DEVELOPING AND USING AN ASSESSMENT INSTRUMENT FOR SPATIAL SKILLS IN GRADE 10 GEOMETRY LEARNERS

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ABSTRACT

This qualitative investigation took the form of a case study and fell within the interpretive research paradigm. The Mathematics Chair at the Education Department of Rhodes University launched the Mathematics Teacher Enrichment Programme (MTEP) in 2010 in order to combat poor Mathematics performance of learners in the lower Albany district of the Eastern Cape. The challenge that the participating MTEP teachers faced was a lack of time available to implement new teaching ideas. This was because most of their time was spent catching up "lost" or untaught concepts in the classroom.

To address this problem, the Catch-Up Project was launched, whereby selected Mathematics teachers in the area taught lost concepts to Grade Ten learners during afternoon classes in an attempt to improve their fundamental Mathematics knowledge. In order to establish which sections of Mathematics were more difficult for the learners in this programme, bench mark tests were administered biannually. Whilst these tests certainly identified deficient areas within their Mathematics knowledge, the poorest performance areas were the sections of the syllabus which were spatial in nature, such as Space and Shape and Geometry. However, a more in depth assessment tool was required to establish which specific spatial skills the learners were not able to employ when doing these Geometry tasks.

To this end, the Spatial Skills Assessment Tasks (SSAT) was developed. It consisted of traditional text book type Geometry tasks and real-world context tasks, both of which were used to assess six spatial skills deemed crucial to successfully facilitate learning Geometry. The case study took place in two of the schools which participated in the Grade Ten Catch-Up project. The case was focused on Grade Ten learners and the unit of analysis was their responses to the SSAT instrument. The learners that participated all did so on a strictly voluntary basis and great care was taken to protect their wellbeing and anonymity at all times.

The results of the SSAT instrument revealed that the real world context tasks were in general far more successfully answered than the traditional text book type questions. Important trends in learner responses were noted and highlighted. For example, geometric terminology remains a huge challenge for learners, especially as they study Mathematics in their second language. The

ability of the learners to differentiate between such concepts as congruency and similarity is severely compromised, partly due to a lack of terminological understanding but also due to a perceived lack of exposure to the material. Concepts such as verticality and horizontality also remain a huge challenge, possibly for the same reasons. They are poorly understood and yet vital to achievement in Geometry.

Recommendations for the development and strengthening of spatial skills support the constructivist approach to learning. Hands on activities and intensive sustained practice over a period of a few months, in which both teachers and learners are actively involved in the learning process, would be considered most beneficial to the long term enhancement of these vital spatial skills and to the learning of Geometry in general.

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ACRONYMS

2D	Two Dimensional
3D	Three Dimensional
ANA	Annual National Assessments
CAPS	Curriculum and Assessment Policy Statement
CoPF	Community of Practice Forum
DBE	Department of Basic Education
EC DoE	Eastern Cape Department of Education
FET	Further Education and Training
FRF	First Rand Foundation
HSRC	Human Sciences Research Council
MEC	Member of the Executive Council
MTEP	Mathematics Teacher Enrichment Programme
NCS	National Curriculum Statement
NCTM	National Council of Teachers of Mathematics
PIRLS	Progress in International Reading Literacy Study
SACMEQ	Southern and Eastern African Consortium for Monitoring Educational Quality
SSAT	Spatial Skills Assessment Tasks
STEM	Science, Technology, Engineering and Mathematics
TIMSS	Trends in International Mathematics and Science Study
TOMA-3	Test Of Mathematical Abilities (3rd edition)

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DECLARATION OF ORIGINALITY

I, **Jane Mary Cowley**, declare that this thesis is my own work, written in my own words. Where I have drawn on the work, words and ideas of others, I have acknowledged them using complete references in accordance with Departmental regulations.

Signature

Date 24 November 2014

Student Number 13C7950

CHAPTER 1 - INTRODUCTION

> "*Philosophy is written in that great book which is ever before our eyes…..I mean the universe…..but we cannot understand it if we do not first learn the language and grasp the symbols in which it is written. The book is written in mathematical language, and the symbols are triangles, circles and other geometrical figures, without whose help it is impossible to comprehend a single word of it; without which one wonders in vain through a dark labyrinth*."
>
> (Galileo Galilei (1623), as quoted by Burtt, 2003, p. 75).

This introduction serves to outline the rationale behind the study which was conducted, the purpose of the study and the significance and limitations of the study. It concludes with a brief overview of the chapters that follow.

1.1. Rationale

Many secondary school mathematics learners in South Africa struggle to achieve satisfactory results. The reasons for this poor performance in Mathematics are varied and many.

In an attempt to combat poor performance in Mathematics, the FRF Mathematics Education Chair of the Education Department at Rhodes University launched the Mathematics Teacher Enrichment Programme (MTEP) in January 2010. The MTEP implemented contact sessions with participating teachers were concept-driven as opposed to curriculum-driven. One of the problems that the MTEP teachers faced early in the programme was spending time they could ill afford on revising Mathematics content that the learners lacked, which detracted from the successful implementation of the teaching concepts that had emanated from the MTEP sessions.

This problem was addressed when the Catch-Up Programme was launched in January 2011. Mathematics teachers were employed in this after-hours programme to identify and catch up missing concepts within the Grade 10 curriculum, whilst freeing up contact time during school hours in order for the MTEP teachers to implement new teaching skills and ideas. Benchmark tests were established and administered bi-annually by FRF staff members in order to monitor improvements in Grade 10 Mathematics performance. Sections of these benchmark tests which have been consistently poorly answered by the Grade 10 learners were *Space and Shape*, *Functions and Graphs*, and *Geometry*. In Figure 1.1 to Figure 1.4 we can see the pre- and post-benchmark tests for 2011, 2012, 2013 and 2014 respectively.

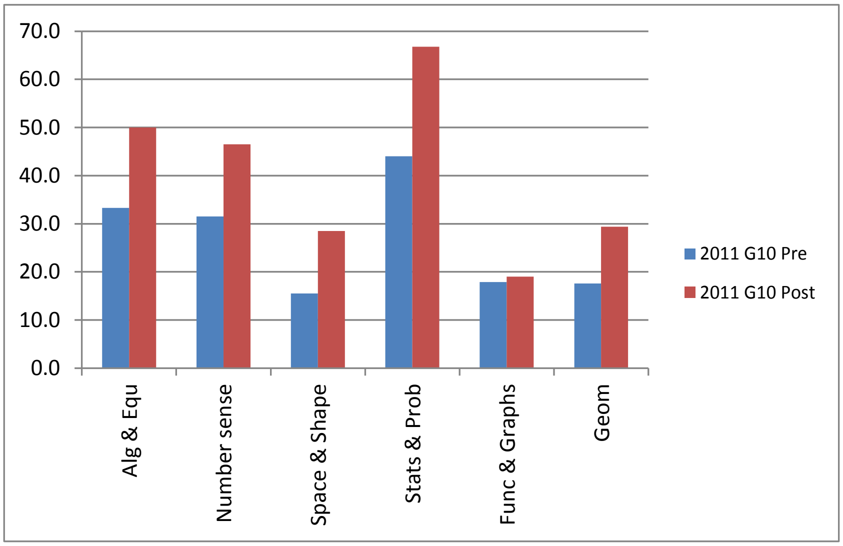


Figure 1.1: Results of benchmark tests for 2011 (Source: CoPF Report: FRF Mathematics Education Chair 2014)

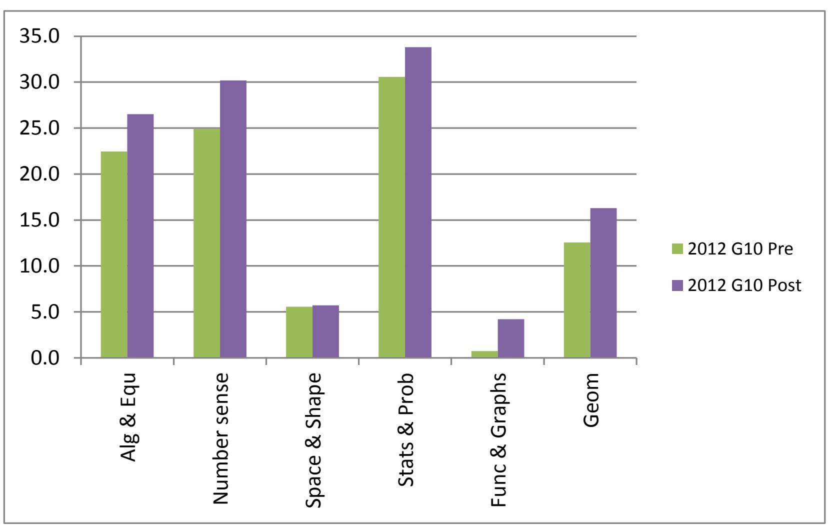


Figure 1.2: Results of benchmark tests for 2012 (Source: CoPF Report: FRF Mathematics Education Chair 2014)

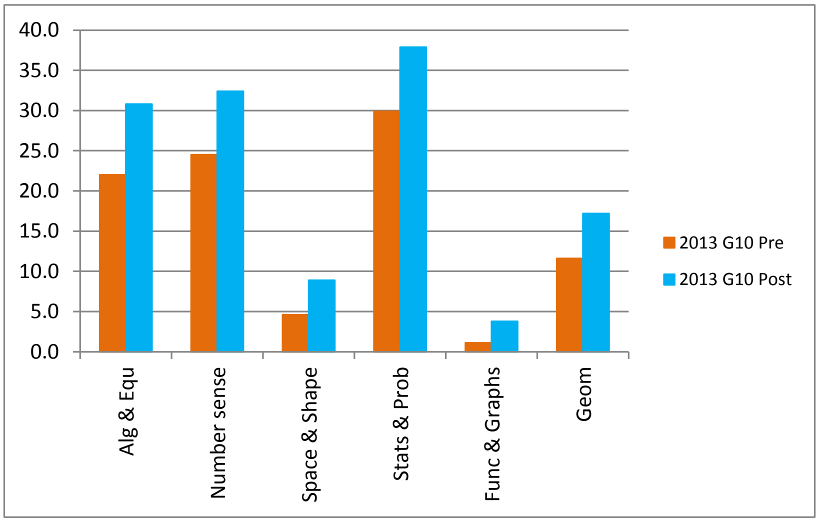


Figure 1.3: Results of benchmark tests for 2013 (Source: CoPF Report: FRF Mathematics Education Chair 2014)

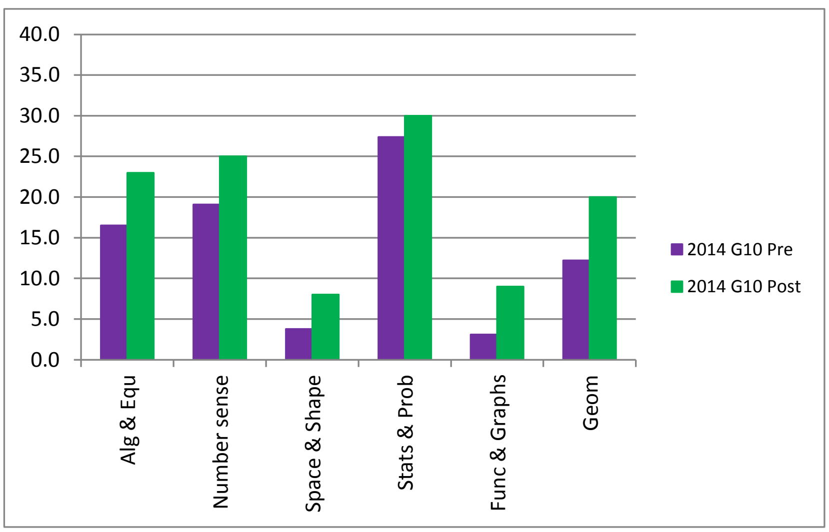


Figure 1. 4: Results of benchmark tests for 2014 (Source: CoPF Report: FRF Mathematics Education Chair 2014)

These sections of the benchmark tests, namely *Space and Shape*, *Functions and Graphs*, and *Geometry*, are all spatial in nature and could thus be indicative of possible weaknesses regarding the spatial skills of the learners concerned. In other words, problems which are presented as a graph, a 2D shape or a 3D object seemingly present greater challenges for the learners than other sections of the syllabus. This led to the assumption that the challenges the learners face could be related to their ability with regard to spatial skills that are crucial to success in Geometry. See the comprehensive bench mark data set in Appendix 2.

