Patterns Test	Participants are asked to determine whether a simple pattern is embedded in a complex configuration. To successfully accomplish the task, participants need to retain an image of the simple figure in mind and detach the pattern from the configuration.	Diagram viewers should be able to focus on the Earth-Moon-Sun alignment for each of the several positions of the Moon around the Earth, and temporarily ignore other information in the diagram.	The Earth-Moon-Sun configuration requires people to mentally manipulate spherical objects in space, while this test requires participants to manipulate 2-D patterns on the plane of the paper.
Card Rotations Test	Participants are presented with a card cut into an irregular shape, together with five drawing of the same card, some rotated and others flipped over. The participants have to decide which of the five cards can be rotated to look like the first card.	Diagram viewers should be able to imagine revolving the Moon around the Earth, and spinning the Earth on its axis.	The Earth-Moon-Sun configuration requires participants to imagine manipulating spherical objects in space, unlike this test which requires participants to manipulate cards on the paper plane.
Cube Comparisons Test	Participants are presented with two drawings of a cube, which have alphabetical letters written on the faces. The participants have to decide whether the two cubes can look alike after rotation of one of the cubes. To successfully accomplish the task, the participants have to imagine each cube as a 3-D object.	Diagram viewers should be able to perceive the Earth, the Sun and the Moon as 3-D objects in space. In addition, they have to imagine rotating the Moon around the Earth, and spinning the Earth on its axis.	The Earth, the Moon and the Sun are spherical in shape, while this test uses cubes.
Form Board Test	Participants are presented with five shapes and a polygon which can be formed by rearranging (some of) the shapes. The participants have to decide which of the five shapes can combine to form the polygon. To successfully accomplish the task, the participants need to rotate, reposition and integrate the shapes.	Diagrams illustrating phases of the Moon require participants to imagine changing relative positions of the Earth, the Sun and the Moon as the Moon orbits the Earth.	The Earth-Moon-Sun system requires participants to mentally manipulate spherical objects in space, not 2-D shapes on the paper plane.
Paper Folding Test	Participants are presented with a sequence of drawings depicting a process of folding a square piece of paper, punching of a hole on the folded paper, and unfolding the paper. In addition, participants are shown five shapes indicating possible locations of the holes on the unfolded paper. The participants have to choose a shape that shows proper locations of the holes.	The diagrams illustrating Moon's phases require participants to mentally manipulate 3-D objects in space, as is the case with the paper in this test.	The folding process is not required to understand concepts associated with the Earth-Moon-Sun system.

Tests	Test demands	Similarities between test demands and skills needed to understand moon phases	Differences between test demands and skills needed to understand moon phases
Surface Development Test	Participants are shown two drawings: a flat piece of paper and a 3-D object that can be formed by folding the paper. The participants have to determine sides of the flat paper corresponding to stipulated edges of the 3-D object. To successfully accomplish this task, participants have to mentally fold the flat shape to form a 3-D object, and to match sides of the flat paper against the edges of the 3-D object. This might require the participants to mentally rotate the 3-D object, or to imagine viewing the object from different perspectives.	Diagrams illustrating phases of the Moon require people to mentally construct 3-D objects from 2-D illustrations. In addition, the diagrams require people to perform a series of mental manipulations in space, as required by this test.	Folding is not required to understand concepts associated with phases of the Moon. In addition, the diagrams illustrating Moon's phases require learners to mentally construct spherical objects using 2-D drawings, not to construct solids used in the test.

Appendix G(vi): Mean scores reported in studies which administered one part of each spatial ability tests (total scores are half of those reported in Table 2.5)