However, a more reliable form of testing needed to be established in order to assess these skills, as the benchmark tests used had limitations in that they were closed pen and paper questions with marks allocated for correct steps and answers. This may well have given insight into what the learners could or could not do in Mathematics, but shed little or no light on whether they displayed the necessary spatial skills to succeed in these sections of Mathematics.

1.2. Purpose of the Study

In order to establish which spatial skills the learners demonstrate when tackling Geometry tasks, a specific assessment instrument is required. Six specific spatial skills which have been deemed essential to successfully understand Geometry are included in the instrument. Each of these skills is assessed in two Subtasks: the first Subtask represents a typical text book type question with traditional diagrams that one would ordinarily find in a school text book or study guide; the second Subtask represents a real-world context subtask that one would ordinarily happen upon in everyday life.

The purpose of the dual Subtasks is to establish whether learners cope better with traditional tasks or real-world context tasks or whether no distinction can be made between the two sets of responses to the Subtasks. This will then inform the study as to the status of spatial ability in Geometry learners.

A further purpose of this study is to establish the terminological understanding of the Geometry learners, and the impact of a lack of understanding of basic geometric terminologies on success in Geometry.

1.3. Research Goals

The research goals to be achieved from this study are threefold:

- Firstly, to develop a suitable skills assessment instrument for Geometry learners;

- Secondly, to implement the spatial skills assessment tool in two peri-urban secondary schools in the Albany district of the Eastern Cape in order to establish which spatial skills the learners are deploying when completing Geometry tasks; and
- Thirdly, to assess the terminological understanding of the learners, who are studying Mathematics in their second language.

The overarching goal of this study is to gain a better understanding of the paucity of spatial skills which prevent mathematics learners from achieving greater success in Mathematics, and specifically in Geometry. Once a clearer understanding of these issues has been reached, a suitable developmental remediation programme for the improvement of these skills can be developed.

1.4 Significance of the Study

Roger M Downs of Pennsylvania State University, as quoted in Newcombe (2006), states that "*without explicit attention to spatial thinking, we cannot meet our responsibility for equipping the next generation of students for life and work in the 21st century*". This sentiment is supported by Newcombe, who highlights how critical spatial thinking is for the STEM disciplines, namely Science, Technology, Engineering and Mathematics.

The crisis in South African Education has been, for some time now, foregrounded by poor learner performance in both Mathematics and Science. While a variety of international and national bench mark tests have confirmed that South African learners do indeed perform very poorly in these learning areas, the tests are structured in such a way that they simply indicate a correct or incorrect answer, without delving into the thought processes of the learners or their interpretation of the questions presented to them. In Geometry in particular, an interactive assessment instrument which focuses on pinpointing which spatial skills learners display, or lack, is essential. Once the spatial skill sets have been identified, a suitable remediation strategy can be devised in order to develop those spatial skills which require improvement.

Another significant facet of this study is the focus on learner interpretation with regard to geometric terminology. According to Newcombe & Learmonth (2005), talking about space can be difficult, partly because the speaker and the listener need to agree on spatial frames of reference in order to avoid ambiguity. Further, proficiency in spatial language is assisted by parental scaffolding. A parent may use directive prompts to improve the child's spatial communication (Plumert & Nichols-Whitehead, 1996), for example, "tell Tom his ball is next to the red chair instead of saying it is on the carpet". This assists the child in resolving ambiguity with regard to spatial language. If this amount of effort is necessary to develop spatial communication in one's home language, it can be assumed that the problem of understanding spatial language when one learns in a second language is substantially exacerbated, especially when many of the parents of these learners are unable to speak the second language (in this case, English) and are thus unable to provide the necessary scaffolding.

1.5 Limitations of the Study

While several schools in the Grahamstown district took part in the Mathematics Catch-Up Programme, I was the facilitator at only two of them. As a relationship of trust and mutual respect was necessary for the learners to communicate freely whilst completing the interactive assessment instrument, only the learners from the two schools at which I facilitated took part in the case study, as we had had the opportunity to develop this relationship. Altogether, 30 learners completed the assessment instrument. This is considered a small sample and therefore no generalisations may be made.

The two schools that took part in the research were both black peri-urban schools in the Grahamstown district, so the study was geographically very limited. Further, the study only covered one section of the mathematics syllabus, namely Geometry, as this section was considered more problematic for learners and contained more spatial elements than other parts of the mathematics syllabus.

1.6 Thesis Overview

1.6.1 Chapter 2

In this chapter, the chronological development of learning theories, particularly those pertaining to the learning of Geometry, is reviewed. The importance of learning Geometry both at school and as a necessary life skill is also reviewed. Thereafter I review literature on the development of spatial skills and the expected time frames for this development in learners. I then examine literature on suitable assessment strategies for Geometry. The final section of the chapter deals with learner performance in Geometry in the South African context and how a suitable assessment tool could be used to identify weaknesses in Geometry and shape future remediation strategies.

1.6.2 Chapter 3

This chapter describes how the study falls within the interpretive research paradigm. The distinction between the qualitative research perspective and the quantitative perspective is made, and the selection of the qualitative perspective is justified by elaborating on the shared experience of the researcher and the participants, which lends itself to a data-rich encounter. It then explains the research design which has two components – firstly the design of the assessment instrument, and secondly the implementation of the instrument and the consequent analysis of data. The selected methodology, which takes the form of a case study, is explicated. The structure of the instrument is then discussed, along with the participants and the ethical issues around the involvement of the participants in this study.

1.6.3 Chapter 4

In this chapter all results from both sections of the assessment instrument are presented and discussed. A comparison is drawn between the text book-type questions, which formed the A Subtasks, and the real-world context questions, which formed the B Subtasks. The results are presented graphically and in terms of percentages where applicable. A discussion of these results ensues. Lack of exposure to 2D shapes and 3D objects is discussed and the conundrum of congruency is further analysed. Issues regarding the terms horizontal and vertical are discussed. Another trend that was highlighted in the discussion is the orientation of objects in relation to the orientation of the learner. The data pertaining to terminology is then presented and discussed.

1.6.4 Chapter 5

This chapter summarises the results from the previous chapter and puts them into a teaching and learning perspective. Recommendations for remediation and development strategies and programmes that are cost effective, practical and easy to implement in the classroom are made. The significance of the study is highlighted and so are the limitations. Recommendations for further research are also made. The chapter concludes with my personal reflection.

CHAPTER 2 – LITERATURE REVIEW

2.1. Introduction

In this chapter I shall undertake to review literature that is relevant to this study. The review will include learning theories as they have developed chronologically, particularly those pertinent to the learning of Geometry. I will review the importance of learning Geometry at school and the impact of acquiring geometric skills both as an academic discipline and as a skill for everyday living. Thereafter I shall review literature on spatial skills and the expected time frames for the development of these skills in learners. Literature on assessment strategies that are relevant to the study of Geometry will then be reviewed, followed by a summary of Geometry performance in the South African context and how the development of a SSAT instrument will seek to establish the spatial weaknesses demonstrated by Geometry learners and how these can be remediated in the future.

2.2. Learning Theories

There has been much research on the development of geometric thinking. Jean Piaget, a genetic epistemologist, spent most of his life studying the development of intellectual structures and knowledge (Wadsworth, 1989). He believed that from birth, knowledge is constructed by the individual and stored in mental structures known as schemata. These schemata constantly assimilate and accommodate new stimuli, which results in cognitive development. Together with Inhelder, Piaget (1967) developed the theory of topological primacy, in which they assert that children firstly develop spatial concept via topological relations; thereafter projective and finally Euclidean relations develop.

When referring to topological relations, they claim that young pre-school children are unable to describe or draw shapes with any accuracy at first. For example, squares and circles are indistinguishable from each other. Topological features (such as whether a figure is open or closed) are represented first. Differentiation of the Euclidean features of shapes is a slow process, spanning over months and even years (Clements & Battista, 1992). As children develop, their thinking becomes less egocentric and they begin to imagine objects and space from differing perspectives, or points of view. Figures and objects are no longer seen in isolation and children perceive that they are related to objects in space. These findings were confirmed by the well-known “three mountains” task, in which young children had to construct a certain scene from the perspective of a suitably positioned doll. All the constructions were representative of their own viewpoints, as they had not yet developed a “global” system of reference, which is the basic prerequisite for constructing projective relations. Finally, in middle childhood, children come to “see” objects as located in a 2D frame of reference. This frame is the culminating point of the development of Euclidean space. (Clements & Battista, 1992).

This theory is not widely supported, as it is believed that children’s geometric ideas do not necessarily follow such rigid order; but rather that geometric ideas of all types develop concurrently and become increasingly integrated and synthesised over time. However, their theory that children’s representation of space is not a perceptual “reading off” of their spatial environment, but is constructed from active manipulation of that environment (Clements & Battista, 1992), is supported by Fishbein (1987) who argues that people’s intuition of space is not innate and cannot be reduced to a collection of sensorial images. He elaborates that this intuition of space is a “highly complex system of expectations, and programs of action, related to the movement of our body and its parts, which constitutes the intuition of space” (p. 87).

Pierre and Dina van Hiele (Van Hiele, 1986), theorised that learners progress through levels of geometric thought, starting from a Gestalt-like visual level and then moving on to the increasingly sophisticated levels of description; analysis; abstraction and finally proof. A brief summary of the five van Hiele levels of thinking in Geometry follows:

- Level 1: Visual. The learner is able to identify a figure only as a visual gestalt. He or she is not yet able to identify any characteristics of a geometric figure.
- Level 2: Analysis. The learner can recognise and characterise a shape by its properties. The properties are established experimentally by observing, measuring, drawing and modelling.
- Level 3: Abstract/Informal deduction. The learner can now form definitions, can classify shapes and objects according to their characteristics, can classify the shapes and objects and justify his/her classification informally.

- Level 4: Formal Deduction. The learner is now able to interpret axioms, definitions and theorems. He or she is able to construct an original proof with regard to the properties of classes of figures, by using logic and reasoning. Links within the geometric system are established.
- Level 5: Rigor. The learner is now able to reason by manipulating geometric statements. The outcome of this reasoning is the establishment, analysis and comparison of different geometric constructs. (Grinstein & Lipsey, 2001).

An additional van Hiele level was proposed by Usiskin (1982). Learners who were as yet unable to attain van Hiele Level 1 were classified as pre-recognition at van Hiele Level 0. Atebe (2008) studied these levels of geometric thinking in a comparative study of Nigerian and South African learners. His study revealed a huge discrepancy between anticipated van Hiele levels and actual van Hiele levels of attainment in senior secondary Geometry learners, with the majority of learners falling into Level 0 (pre-recognition) and Level 1 (visual). He concluded that the vast majority of learners that he had observed were not equipped to master formal deduction and proof. Characteristics that define the Van Hiele model are as follows:

- Levels of learning are discrete and qualitatively different.
- These levels of learning are sequential and hierarchical.
- Concepts that are implicitly understood at one level become explicitly understood at the next level.
- Each level has its own language. Language structure is a critical factor in the learner's movement through the levels.

The van Hieles proposed five levels of instruction to facilitate progress from one level to the next. These are described as follows:

- Level 1: Information. The teacher presents materials and activities to acquaint the learners with a topic.
- Level 2: Guided orientation. Suitable tasks are presented to the learners to reveal certain relations within a topic.
- Level 3: Explicitation. Learners are led to become aware of their geometric conceptualization. They describe it in their own words at first and then use correct terminology that is introduced by the teacher.

- Level 4: Free orientation. Learners explore relations within a topic by doing more complicated tasks and using different methods.
- Level 5: Integration. The learners summarize their new knowledge and integrate it into a coherent network.

Criticisms of the van Hiele theory include the fear that whilst the levels of geometric thinking have been directly linked to phases of instruction, these implications for instruction have been inadequately addressed. Language usage is a huge factor and teachers need to constantly remember that children's concepts underlying language may be vastly different than teachers think (Burger & Shaunessy, 1986; Clements & Battista, 1989). Also, the belief that geometric levels of thought, and therefore the phases of instruction, are discrete has been refuted by some researchers. For example, a recent study conducted in Namibia concluded that "the teachers navigated quite freely from one phase of instruction to the next, but also returned to the earlier phases for clarification and reinforcement" (Dongwi, 2012). According to Burger & Shaunessy (1986), the levels "are more dynamic than static and more continuous in nature than their discrete descriptions would lead one to believe."

Whilst these theories of cognitive development in Geometry go a long way to clarifying how children are able to solve increasingly difficult geometric problems, they do not explain why some learners appear to be unable to think geometrically.

2.3. The Importance of Geometry

We live in a 3D world and it is vital that learners are able to perceive, explore and understand the spaces and shapes that make up our natural environment. According to the National Council of Teachers of Mathematics (1989, p. 48) "*Spatial understandings are necessary for interpreting, understanding, and appreciating our inherently geometric world*". Consequently, the study of Geometry at primary and secondary school level is essential in order to develop the spatial skills and reasoning required to work successfully within the geometric realm.

According to the South African Department of Education (South Africa: Department of Education, 2003, p. 10), the purpose of Mathematics in the Further Education and Training (FET) band is to establish proper connections between Mathematics as a discipline and the application of Mathematics in real-world contexts, thus allowing learners to deepen their understanding of Mathematics while adding to their mathematical tools for solving real-world problems. Similarly, the Learning Outcomes set out in the same document indicate that learners of Geometry should "*be able to describe, represent, analyse and explain properties of shapes in 2D and 3D space with justification*".

According to Higgins (2005) it is as learners become proficient in Geometry that their understanding of its importance is shaped. Muyeghu (2008) supports this sentiment and adds that Geometry is necessary for all learners and will contribute to them becoming effective citizens.

Geometry has always formed part of the school curriculum, as it offers opportunities to:

- Extend spatial awareness,
- Develop the skills of reasoning, and
- Stimulate, challenge and inform (French, 2004).

According to French (2004), this spatial awareness refers to our ability to perceive and manipulate geometric objects. The usefulness of this sense of shape and space extends beyond the obvious daily tasks such as building a shelf or landscaping a garden, to the more sophisticated applications such as architecture, navigation, design and even surgery.

Mathematics, according to Goldenburg, Cuoco & Mark (1998) establishes mathematical "*habits of mind*", which include the urge to pose and solve problems, searching for patterns in maths, noting connections between these patterns and attempting to prove theories. Geometry even more so, as it is rich with problems that have an intuitive appeal and require arguments that may not be procedural.

To learn Geometry successfully requires factual knowledge, an ability to argue logically and also a less tangible ability to see clues which are not obvious, but are nonetheless essential for solving a problem or proving a theorem. While the ability to reason can to some degree be learnt, what is far less apparent is how we can go about developing intuitive skills in Geometry learners.

According to the Curriculum and Assessment Policy Statement (CAPS) for Mathematics for the Senior Phase (South Africa: Department of Basic Education, 2011a, p. 27), learners should be able to acquire and demonstrate the following cognitive skills in Geometry:

- Investigating new properties of shapes and objects;

- Developing from informal descriptions of geometric figures to more formal definitions and classification of shapes and objects;
- Solving more complex geometric problems using known properties of geometric figures; and
- Developing from inductive reasoning to deductive reasoning.

The same document lists the following skills as necessary for measurement in the senior phase. (This topic becomes included in Geometry in the FET phase)

- Progression in measurement is achieved by finding area, perimeter, surface area and volume using more complex formulae and more complex objects and shapes.
- The use of formulae in this phase provides a useful context to practise solving equations.
- The introduction of the Theorem of Pythagoras to calculate the lengths and sides in right-angled triangles. It becomes a useful tool when learners solve geometric problems involving right-angled triangles.

Thus, the following cognitive skills are deemed by the Department of Basic Education to be essential in Geometry learners: the ability to investigate, to apply formulae appropriately, to classify, to represent shapes and objects, to reason and to solve problems, both of a routine and non-routine nature.

While all of the cognitive skills mentioned above are necessary to develop mathematical understanding in general, and Geometry in particular, an instrument that only uses these skills as indicators of mathematical performance may not reveal the underlying problems experienced by learners who are unable to do or understand Geometry. A more in-depth approach needs to be adopted in order to establish which spatial skills the learners need to acquire or improve, in order to perform tasks that are spatial in nature.

Problems with the teaching and learning of Geometry are not new. As far back as 1923, the Mathematical Association of Great Britain proposed that deductive Geometry be preceded by an experimental stage where students engage in a range of practical activities including measuring, cutting and folding, in order to acquire an intuitive feel for geometric objects and relationships. In their second Geometry report, the Mathematical Association made the following statement, which still resonates clearly today: "*One of the great mistakes in the* *teaching of mathematics, and one to which we are always liable, is that of presenting abstractions familiar to ourselves to minds unprepared for them*". (1938)

2.3.1. Geometry and the Real-World Context

According to the CAPS document in the FET phase (South Africa: Department of Basic Education, 2011b), mathematical modelling is an important focal point of the curriculum and real life problems should be incorporated whenever appropriate. These real-world problems should not be contrived and should include issues relating to health, social, economic, cultural, scientific, political and environmental contexts (p. 8). This emphasis on real-world contexts is supported by Kolb (1984) who states that most students learn best when they can connect new concepts to the real world through their own experiences or experiences that their teachers can provide for them.

Giving meaning to problems from a real world context allows learners to construct their own mathematical knowledge, according to Freudenthal (1978). Siyepu & Mtonjeni (2014) concur and they further elaborate by stating that actively engaging learners and developing their critical thinking skills using real-world contexts will defuse the widely held belief that Geometry exists only in the classroom.

2.4. Spatial Skills

According to Newcombe & Learmonth (2005), spatial behaviour is a fundamental aspect of any creature that moves intentionally in the environment. Organisms which move need to encode their location with respect to the location of other objects, specifically objects they wish to avoid (such as predators and physical dangers) or objects they wish to encounter (such as food or social partners). Another aspect of human spatial competence is the ability to imagine what a scene would look like from another perspective, or visualise what an object would look like after it has been transformed or manipulated in some way. According to Schäfer (2003), this ability to visualise is dynamic and involves motion. It is likely to be linked to another human adaptation, which is the ability to make and use tools. A further spatial competence which is unique to humans is the ability to communicate about space using symbols. A fourth, and possibly the most interesting of spatial competencies, is the ability to use spatial thinking to resolve non-spatial problems in reasoning and problem solving.

With the appearance in recent years of a number of studies in space perception and visual imagery, teachers of high school mathematics have become increasingly aware of the part played in this subject by the pupil's ability to perceive, remember, analyze and work over in imagination space relations of two and three dimensions. A brief survey of almost any classroom situation in which geometrical mathematics is the subject of study reveals the fact that the pupil's success or failure is conditioned to no small extent by his ability to "see the figure'', to rearrange the parts of a figure, to construct in imagination essential but missing parts of a figure, to hold certain elements of the figure or situation in mind while adding or taking away others.

Irwin (1918)

This excerpt lends weight to the long-held belief that success in Geometry requires much more than simply a strong theoretical grounding. It becomes more and more apparent that the Geometry learner must be able to imagine geometric shapes undergoing various transformations and then be able to express those transformations using suitable geometric terminology.

Wheatley (1990) states unequivocally that "*spatial sense plays a major role in mathematical reasoning*". He goes further to say that spatial sense is "*indispensable in giving meaning to our mathematical experience*".

According to Del Grande (1990) "*Geometry has been difficult for pupils due to an emphasis on the deductive aspects of the subject and a neglect of the underlying spatial abilities……that are necessary prerequisites for understanding and mastery of geometrical concepts*".

2.4.1. Defining Spatial Skills

According to Humphries & Lubinski (1998), spatial ability is the capacity to understand and remember the spatial relations among objects. This skill consists of many sub-skills which develop throughout one's life. They are necessary not only for navigating everyday problems such as looking in one's rear view mirror while reversing or reading maps, but are considered very important for success in many fields of study such as meteorology, radiology and engineering, to name but a few.

Metz, Donahue & Moore (2012) state that strong spatial-visualisation skills, particularly the ability to visualise in three dimensions, are linked to success in the STEM (Science, Technology, Engineering and Mathematics) disciplines.

Hoffer, as cited in Del Grande (1990), identified seven spatial abilities as having relevance to Mathematics and Geometry in particular. They are as follows:

2.4.1.1 Eye-Motor Co-Ordination

This is defined as the ability to coordinate vision with the movement of the body. Everyday activities such as getting dressed or cutting and pasting paper items require this ability. Geometric tasks such as tracing shapes or joining dots on geopaper also require this ability.

2.4.1.2 Figure-Ground Perception

This is defined as the visual act of identifying a specific component within a complex background of hidden and overlapping forms. In nature, camouflage is a beautiful example of this ability to become "lost" in a busy background. The human ability, is, of course, being able to spot the camouflaged animal. Geometric activities involving this ability are completing a given figure and assembling a figure, such as a tangram, from its parts.

2.4.1.3 Perceptual Constancy

This is the ability to constantly recognise a shape, despite variations in size, shape, colour and orientation in space. For example, a tennis court is seldom perceived as a rectangle, but we intuitively know that it is one. Activities for Geometry learners which include perceptual constancy are identifying figures with the same shape but different size, or ordering shapes from smallest to largest.

2.4.1.4 Position-in-Space Perception

This is the ability of a learner to relate an object in space to himself or herself. For example, he or she must be able to easily distinguish between a "b" and a "d", which are the same, but with different positions in space, and a "b" and a "b", which are the same and have the same orientation in space. This ability leads to the learner being able to identify congruent shapes even if they have been translated in some way.

2.4.1.5 Perception of Spatial Relationships

This is defined as the ability to see objects in space in relation to the viewer and to each other. It is very closely linked to position-in-space perception and requires a strong sense of one's body orientation. This ability is very useful in everyday activities such as riding a bicycle, where distances between the bicycle and other objects need to be judged with accuracy.

2.4.1.6 Visual Discrimination

This is the ability to identify differences and similarities between objects and shapes, and is independent of position. Geometric activities that enhance this ability include sorting blocks and classifying shapes according to their characteristics.

2.4.1.7 Visual Memory

This is defined as the ability to accurately recall or bring to mind objects or features of objects which are no longer in view. This ability can be developed, through exercises such as mnemonics. Activities to develop this ability in Geometry could include showing the learners a shape for a brief period of time and then asking the learners to copy what they saw onto geopaper.

The seven abilities listed above formed a solid and thorough framework from which subsequent research on spatial ability could springboard. Del Grande (1990) promotes the constructivist approach to knowledge acquisition, by including uncomplicated hands-on activities which link directly to spatial skill development that is pertinent to Geometry. This approach is supported by Pederson (1983) who stated that "*Geometry is a skill of the eyes and the hands as well as the mind*.

Sorby (1999) differentiated between the terms "spatial abilities" and "spatial skills" by stating that the word "ability" implies an innate characteristic which one either has or does not have, for example the ability to sing. The term "skill" on the other hand, implies characteristics that have been learned and that can improve with practise. For the purposes of my study, I adopted the same definition and hence refer from now only to spatial skills.

Sorby (1999) went further to say that spatial skills generally refer to a collection of cognitive, perceptual and visualisation skills, which traditionally focussed on understanding and manipulating 2D shapes and to a lesser degree, 3D objects. However, with dramatic advances in computer applications in the past few decades, the research emphasis has shifted to 3D space.

Although extensive research on spatial skills has been undertaken in the past century, it has been done in a large variety of ways which do not align well with one another and a cohesive view of the structure of spatial intellect has failed to develop (Hegarty & Waller, 2005).

According to Sutton & Williams (2008), substantial agreement exists amongst researchers that the core spatial skills are as follows:

- The ability to visualise mental rotations of objects;
- The ability to understand how objects appear in different positions;
- The ability to conceptualise how objects relate to each other in space; and
- The ability to understand objects in 3D space.

However, for the purposes of my study, the definitions of core skills given above are too vague and assessment of such skills would be problematic as much overlapping of core skills would be likely.

A more recent and appropriate typology by Newcombe & Shipley appeared in 2012. This typology is based on the understanding that all objects can be spatially represented using characteristics that are INTRINSIC to the objects. These intrinsic characteristics include the size of the object, the shape of the object, the orientation of the object relative to other objects or a frame of reference, the scaling of these objects and the bending, rotating or cross-sectioning of the objects.