Researcher	Country	Sample	Mean score on spatial tests																	
			CF-2 (200)			S-1 (80)			S-2 (21)			VZ-1 (120)			VZ-2 (10)			VZ-3 (30)		
			Mean	SD	Mean %	Mean	SD	Mean %	Mean	SD	Mean %	Mean	SD	Mean %	Mean	SD	Mean %	Mean	SD	Mean %
Burton & Fogarty (2003)	Australia	213 participants (undergraduate students, and adults from a neighbouring city)	46	15	23	54	15	68	12	4	57	51	18	43	5	2	50	15	5	50
Kozhevnikov, et al. (2002)	USA	60 undergraduate students				58	18	73	9	5	43	11	4	9	6	2	60			
Mayer & Massa (2003)	USA	65 undergraduate females				48	20	60							6	2	50			
		30 undergraduate males				58	15	73							7	3	70			
Sanders (2004)	South Africa	166 Grade 10 learners in the experimental group (pre-test)				45		56	6		29	50		42	4		40	12		40
		166 Grade 10 learners in the experimental group (post-test)				51		64	6		29	57		48	5		50	16		53
		140 Grade 10 learners in the comparison group (pre-test)				45		56	5		24	45		38	4		40	13		43
		140 Grade 10 learners in the comparison group (post-test)				43		54	5		24	51		43	5		50	13		43

Mean scores reported by studies which administered both parts of each of the six spatial ability tests

Researcher	Country	Sample	Mean score on spatial tests																	
			CF-2 (400)			S-1 (160)			S-2 (42)			VZ-1 (240)			VZ-2 (20)			VZ-3 (60)		
			Mean	SD	Mean %	Mean	SD	Mean %	Mean	SD	Mean %	Mean	SD	Mean %	Mean	SD	Mean %	Mean	SD	Mean %
Abdel-Rahim et al. (1990)	Egypt	107 12-to-19 year old high school boys				38	21	24	16	5	38	72	29	30	7	3	35	10	4	17
		97 12-to-19 year old high school girls				39	20	24	17	5	40	62	25	26	6	3	30	8	5	13
Allen et al. (1996)	USA	100 participants (97% university students)							22	10	52							41	14	67
		103 university students							14	10	33							29	14	48
Barnea & Dori (1999)	Israel	177 Grade 10 students (in pre-test)				76	29	48	8	4	19				5	3	25			
		165 Grade 10 students (in post-test)				87	21	54	11	5	26				6	2	30			
Geary & Widaman (1987)	USA	100 university students				101	38	63	17	10	40									
Geary et al. (1996)	USA	66 younger adults				116	26	73	17	10	40									
		44 older adults (57-to-85 year-olds)				60	30	38	5	5	12									

Researcher	Country	Sample	Mean score on spatial tests																	
			CF-2 (400)			S-1 (160)			S-2 (42)			VZ-1 (240)			VZ-2 (20)			VZ-3 (60)		
			Mean	SD	Mean %	Mean	SD	Mean %	Mean	SD	Mean %	Mean	SD	Mean %	Mean	SD	Mean %	Mean	SD	Mean %
	China	40 younger adults				95	28	59	14	9	33									
		40 older adults (60-to-77 year-olds)				58	42	36	4	6	10									
Kozhevnikov & Hegarty (2001)	USA	70 university students				111	34	69	19	12	45				12	4	60			
Miyake et al. (2001)	USA	167 university students	107	26	27	78	20	49							11	4	55			
Peters et al. (1995)	Canada	54 male university students				109	29	68							11	4	55			
		47 female university students				108	33	68							11	3	55			
Smalley et al. (1989)	USA	58 participants for S-1 & S-2, and 54 for CF-2; aged 12 years or older	173	55	43	88	36	55	15	11	36									
Wickett et al. (2000)	Canada	68 20-to-35 year old males	238	60	60										12	4	60			

Appendix G(vii): Studies which investigated strategies used to solve mental rotation tasks

Investigator	Data analyzed			Strategy inferred			
	Response times	Introspective reports	Eye fixations	Object rotation		Frame rotation	Analytic
				Holistic	Partial		
Barratt (1953)		✓		✓	✓		✓
Bejar (1990)				✓			
Bethel-Fox & Shepard (1988)	✓	✓		✓	✓		✓
Carter, Pazak & Kail (1983)	✓			✓			
Cohen & Kubovy (1993)	✓			✓	✓	✓	✓
Cooper (1975)	✓			✓			
Cooper (1976)	✓			✓			
Cooper & Podgorny (1976)	✓			✓			
Cooper & Shepard (1973)	✓			✓			
Folk & Luce (1987)	✓			✓	✓		
Gluck (1999, cited by Gluck & Fitting 2003)		✓		✓			✓
Just & Carpenter (1976)			✓		✓		
Just & Carpenter (1985)		✓	✓	✓	✓		✓
Kail et al. (1980)	✓			✓			
Koriat & Norman (1984)	✓			✓		✓	
Koriat & Norman (1988)	✓			✓			
Pylyshyn (1979)	✓	✓			✓		
Robertson, Palmer, & Gomez (1987)	✓					✓	
Schultz (1991)		✓		✓		✓	✓
Sharps & Nunes (2002)	✓			✓			✓
Shepard & Klun (cited by Cooper & Shepard, 1973)	✓	✓		✓			
Shepard & Metzler (1971)	✓	✓		✓			
Wohlschlagel & Wohlschlagel (1998)	✓			✓			
Yuille & Staiger (1982)	✓				✓		
Zacks et al. (2000)	✓			✓		✓	