In addition, all objects need to be situated EXTRINSICALLY, which means they must have a location relative to other objects or to a frame of reference. Lastly, the spatial skills required to manipulate objects in space are either STATIC (the viewer and the object remain motionless) or DYNAMIC (the viewer, the object or both move relative to a frame of reference).

The four categories of spatial skills are thus as follows:

1. Intrinsic-static: The spatial features of objects, such as size, the arrangement of their parts and their configuration are noted.
2. Intrinsic-dynamic: The spatial coding of objects is transformed in some way, such as rotating, cross-sectioning, folding or deforming of the object.
3. Extrinsic-static: The spatial location of objects relative to other objects or a frame of reference is coded.

4. Extrinsic-dynamic: The inter-relations of objects are transformed when one or more of them moves, including the viewer.

This schema is appealing in its simplicity and comfortably encompasses existing literature on spatial skills. However, it is relatively new and as yet not widely used outside of research in the STEM fields of study and the geosciences. Thus for this study I intend using a combination of the skills cited by Del Grande (1990) and those listed above by Newcombe & Shipley. In the table below, I have given a succinct definition for each of the six spatial skills that I have selected as pertinent to this study. I have included a column on how these spatial skills are relevant to the study of school Geometry at Grade Ten level and a further column linking each skill to the appropriate category from the schema of Newcombe & Shipley (2012).

Table 1: Spatial Skills to be assessed in the SSAT Instrument

Skill according to Del Grande (1990)	Definition	Relevance to Geometry	Schema of Newcombe & Shipley (2012)
Figure-ground perception	The ability to identify a specific component against a background of intersecting and hidden forms.	Isolating the relevant shapes or objects from a complex diagram in order to solve a Geometry problem.	Intrinsic-static
Visual discrimination	The ability to identify and classify 2D shapes and 3D objects according to their similarities and differences.	Honing classification skills and working with similarity and congruency.	Intrinsic-static
Spatial visualisation	The ability to visualise imaginary movements in 3D space, or to manipulate objects in the imagination (e.g. folding paper and perforating it, cutting shapes, etc.	Making mental adjustments to shapes and objects that have undergone change, e.g. forming a 3-D object from a net. Visualising inverse functions on a set of axes.	Intrinsic-dynamic
Spatial orientation (also called position-in-space perception)	The ability to imagine how a shape would look from a different angle or perspective.	Adjusting the orientation of shapes or objects to assess their similarity or congruency. Understanding the translation of shapes.	Extrinsic-dynamic

Skill according to Del Grande (1990)	Definition	Relevance to Geometry	Schema of Newcombe & Shipley (2012)
Spatial perception (also called perceptual constancy)	Understanding abstract spatial principles such as horizontal invariance or verticality.	Strengthening concepts such as perpendicularity and parallelism. Finding the perpendicular height of a triangle.	Extrinsic-static
Perspective	Visualising a scene in its entirety when looking from a different position.	Correctly identifying shapes and objects from unfamiliar perspectives, such as above or below.	Extrinsic-dynamic

Piaget claimed that spatial understanding does not reach an adult level until a child is nine or ten (Piaget & Inhelder, 1967). Piaget's theory of topological primacy led much of the early research in spatial development, however many of his claims have been challenged in subsequent research.

According to Newcombe & Learmonth (2005), three fairly broad approaches to spatial development have emerged from this subsequent research. The first is that of nativism, which claims that children are born with a "geometric module" and demonstrate spatial functioning at birth (Hermer & Spelke, 1994). This research has contributed much to current knowledge on infant competence, but very little on later spatial development. The second approach to spatial competence stems from Vygotskyan theories that focus on the cultural embeddedness of spatial learning (Gauvain, 1995) as well as the role of spatial language in aiding spatial thinking, but neglects the constructivist approach of children, who actively explore their environment and receive feedback from their experiences which influence how their spatial competence will develop. The third is the interactionist theory which attempts to integrate the constructivist, nativist and Vygotskyan theories (Newcombe & Huttenlocher, 2000). This theory seeks to specify the earliest starting points of spatial development, the nature of subsequent development, and the influence of the environment, neural maturation and cultural input on later changes in spatial development.

In Newcombe & Learmonth (2005), a summary of milestones in the development of spatial skills is given. I have further simplified the table and selected, where possible, the spatial skills which are pertinent to this study.

Table 2: Summary of Milestones in the Development of Spatial Competence. Adapted from Newcombe & Learmonth (2005)

1 – 3 years	Children acquire basic spatial terms.
3 – 4 years	Children can succeed at simple mental rotation of objects.
3 – 4 years	Children can take the perspective of other viewers, without conflicting frames of reference.
7 years	Children show adult levels of performance on place learning tasks.
6 – 9 years	Map skills develop to complex level. Perspective and mapping conventions are included.
9 – 10 years	Children can take perspective even when frames of reference conflict.
10 – 12 years	Children show mature coding on a par with adults.

The table thus suggests that children are capable of developing sufficient spatial skills with which to order and classify objects, read and interpret maps, take or keep perspective, mentally rotate objects and mentally visualise objects in place learning tasks by the time that they reach high school.

Sadly, evidence from South African classrooms suggests otherwise. In the Department of Basic Education's Diagnostic Report on the 2013 National Senior Certificate examinations (South Africa. DBE: 2014), the evidence that the majority of our learners demonstrate a distinct lack of spatial skills is damning:

- "*candidates were unable to identify perpendicular lines*"
- "*candidates were unable to see the link between different parts of the question (on transformation Geometry)…….this could have been on account of the candidates having a poor understanding of the spoken language*"
- "*Many candidates were unable to differentiate between rotation in a clockwise direction and rotation in an anticlockwise direction*"

Recommendations made to teachers in the same report focussed largely on encouraging far more practical work and investigation of concepts as opposed to memorising sets of rules. Cutting out shapes, working with nets, navigating plans and maps, plotting points on a system of axes and using the correct mathematical terminology in the classroom were all recommended.

These classroom activities, if implemented, would go a long way to improving the spatial skills of Geometry learners. There is much evidence that spatial skills can be improved through well-constructed classroom activities. Del Grande (1990) highlighted the interdependence of improving spatial skills and learning Geometry and that, "*like a chain reaction, an improvement in one leads to an improvement in the other*" (p. 19). Newcombe (2006) states that "*we know that spatial cognition is malleable, and that spatial thinking can be improved by effective technology and education*".

More recently Hill, Corbett & St. Rose (2010) recommended to teachers, parents and volunteers of professional organisations to encourage learners to "*play with construction toys, take things apart and put them back together again, play games that involve fitting objects into different places, draw and work with their hands*". They went further to recommend that learners use handheld models, as opposed to computer models, whenever possible in order to help them visualise what they see on paper. All recommendations listed above firmly encompass the constructivist approach to learning, with the learners engaging in hands-on activities and constructing meaning through their own experiences.

Having reviewed the literature on the development of geometric thinking and more specifically the development of spatial skills in learners, as well as how these spatial skills can be learned and improved, it would be appropriate to now review literature on the assessment of these spatial skills in order to develop a suitable strategy for assessing the spatial skills of learners in the South African context.

2.5. Assessment in Mathematics

Assessment has been defined as "*the process of gathering evidence about a student's knowledge of, ability to use, and disposition toward, mathematics and of making inferences from that evidence for a variety of purposes*" (National Council of Teachers of Mathematics, 1995). According to Brahier (2000), assessment can be broadly framed as a "data collection process". Assessment can take many different forms and provides the teacher with helpful data with which to guide the teaching and learning process. According to the Mathematics Curriculum and Assessment Policy Statement (CAPS) of the Department of Basic Education of South Africa, assessment is "*a continuous planned process of identifying, gathering and interpreting* *information regarding the performance of learners…..and using this information in order to improve the process of learning and teaching*". (South Africa: DBE, 2011a)

Differentiation can be made between formative assessment, which is used throughout the year to assess whether a learner is progressing acceptably, and summative assessment which is essentially a summary of the learner's performance at the end of the year.

However, assessment can also be used as a diagnostic tool to assess whether there are inherent misconceptions regarding a learner's understanding of Mathematics, and to what extent these problems affect the learner's disposition towards Mathematics (Ben-Hur, M. 2006). Whilst the core function of assessment is to gather information about how a learner is performing, there are many different ways of doing so – some of them formal, such as administering tests and assignments, while other methods are informal, such as observation of the learners, interviews and discussion groups (Brahier, D J., 2001). Almost seventy years ago, Sueltz, Boyton & Sauble (1946) commented on the efficacy of assessment, by stating that "*in general, observation, discussion, and interview serve better than paper-and-pencil tests in evaluating a pupil's ability to understand the principles and procedures he [sic] uses*" (p. 145) .

According to Ben-Hur (2006) assessment methods should be authentic and should reveal the progress in students' mathematics thinking and problem solving with tools and methods that focus not on the right answers, but on reasoning itself. Brahier (2001) states that using a variety of assessment strategies to capture a holistic view of learner achievement is at the same time helpful in "*getting students to recognise that we, as teachers, value more than correct answers – we value the process of doing mathematics as well*" (p. 18).

A critical aspect of assessment in education facilities is the use of the analysed assessment data to inform future instructional practices. If, for example, a whole school or an entire district seems to struggle with a specific mathematical concept, then the data gleaned from a variety of assessments pertaining to that mathematical concept can be used to guide the teachers in achieving the outcomes as set out in the curriculum by adjusting or enriching their teaching methods, or even perhaps to modify the outcomes set out in the curriculum (Brahier, 2000).

2.5.1. Types of Assessment

2.5.1.1 Traditional Pen and Paper Tests

Brahier (2001) states that mathematics achievement was traditionally based on the view that a learner either could either do mathematics or could not do mathematics. He therefore developed the Ideal Line of Inference Model, which acknowledges that mathematics achievement develops on a continuum and that as conceptual understanding develops, so does the learner's ability to demonstrate that understanding. This Ideal Line would then also indicate a perfect marriage between what the learner knows and what the assessment instrument measures.

In traditional pen and paper tests, questions are posed and marks are allocated for correct steps and correct answers. The questions are also closed, which means they only have one correct answer. However, these tests do not always reflect the mathematic ability of the learners. For example, a learner may understand the concept of area very well, but may make a small computational error in an early step of an area problem, thus losing most, if not all, of the marks allocated to the solving of that problem. Conversely, another learner may not understand the concept of area at all, but has learned all the relevant formulae by rote, and manages to score full marks for the same question without truly understanding what area is.

In South Africa, the Senior Certificate Examination is set as a traditional closed pen and paper test. To familiarise learners with the format of this examination and the types of questions likely to be asked, most teachers set their class tests as closed pen and paper tests too. Unfortunately this type of test does little to guide the teacher with regard to the conceptual understanding that the learners may or may not display.

2.5.1.2 Open-Ended Questions

Open ended questions are those which have either one correct answer, but many methods of arriving at that answer, or several correct answers. According to Brahier (2000), these questions allow teachers to gather rich data about how the learners are thinking about Mathematics, as well as the fact that the learners' methods of thinking hold value. Furthermore, these questions prompt learners to communicate more effectively about their findings, thus enhancing their use of mathematical terminology and their ability to effectively communicate their mathematical knowledge (Brahier, 2001). An example of a traditional closed pen and paper question that has been modified to an open question follows:

Table 1: Comparison of traditional and open-ended questions. Adapted from Brahier (2001)

Traditional Question	Open-Ended Question
Find the length of a diagonal in a rectangle measuring 200cm by 90 cm.	You have bought a big round mirror with a diameter of 240cm. Can you fit it through a doorway that measures 90 cm wide and 200 cm high? Show how you arrive at your answer.

The question on the left will test the learner's ability to recall a formula, as well as any procedural skill he or she demonstrates. It is seemingly removed from any other learning area. The question on the right, however, assesses the learner's problem-solving, reasoning and communication skills in mathematics. The question is embedded in a real-world context, (Brahier 2001) and has instant appeal to learners as it gives relevance to the knowledge they are acquiring.

2.5.1.3 Rubrics

Because open-ended questions reveal much richer data with regard to the mathematical understanding of the learner and can be answered in a variety of ways, they are potentially far more difficult to assess. Consequently, a well-designed rubric which clearly describes each performance level that the learner may demonstrate is more meaningful (Brahier, 2000).

According to Kothari (2013), the use of rubrics allows for more consistent grading, which in turn gives a clearer picture of learning gains. Rubrics also give clarity to learners with regard to expectations of their performance on tasks. Rubrics may have anything from three response levels up to ten response levels, depending upon the depth of understanding and detail required by the educator. According to Brahier (2000), the number of the rubric response does not indicate a percentage, but rather a category into which the learner is placed according to his/her response. The teacher can then track the learner's response categories over time in order to gain insight into the conceptual development of the learner (p. 227). He goes further to say that rubrics provide a holistic alternative to scoring as opposed to allocating scores to correct steps when solving problems.

Schloemer (1996) states that using rubrics can be time consuming and difficult at first, but as learners and teachers become accustomed to using them, the guesswork is removed from assigning performance levels. The teacher simply decides whether performance criteria have been met or not and the learner receives instant feedback with regard to his/her performance with guidelines for better achievement in the next task.

2.6. The South African Context

According to the South African Department of Basic Education's Curriculum and Assessment Policy Statement (CAPS), (South Africa. DBE 2011b, p. 8), Mathematics "*helps to develop mental processes that enhance logical and critical thinking, accuracy and problem-solving that will contribute in decision-making. Mathematical problem solving enables us to understand the world around us and, most of all, teaches us to think creatively*". They go further to list the essential skills that learners should acquire to this end. Learners should:

- Develop the correct use of the language of Mathematics;
- Collect, analyse and organise quantitative data to evaluate and critique conclusions;
- Use mathematical process skills to identify, investigate and solve problems creatively and critically;
- Use spatial skills and properties of shapes and objects to identify, pose and solve problems creatively and critically;
- Participate as responsible citizens in the life of local, national and global communities; and
- Communicate appropriately by using descriptions such as words, graphs, symbols, tables and diagrams.

Sadly, matric results over the past five years suggest that mathematical cognitive and spatial skills are lacking as learner performance in Mathematics continues to be disappointingly weak. While the national Mathematics pass rate of 59.1% in 2013 improved from 54% in 2012, the skills gap in Mathematics impacts negatively on many subjects and "*the lack of foundational competencies in Mathematics remains a challenge across the board*" (South Africa. DBE: NCS

Diagnostic Report; 2013; p. 15). Even more disturbing were the Annual National Assessment (ANA) results for Grade 9 Mathematics in December 2013. According to statistics released by the Department of Basic Education, the average national percentage was just 14% (this indicates the percentage of questions answered correctly), while the average in the Eastern Cape Province was 15,8% (South Africa. DBE, Report on Annual National Assessment 2013). A mere 3.3% of Grade 9 learners in the Eastern Cape achieved 50% or higher in the 2013 ANA.

This poor performance was recently highlighted in two international assessments, namely Progress in International Reading Literacy Study (PIRLS) and Trends in International Mathematics and Science Study (TIMSS), which placed South Africa in the bottom five performing nations in Mathematics. Disturbingly, the South African participating learners were from Grade 9 whilst participants from all 55 other participating countries or entities, except Botswana and Honduras, were Grade 8 learners. In the TIMSS study (TIMSS, 2011), only 24% of our learners managed to achieve an International Benchmark rating. The majority of these were in the Low Benchmark level, while the rest of our learners did not meet the criteria for a rating.

The Eastern Cape remains one of the worst performing provinces in our country. According to Vijay Reddy, Executive Director of the Human Sciences Research Council (HSRC), rural schools with the least resources achieved the lowest Matric results (Nkosi, 2012). Eastern Cape Education Member of the Executive Council (MEC), Mr Mandla Makupula, in an official Government statement released by the Eastern Cape Department of Education on the 13th of January 2014, observed that while the Provincial matric pass rate had increased from 61.6% to 64.9%, the Provincial average mark for Mathematics was just 43.4%. While this mark had improved from 38.1% in 2012, it is indicative of a crisis in the teaching and understanding of this discipline (South Africa. Eastern Cape Department of Education, 2014). Furthermore, the Eastern Cape Mathematics pass rate was a full 10.2% lower than the second weakest performing province, KwaZulu Natal.

In an attempt to combat poor performance in Mathematics in the Eastern Province of South Africa, the FRF Mathematics Education Chair of the Education Department at Rhodes University launched the Mathematics Teacher Enrichment Programme (MTEP) in January 2010. The MTEP implemented contact sessions with participating teachers which are concept-driven as opposed to curriculum-driven. These concepts not only enrich mathematical ideas but also inform classroom practice. This aspect of the MTEP programme requires onsite support to facilitate the incorporation of new concepts into classroom activities. However, a major stumbling block the MTEP teachers faced initially was that they spent far too much time catching up on Mathematics content that the learners were lacking, which left very little time available for them to implement the teaching ideas that had emanated from the MTEP contact sessions.

To combat this problem, the Mathematics Catch-Up programme was launched. The overarching goal of this programme was to identify "gaps" within the Grade 10 learners' knowledge and employ Mathematics teachers in an after-hours Mathematics programme with a view to catching up lost concepts within the Mathematics syllabus. This ongoing programme allows for the MTEP teachers to focus more freely on incorporating concepts from MTEP sessions into their classroom practice. The Catch-Up lessons are also conceptual in nature and not curriculum-driven. These sessions thus yield a more in-depth understanding of the nature of the backlog, which in turn informs the MTEP and In-School support programmes of the FRF Mathematics Education Chair.

According to the benchmark tests administered by the FRF staff members, the area of weakest performance across all participating schools in Grade 10 was *Space and Shape*. Benchmark tests are administered twice a year, the same test being used on both occasions. Pre-tests are conducted shortly after the start of the school year, while post-tests are conducted shortly before the end of the school year. The results of the pre-benchmark tests for 2011 indicate that just 15.5% of the marks allocated to *Space and Shape* were answered correctly, and for the post-benchmark test at the end of the year, 28.5% of the marks allocated were answered correctly. In 2012, the results of the pre-benchmark test showed that 5.6% of *Space and Shape* marks were answered correctly and in the post-benchmark test at the end of the year, 5.7% of *Space and Shape* marks were answered correctly. Two other sections of the benchmark tests that were consistently poorly answered are *Functions and Graphs* and *Geometry.*

The *Space and Shape* questions focused on lines, angles, 2D and 3D shapes and perimeter, area, volume and surface area. The Geometry questions were based on Euclidean Geometry. In the Senior Phase Curriculum and Assessment Policy Statement (CAPS) of the Department of Basic Education (South Africa. DBE, 2011a), the content area called *Space and Shape* includes the construction, classification and transformations of 2D shapes and 3D objects, while the content area called Measurement covers the use of formulae to measure perimeter, area, volume and surface areas of 2D shapes and 3D objects, and the use of the Theorem of Pythagoras to solve problems involving right-angled triangles. For the purposes of this study, the term Geometry will be used to include both content areas mentioned above.

It is interesting to note that the sections in the benchmark tests that are spatial in nature consistently generated the weakest results. This trend could be indicative of a weakness with regard to the spatial skills of the learners and requires further investigation. The benchmark tests that have been used thus far have limitations. The questions used have been sourced from teacher resource files and old examination papers and are fairly standard in the sense that they are closed pen and paper questions which have marks allocated for correct steps and answers.

Whilst the results of these tests are a fair indicator of what the learners can and cannot do, they are inadequate in terms of shedding light on the conceptual understanding, or lack thereof, that the learners display. A more nuanced picture of learner ability is required in order to inform the MTEP and Catch-Up Programmes more deeply and comprehensively.

A review of some international instruments designed to establish the cognitive levels of Mathematics learners, such as the TIMSS (2011), TOMA-3 (2013) and SAQMEC III (2007), revealed that much of the terminology used is Americanised and many words and phrases are unfamiliar to the majority of South African learners. The tests are also based on all aspects of school Mathematics. I thus planned to design and implement an instrument suited to the South African context, which would assess the spatial skills that the learners display when doing Geometry.

The instrument took the form of open-ended questions relating to the six spatial skills selected as pertinent to this study. (Refer to Table 1). The instrument is called the Spatial Skills Assessment Task (SSAT) and consists of twelve questions, six of which are traditional questions and six of which are questions embedded in real-world contexts. The learners were encouraged to verbalise, in either English or Xhosa, their thinking whilst tackling the tasks as set out in the SSAT. Each learner completed the SSAT individually. Questions pertinent to the tasks were posed to each learner throughout the task. Each session was video- and audiotaped in order to glean as much information from the SSAT as possible. I hope that this information will firstly reveal which spatial skills are suitably developed and which require further development, and secondly that the data will inform the future development of a remediation programme in the teaching and learning of Geometry.

CHAPTER 3 - METHODOLOGY

3.1. Orientation

The study took the form of a qualitative investigation. According to Hammersley & Atkinson (1983, p. 14) "*researchers are inescapably part of the social world that they are researching*". The qualitative approach recognises that the researcher influences the research and that research is also much more open and emergent in qualitative approaches (Cohen, Manion & Morrison, 2007). Babbie & Mouton (2001) describe the qualitative research paradigm as an approach that attempts to study the insider or "emic" perspective. The goals are thus describing and understanding as opposed to explaining and predicting human behaviour. The qualitative researcher therefore sets out to gain an insider perspective by "*walking in the shoes of the people they are observing and studying*". This research technique leads to "thick description", a phrase coined by Clifford Geertz (1973) to mean a rich and detailed description that encapsulates the essence of the research phenomenon.

Erickson (1985) used the term INTERPRETIVE to refer to an array of approaches to participant observational research. It avoids the suggestion that the approaches are simply non-quantitative, and highlights the central role that the researcher must play in elucidating and interpreting observed behaviours (Best & Kahn, 2006). Kilpatrick (1988, p. 98) states that the interpretivist research perspective sets out to "*capture and share the understanding that participants in an educational encounter have of what they are teaching and learning*". Thus the researcher moves into the encounter in order to gain clearer insights into teaching and learning practices from within. Cohen et al., (2007, p. 21) encapsulate this perspective by saying that the "*central endeavour in the context of the interpretive paradigm is to understand the subjective world of human experience*".

Thus the central endeavour of this study was to establish which spatial skills the learners demonstrated whilst completing carefully structured Geometry tasks. In order to encapsulate the interpretive research perspective, each learner completed the tasks individually in my presence. The reasons for this approach were threefold. Firstly it was essential that each learner feel free to express his/her view without feeling intimidated by the presence of other learners; secondly I was able to allay any nervous tension that may have arisen from answering the tasks, and thirdly I was able to capitalise on windows of opportunity that arose from commentary that learners made whilst completing the tasks. This shared experience was of great benefit in developing the “thick description” of data that Geerts (1973) refers to. This investigation therefore falls within the interpretive paradigm.

3.2 Research Design

This research was divided into two phases:

- Phase One: This phase comprised the development and design of a suitable instrument, called Spatial Skills Assessment Tasks (SSAT) which was used to assess which spatial skills Geometry learners demonstrate when completing Geometry tasks.
- Phase Two: This phase included the implementation of the assessment instrument in schools and the consequent analysis of responses to both the instrument and the open-ended interviews.

3.3 Methodology

3.3.1 Methods

Phase Two was designed as a case study. According to Cohen et al. (2007), the case study provides a unique example of real people in real situations. This sentiment is revisited in Cohen et al. (2011) when they state that case studies strive to portray what it is like to be in a particular situation, to catch the close up reality of participants’ lived experiences of a situation (p. 290). The Catch-Up Programme is currently in its fourth year in a selection of schools in the Lower Albany district of the Eastern Cape Province of South Africa. I have been involved in teaching for the Catch-Up programme in two of these schools. My study thus comprised the Grade 10 learners from these two schools, as I am familiar with the staff and learners of these institutions and have built up a relationship of trust and mutual respect with all stakeholders at both institutions. Thus, in this study the case comprised of these two groups of Grade 10 learners.

Stake (2006) further elaborates by saying that qualitative understanding of cases requires experiencing the activity of the case as it occurs in its contexts and in its particular situation. According to Yin (1998, p. 239) “*even a single case study can enable a researcher to generalise to other cases that represent similar theoretical conditions*”. This would ideally lead to the researcher gaining a better understanding of other similar cases. These sentiments lent further weight to my decision to interview each learner individually, as the information gleaned from these one-on-one experiences could reveal truths about geometrical and spatial understanding that extend far beyond just one learner, school or district.