APPENDIX H: Learners' spatial ability scores

Learners' spatial ability scores

This appendix presents learners' standardized spatial ability scores. The shaded rows indicate learners who participated in interviews.

Learner	CF-2	S-1	S-2	VZ-1	VZ-2	VZ-3	Sum of z-scores	Composite z-scores
1	-1.51	-2.12	-1.23	-0.21	-0.90	-1.56	-7.53	-2.22
2	-2.08	-2.12	-1.23	0.12	0.58	-0.44	-5.18	-1.52
3	-1.28	-1.64	0.39	-0.85	-1.40	-0.38	-5.15	-1.52
4	-0.71	-1.37	-0.01	-1.22	-1.40	-0.44	-5.14	-1.51
5	-0.13	-1.26	-0.83	-0.62	-0.90	-1.32	-5.06	-1.49
6	-0.90	0.26	-1.23	-2.67	-0.90	0.44	-5.00	-1.47
7	-0.39	0.80	-0.83	-2.11	-1.40	-0.73	-4.65	-1.37
8	-1.47	-1.10	-0.42	-1.29	-0.21	-0.14	-4.64	-1.36
9	-0.07	-1.37	-0.42	-0.73	-0.90	-1.09	-4.58	-1.35
10	-0.52	-1.42	-0.42	-1.25	-0.90	0.44	-4.07	-1.20
11	-0.96	-0.12	-0.22	-0.77	-0.01	-1.91	-3.99	-1.18
12	-0.71	-1.47	-1.23	0.08	0.09	-0.73	-3.98	-1.17
13	-0.77	0.20	-0.01	-2.15	-1.10	-0.14	-3.97	-1.17
14	-0.77	-0.45	-0.83	-0.14	-1.89	0.15	-3.92	-1.15
15	-0.52	-1.31	1.21	-1.37	-0.41	-1.32	-3.72	-1.09
16	-1.35	0.80	-0.83	-1.11	-0.61	-0.38	-3.47	-1.02
17	-0.33	0.47	0.80	-1.14	-1.40	-1.32	-2.91	-0.86
18	-1.22	0.31	-0.22	-0.62	-0.90	-0.14	-2.79	-0.82
19	-1.79	0.53	-0.62	-0.92	-0.21	0.44	-2.58	-0.76
20	0.38	-0.93	-2.05	1.09	0.09	-0.67	-2.10	-0.62
21	0.57	0.04	-0.42	-2.11	-0.90	0.74	-2.08	-0.61
22	-0.80	-0.34	-0.83	0.46	-0.11	-0.44	-2.06	-0.61
23	-1.44	0.15	-0.83	0.23	0.38	-0.44	-1.94	-0.57
24	0.15	-1.80	-0.01	0.05	0.09	-0.38	-1.91	-0.56
25	0.57	-0.23	-1.23	-0.77	-0.41	0.74	-1.34	-0.39
26	0.41	-0.39	-1.23	-0.25	0.58	-0.44	-1.33	-0.39
27	-0.42	-0.18	-0.42	0.64	-0.21	-0.73	-1.32	-0.39
28	0.19	-1.10	-0.62	-0.44	0.09	0.74	-1.15	-0.34
29	-0.04	1.02	-0.83	-0.06	-1.40	0.44	-0.87	-0.25
30	-0.58	1.56	-0.42	0.49	-0.21	-1.61	-0.78	-0.23
31	0.28	-0.50	-1.23	1.50	0.09	-0.73	-0.60	-0.18
32	0.79	1.99	0.39	-2.30	-0.41	-1.03	-0.56	-0.16
33	1.01	0.04	-1.23	0.01	-1.40	1.03	-0.53	-0.16
34	0.06	-0.72	0.80	-0.10	-0.41	-0.14	-0.51	-0.15
35	1.17	0.04	0.80	-0.58	-1.00	-0.73	-0.30	-0.09
36	0.50	0.58	-0.22	0.68	-0.90	-0.67	-0.03	-0.01
37	-0.90	-0.28	0.80	0.27	-0.51	0.68	0.06	0.02
38	2.61	-2.07	-0.01	-0.36	-1.40	1.33	0.10	0.03
39	0.76	0.69	0.39	-0.32	-1.40	0.39	0.51	0.15