According to Babbie & Mouton (2001), units of analysis are those phenomena we study in order to construct descriptions and to explain differences among them. The unit of analysis was therefore the responses of the learners to the spatial tasks in the SSAT instrument as well as their responses to questions posed by the researcher to establish their terminological understanding.

3.3.2. Assessment Instrument

The assessment instrument was structured in such a way that it would give clarity with regard to which spatial skills the individual learners demonstrated when doing Geometry tasks.

An open-ended question and answer approach was used in setting up and administering the research instrument. According to Brahier (2001), open-ended questions require far more careful assessment, as there is usually a variety of ways to answer the questions, but they have the potential to more accurately assess student thinking processes than the closed version of the question. As Cohen et al. (2000, p. 255) so succinctly state, it is open-ended questions that allow for open-ended answers, which "*may contain the 'gems' of information that otherwise might not be caught in the questionnaire*".

The instrument therefore took the form of a multi-faceted worksheet and interview, which was sufficiently open-ended that the learner could make expansions and digress where necessary. Each learner was encouraged to "talk through" their thought processes while tackling the Geometry subtasks in the worksheet. This gave greater insights into the spatial skills that they attempted to employ. It also gave the researcher the opportunity to further explore matters that arose through observation (Carspecken, 1996). Field notes were taken and each interview was videoed to ensure data validity. The greatest care was taken to ensure that the integrity of the subtasks was not compromised by prompting.

As different schools teach different parts of the school curriculum throughout the year, the research instrument was based on all Geometry concepts covered in the curriculum up to the end of the Senior Phase of education (Grade 9), so as to circumvent any potential problems arising from some schools having covered Grade 10 work that other schools had not. All data collected from the participants was thus based on prior learning.

3.3.2.1 The SSAT Instrument

The assessment instrument was divided into six sections, based on the six spatial skills listed in Section 2.4. Each section comprised one spatial skill and had adequate space for written answers. Each spatial skill was assessed in two different subtasks. The first subtask was illustrated with traditionally geometric diagrams that the learners could typically encounter in their textbooks and lessons (Subtask A). The second subtask (Subtask B) for each spatial skill consisted of shapes, objects, artefacts and scenes that are embedded in real-world contexts. A comparison of the two sets of responses would possibly reveal interesting data. As all the participants are studying Mathematics in their first additional language, allowance was made for the learner to explain him or herself in isiXhosa in instances where the learner was unable to express him or herself satisfactorily in English. For purposes of validity and reliability, each interview was videotaped to capture any commentary that could yield further data.

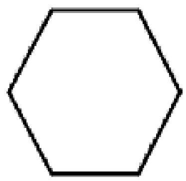
The questions posed by the researcher during the administration of the tasks were of an encouraging nature, to try to put the learners at ease but without compromising the essence of the tasks. They were asked to talk through their solutions to the various tasks in order to justify them. Their answers could reveal much about their ability with regard to spatial skills as well as their understanding of appropriate terminology.

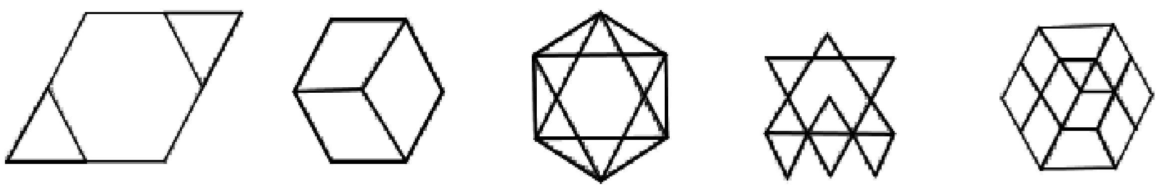
In each of the six sets of questions, the first question represented a traditional format that one would be likely to find in a text book or a Mathematics test, while the second question in each set was grounded in an everyday or real world context.

Figure -Ground Perception Tasks

Subtask A

In the diagram below, a hexagon is shown.





In which of the five labelled diagrams above can you identify a hexagon?

Answer:

Subtask B

In each of the photographs below, there is a hidden animal. Can you find the animals?

A:

B:

C:

D:

Rubric for Figure-Ground Perception Tasks

Figure-Ground Perception Task	Unable	Partially Able	Able	Excels
Hexagon subtask	The learner cannot see the hexagon in any of the diagrams and struggles to verbalise his/her thoughts.	The learner can see the hexagon in one or two diagrams, but is distracted by extra features in the diagrams.	The learner sees at least one hexagon in all the diagrams.	The learner is able to see more than one hexagon in some of the diagrams and is able to discuss other features that appear.
Animal Identification subtask	The learner cannot see any animals in the photographs.	The learner can discern one or two of the animals in the photographs.	The learner sees all of the animals in the photographs. He /she is not distracted by the background information.	The learner sees all the animals in the photographs and explains the connection between the two questions by referring to looking for objects that are “hidden” by the background.

Figure-ground perception is defined as the ability to identify a specific component against a background of intersecting and hidden forms.

In the first task the learners were encouraged to look carefully at all five diagrams and then indicate which of these five contained the illustrated form of a hexagon. The given diagrams varied in difficulty from easier to more difficult. The learners were made aware, through prompting, that diagrams could possibly contain more than one hexagon. Two of the diagrams did in fact contain more than one hexagon.

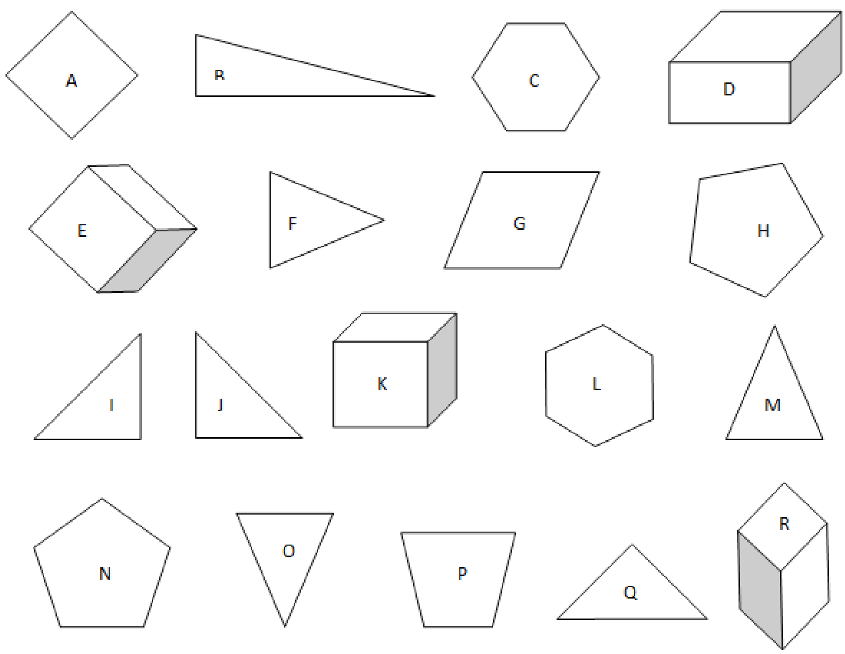
In the second task, four photographs of animals in camouflage were presented. The learners were tasked to identify the animals in each photograph. The levels of difficulty were dependent upon the individual. The learners were once again made aware that more than one animal could appear in a photograph.

Visual Discrimination Tasks

Subtask A

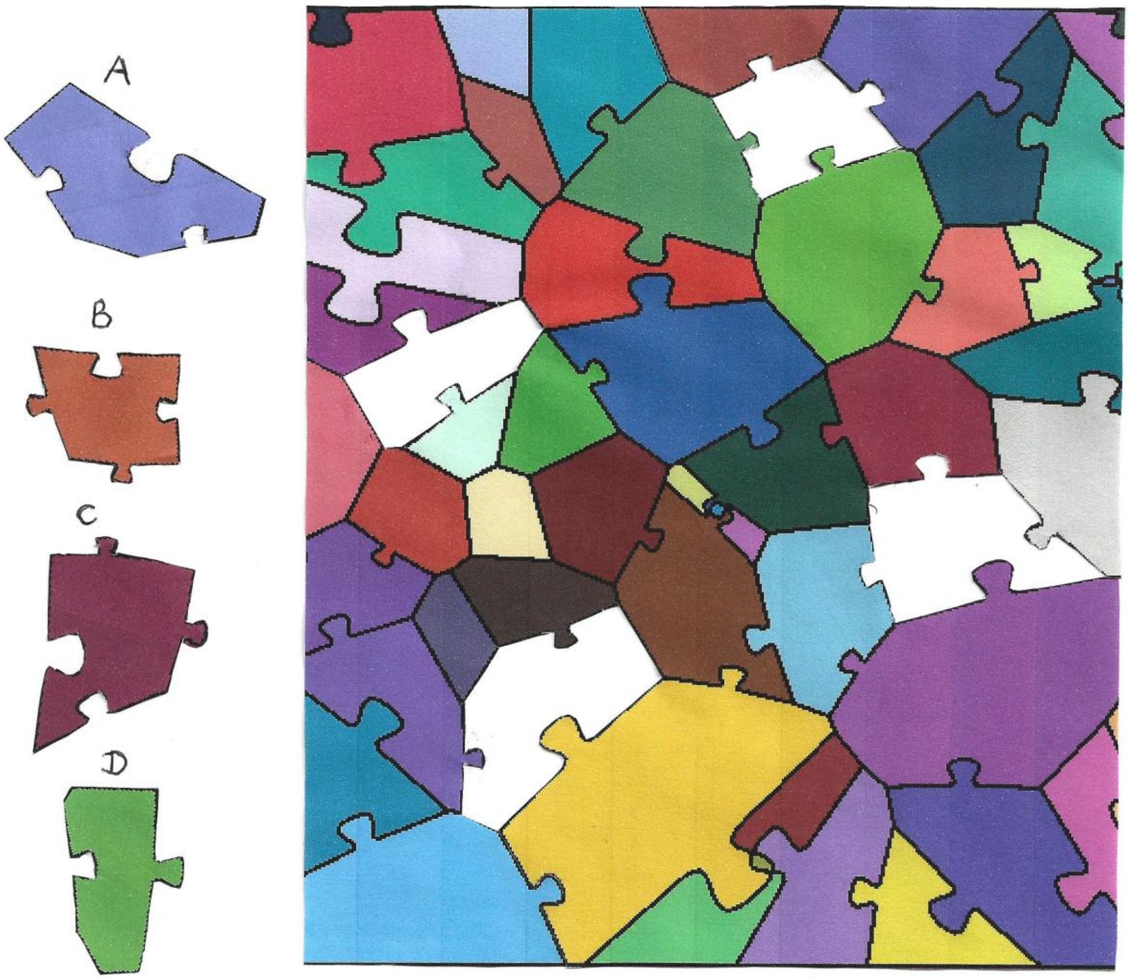
Study the four shapes given below and then complete the table by writing the letter of each shape that is identical (congruent) to shapes 1, 2, 3 and 4.

Shape	**Number of Identical (Congruent) Shape**
Shape 1	
Shape 2	
Shape 3	
Shape 4	



Subtask B

In the jigsaw puzzle below, four pieces have been removed from the puzzle. Write the name of each piece (A or B or C or D) in each of the open spaces in the puzzle in order to finish it. If you think that the pieces are not correct for any of the spaces, explain why.



Rubric for Visual Discrimination Tasks

Visual Discrimination Task	Unable	Partially Able	Able	Excels
Congruent Shapes Subtask	The learner is unable to discriminate between the shapes sufficiently and is thus unable to categorise them. He or she cannot verbalise the concept of congruency.	The learner discriminates between some of the shapes, for example those with different numbers of sides, but is unable to differentiate between the triangles.	The learner is able to discriminate between all the different shapes and categorises them correctly.	The learner is able to discriminate easily between all the shapes and can verbalise the concept of congruency with ease.
Puzzle subtask	The learner is not able to discern which puzzle piece should fit into each open space in the puzzle. He / she is not able to retain the shape of the missing piece and find a suitable open space.	The learner is able to fit one or two of the puzzle pieces but struggles to identify which piece will fit into which open space. He or she can give one or two verbal cues as to the process of fitting puzzle pieces.	The learner manages to fit all the missing puzzle pieces into the open spaces of the puzzle. He/she Is mostly able to verbalise the process of looking for clues to fit puzzle pieces into the correct open spaces.	The learner is easily able to fit all the puzzle pieces into their correct spaces. He or she is able to describe how to look for clues within the task in order to complete it.

Visual discrimination is defined as the ability to identify and classify 2D shapes and 3D objects according to their similarities and differences.

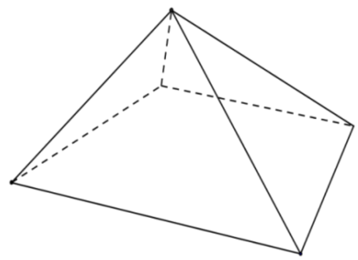
In the first task, learners were asked to classify all the shapes below the table according to whether they were congruent to any of the four shapes appearing at the top of the table. This task sought to establish whether learners could differentiate between shapes and objects (e.g. squares and cubes) as well as different shapes from the same group (e.g. different triangles).

The second task required that the learners study the four missing puzzle pieces and establish where they would fit, according to their size, shape, gaps and protuberances.

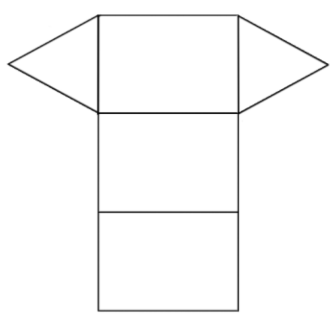
Spatial Visualisation Tasks

Subtask A

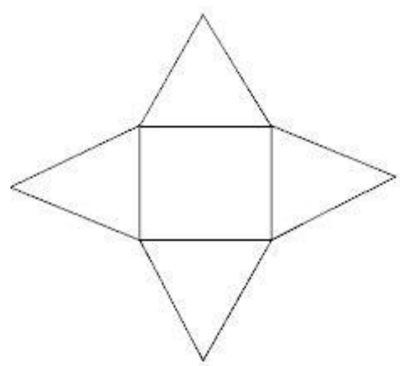
If you unfold this 3D object, what will the net look like?



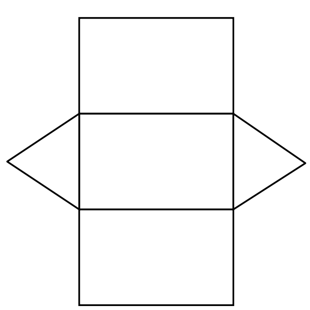
A



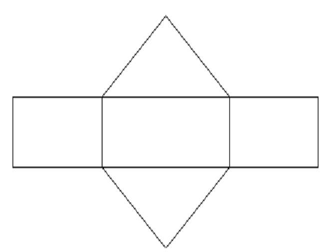
B



C



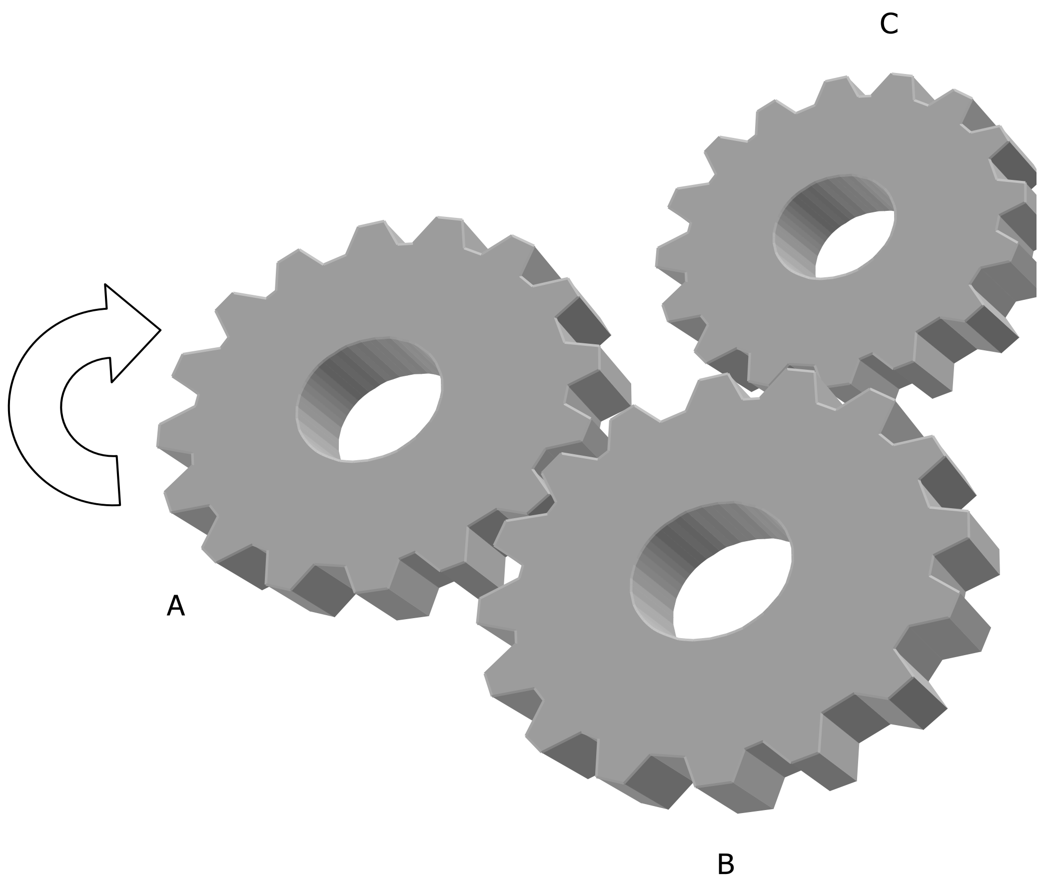
D



Subtask B

If cog A spins in the direction shown by the arrow, which way will cog B and cog C spin?

Explain



Rubric for Spatial Visualisation Tasks

Spatial Visualisation Task	Unable	Partially Able	Able	Excels
Net Identification subtask	The learner is not familiar with nets of 3D objects and is unable to select an option.	The learner attempts to visualise what the net of the object will look like, but chooses either the wrong option or two different options.	The learner can visualise the correct net for the 3D option with an explanation.	The learner chooses the correct net and can identify that 2 of the other nets will both produce a triangular prism, despite being different in appearance.
Cog movement Subtask	The learner is unable to visualise which way any of the cogs will spin.	The learner visualises that both cogs B and C will spin in the same way, or that all the cogs spin in the same direction.	The learner visualises that cog B will spin anticlockwise and cog C will spin clockwise.	The learner visualises the correct movement of the cogs and can predict the movement of added cogs.

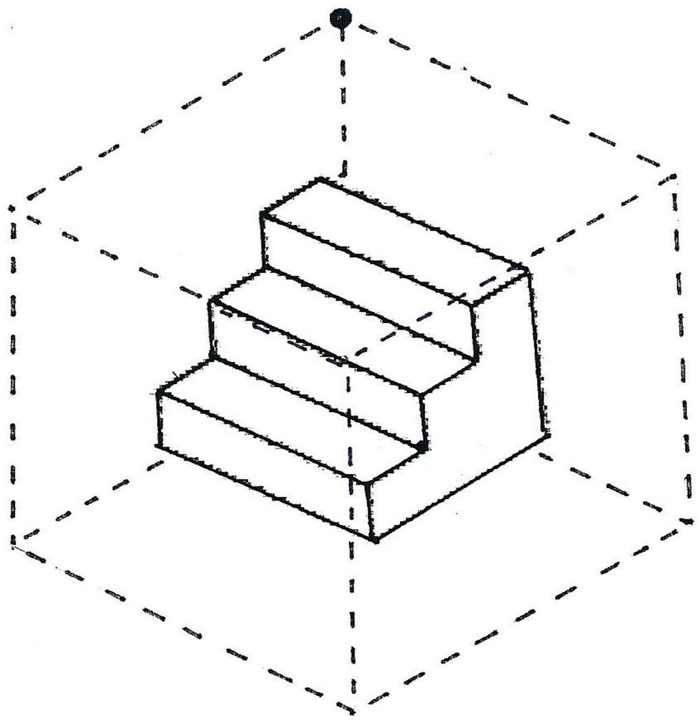
Spatial Visualisation is defined as the ability to visualise imaginary movements in 3D space, or to manipulate objects in the imagination. (e.g. folding paper and perforating it, cutting shapes, etc.)

In the first task, the learners are encouraged to try to imagine what the square pyramid would look like if it were unfolded and laid flat in a net. They are prompted to verbalise anything interesting that they observe about the given nets. In the second task, the learners must imagine how the movement of one cog will impact on the direction of movement of the other two cogs. They are challenged to imagine the direction in which an added cog would move.

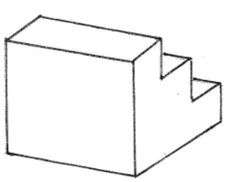
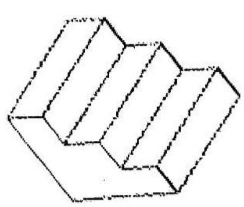
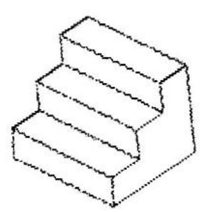
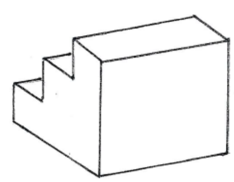
Spatial Orientation Tasks

Subtask A

If you were looking at the stairs from where the black dot is, what would you see? Explain.



A **B** C D

Subtask B

The church in your village has a new stained glass window. If you look at the window from **inside** the church, it looks like this:

If you look at the new window from **outside** the church, will it look like window A, window B or window C, or none of them? Explain your answer.

A

B

C

Rubric for Spatial Orientation Tasks

Spatial Orientation Tasks	Unable	Partially Able	Able	Excels
Staircase orientation subtask	The learner is unable to imagine how the stairs would look from another view or angle.	The learner makes an effort to imagine the stairs from another angle, by using words such as “from behind” or “if I walk around the stairs…”, but is confused by the selection of options.	The learner is able to identify the correct orientation of the stairs from the dot.	The learner selects the correct option and is able to explain why the other orientations of the stairs are incorrect.
Church window orientation subtask	The learner is unable to imagine what the window would look like from the outside.	The learner understands that the window’s orientation would have changed, but is not sure which option is correct. The learner may indicate that two options could be correct.	The learner correctly identifies the correct orientation of the window from the outside.	The learner correctly identifies the correct orientation of the window and is able to justify his/her selection.

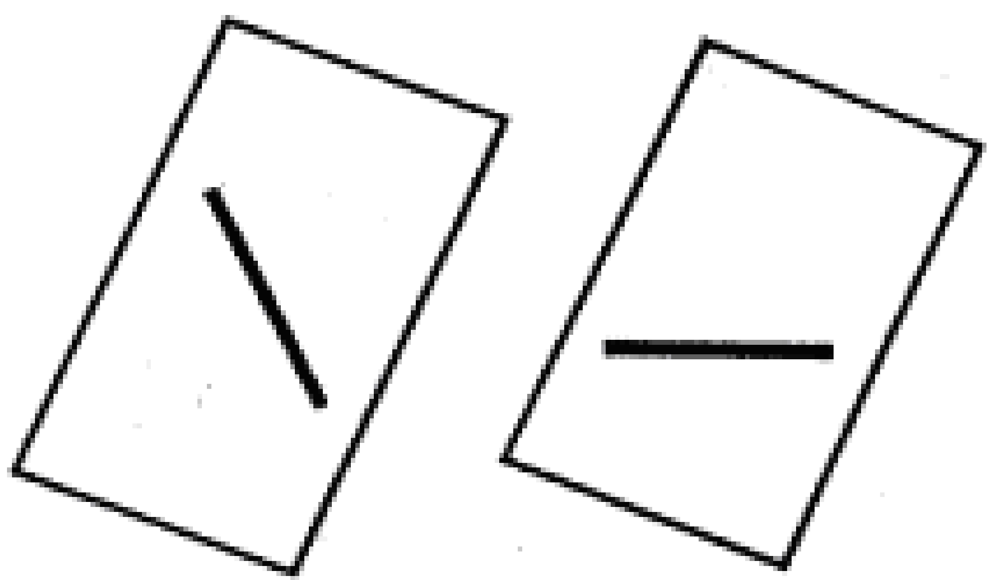
Spatial Orientation is defined as the ability to imagine how a shape would look from a different angle or perspective.