Learner	CF-2	S-1	S-2	VZ-1	VZ-2	VZ-3	Sum of z-scores	Composite z-scores
40	-0.36	1.67	0.39	0.27	-0.41	-1.03	0.54	0.16
41	-1.67	-1.37	0.80	1.09	1.07	0.68	0.61	0.18
42	0.57	-0.01	-0.42	0.53	0.58	-0.56	0.69	0.20
43	0.12	-0.01	-0.83	1.68	1.07	-1.32	0.72	0.21
44	0.98	-1.04	0.39	-0.10	0.18	0.33	0.74	0.22
45	-1.44	0.74	-0.42	0.64	1.07	0.15	0.75	0.22
46	0.03	0.58	-0.42	0.38	0.58	-0.14	1.00	0.30
47	0.76	-0.12	1.21	-0.51	0.09	-0.32	1.10	0.32
48	3.41	0.10	-0.83	-0.88	0.58	-1.26	1.11	0.33
49	0.54	0.37	2.02	0.42	-0.70	-1.32	1.32	0.39
50	0.98	-1.85	1.61	0.57	-0.90	1.03	1.44	0.42
51	-0.17	-0.55	0.80	1.35	0.58	-0.44	1.57	0.46
52	-0.17	1.02	1.00	-0.47	0.68	-0.44	1.62	0.48
53	0.38	0.10	-0.42	0.79	1.07	-0.20	1.71	0.50
54	1.65	2.10	-0.83	-1.29	0.68	-0.56	1.75	0.52
55	0.38	0.26	1.00	-0.47	0.18	0.62	1.97	0.58
56	0.28	0.26	-0.42	0.38	1.57	-0.09	1.98	0.58
57	0.31	0.69	0.39	1.09	-0.90	0.44	2.03	0.60
58	-0.01	0.47	-1.23	0.94	1.07	0.80	2.04	0.60
59	-1.70	0.96	-0.42	1.01	0.97	1.38	2.22	0.65
60	0.70	-0.61	0.80	1.16	-0.90	1.33	2.47	0.73
61	0.15	0.69	-0.42	0.72	0.58	0.86	2.57	0.76
62	-0.39	0.47	1.00	0.72	0.58	0.39	2.77	0.81
63	-0.61	1.88	-0.83	0.72	1.07	0.74	2.97	0.87
64	0.79	0.04	1.61	0.42	0.48	-0.20	3.14	0.92
65	0.03	0.47	1.21	1.31	0.58	-0.44	3.16	0.93
66	1.72	0.69	-0.01	0.49	0.09	0.44	3.42	1.01
67	0.54	0.69	0.39	0.72	1.07	0.44	3.85	1.13
68	0.63	0.91	-0.22	0.75	2.55	-0.44	4.19	1.23
69	1.14	1.02	0.60	0.23	0.58	1.03	4.60	1.35
70	0.57	0.47	1.61	0.64	0.48	1.74	5.52	1.62
71	-1.00	0.64	1.21	-0.06	1.07	4.21	6.06	1.78
72	0.73	1.02	3.24	1.24	-0.41	0.44	6.25	1.84
73	0.95	0.80	0.39	1.39	2.55	0.74	6.82	2.01
74	0.31	0.37	2.83	1.09	2.06	0.68	7.34	2.16
75	1.08	0.91	-0.22	1.91	2.55	2.80	9.03	2.66