In the first task, a staircase within a 3D framework is presented. The learner is asked to select which view of the staircase would be correct if he or she were to view the staircase from the position of the black dot. This task is considered difficult as the learner needs to change orientation in two planes, i.e. the horizontal and vertical plane. The second task requires the learner to identify a reflected image of the one that is given, by changing his/her orientation with regard to the church window.

Spatial Perception Tasks

Subtask A

Cut the two rectangles off the bottom of the page. Cut them out neatly and stick them onto this page so that the lines inside them are vertical.

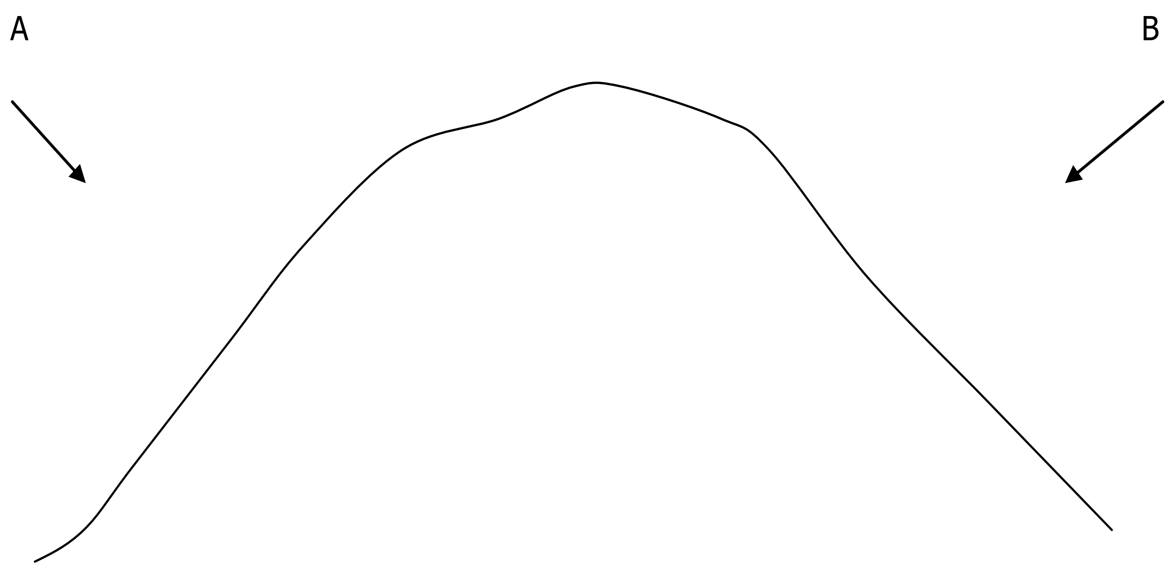


Subtask B

Sipho lives in a house halfway up the mountainside. There is a tree halfway up the other side of the mountain.

Draw Sipho's house where arrow A is pointing.

Draw the tree where arrow B is pointing.



Rubric for Spatial Perception Tasks

Spatial Perception Task	Unable	Partially Able	Able	Excels
Vertical Rectangles subtask	The learner does not understand the concept of vertical and is unable to follow the instructions and complete the task.	The learner places one of the rectangles correctly, but this may be indicative of accurate guess work as the second rectangle is incorrectly placed.	The learner completes the task correctly, with both lines inside the rectangles being in a vertical position. He is able to verbalise the concept of verticality.	The learner completes the task with ease and is able to explain the difference between vertical and horizontal with examples from nature or real life contexts.
Mountain subtask	The learner is either unable to accomplish the task, or draws the house and the tree incorrectly, without demonstrating the concepts of horizontal or vertical to the earth's surface. The house and tree are drawn horizontal and vertical to the mountainside respectively.	The learner is confused by the concepts of horizontal and vertical but successfully draws either the house or the tree correctly with regard to the earth's surface. The second drawing is incorrect.	The learner completes the task successfully by drawing the house horizontal to the earth's surface and the tree vertical to the earth's surface.	The learner completes the drawings successfully and is able to expand on the concepts of verticality and horizontality by giving examples from nature or real life contexts.

Spatial Perception is defined as understanding abstract spatial principles such as horizontal invariance or verticality.

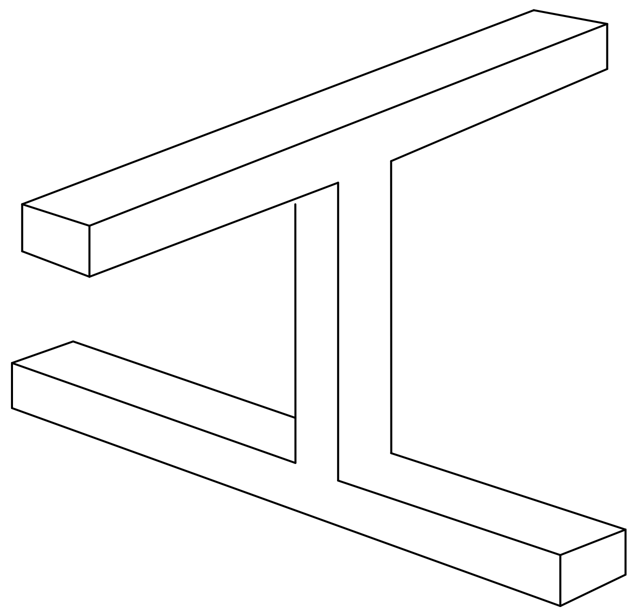
In the first task, the learners' understanding of the term "vertical" is put to the test by requiring them to paste the rectangles so that the lines inside them are vertical.

The second task tests the more abstract understanding of vertical and horizontal in terms of the surface of the earth. This is an essential skill when working with 3D diagrams pertaining to vertical and horizontal planes in graphing and trigonometry.

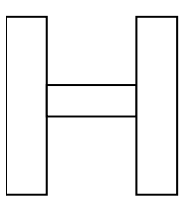
Perspective Tasks

Subtask A

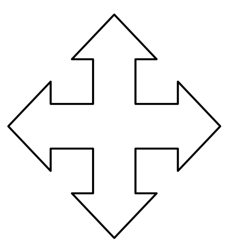
What would the following object look like from directly above? Explain.



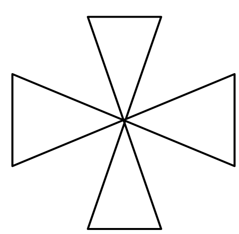
A



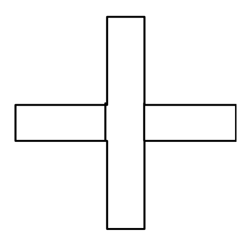
B



C



D



Subtask B

If you look at these items from the opposite side of the table, what will you see? Explain.

A

B

C

D

E

F

Rubric for Perspective Tasks

Perspective Task	Unable	Partially Able	Able	Excels
Geometric Shape subtask	The learner is unable to see that the object is 3D or is unable to see the object from another perspective.	The learner makes an attempt to view the object from a different perspective but is unsure which view option to select.	The learner is able to complete the task and selects the correct view option.	The learner completes the task with ease and is able to verbalise why the other options are not applicable.
Household Items subtask	The learner is unable to imagine the scene from a different perspective.	The learner tries to imagine the scene from the opposite side, but is confused by the differing options.	The learner is able to imagine the scene from the opposite side and selects the correct photo.	The learner completes the task easily and is able to discuss how perspective can change in other real life contexts.

Perspective is defined as visualising a scene in its entirety when looking from a different position.

In the first task, a geometric shape with protruding arms at the base and the apex is given. The learners are required to imagine what the shape would look like from directly above.

In the second task, three household items are arranged in a certain way. The learners are challenged to imagine what the arrangement of the three items would look like from the opposite side. Two of the given options are very similar, with only the orientation of one item different.

3.4 Participants

The participants attend schools which are situated in peri-urban areas and are both traditionally black schools. All the learners are first language isiXhosa speakers who receive their tuition in English. They are of mixed gender and mixed ability, despite them all having enrolled for pure Mathematics in the FET band. One school has 19 Grade 10 learners and the other has 22 Grade 10 learners. Both schools and the mathematics teachers in particular, have shown a true commitment, through their participation in the MTEP programme and the Mathematics Catch-Up Programme, to improving both their teaching skills and the Mathematics achievement of the learners.

The sampling strategy that was adopted for Phase Two of this research is that of a purposive sample. According to Cohen et al. (2007), the researcher handpicks the cases to be included in a sample because they typically possess characteristics being sought. They add that there is little benefit in seeking a random sample when most of this sample will be unable to comment on matters of interest to the researcher. The primary concern of purposive sampling is to acquire in-depth information from those who are in a position to give it. Babbie & Mouton (2001) concur that this sampling technique "*seeks to maximise the range of specific information*" that can be gleaned from a specific context (p. 277). The learners who participated in the Maths Catch-Up Programme had already been identified, through biannual bench mark testing, as having less than adequate skills with regard to Geometry and an in-depth study of how they approached Geometry tasks and the spatial skills that they employed when solving Geometry tasks, generated important data for my study.

Analysis of these bench mark tests also revealed that much of the terminology relating to Geometry is misunderstood by the learners. Because the relationship between researcher and learners is based on trust and mutual respect, it was hoped that the learners would feel confident enough to respond to the questions in the interview which sought to probe their understanding of geometric terminology more deeply, thus gaining a richer insight into the problems encountered by these learners, without engendering feelings of inadequacy.

3.5 Data Capture and Analysis

Individual participants were given the SSAT instrument, which contained six sections. Each of the six sections focussed on one specific spatial skill and contained two subtasks. The first subtask in each section was a typical text book- type subtask. The second subtask was embedded in a real-world context. Each section of the SSAT was analysed with a dedicated rubric, specifically designed to assess each spatial skill. The overall structure of the rubric was consistent for all six sets of questions and took the following format:

- Unable: Learner is unable to complete the task or does not attempt the task.
- Partially able: The learner attempts the task and is able to partially complete the task or completes the task with errors.
- Able: The learner correctly completes the task.
- Excels: The learner easily completes the task and is able to explain the concept/predict further patterns/justify choices/make further observations.

However, the indicators for each spatial skill were question-specific. For example, the tasks linked to spatial orientation contained indicators pertaining to whether the learners could imagine viewing an item from a different orientation, while tasks linked to visual discrimination contained indicators pertaining to whether the learners could differentiate sufficiently between different shapes and objects.

Field notes were taken throughout each interview. Where elucidation was required by learners, prompting was kept to a minimum and every effort was made to keep prompts as consistent as possible for all learners. For example, in the spatial perception task, learners were required to draw a house and a tree. Many of them required affirmation regarding the task. "So, must I draw a house and a tree?" was a common question, to which I responded they should indeed draw the house and the tree.

In addition video and audio footage and transcript data were analysed and coded in terms of emerging themes. These themes were directly linked to the six spatial skills that are embedded in the tasks in order to compare the learners' responses in the traditional subtasks with those in the real-world context subtasks. For example, evidence from the first set of tasks (figure-ground perception) clearly indicates a trend that learners struggle enormously to identify shapes within other shapes, but cope better when looking for animals in camouflage. The theme that thus emerges is that of shape identification and location, which requires further analysis.

In terms of the second research goal the learners' understanding of terminology that is directly linked to the spatial skills in the instrument was also assessed, in order to establish whether this understanding, or lack thereof, impacted on the successful completion of the tasks. Questions were posed to each of the learners with regard to their understanding of important conceptual terms throughout the test. Responses were recorded, whether in English or isiXhosa. For example, when learners were asked what they understood by the word "congruent", some answered by saying "xa izinto ziyafana", which translated means "when things are alike". Body language and hand gestures were also noted to assist in interpretation of raw data. For example, when a learner could not verbalise the direction in which the cogs in the spatial visualisation tasks would move, he or she indicated the direction of movement with the hand or finger. This demonstration of movement was accepted. Analysis of this data revealed distinct patterns with regard to terminological understanding, which will be discussed in the following chapter.

3.6 Validity

McCormick & James (1988, p. 191) argue that a reflexive researcher should constantly monitor his/her own interactions and practices with regard to the research, in order to combat reactivity at a later stage of the research. To this end, the instrument was piloted in order to establish that the tasks flowed smoothly and that all aspects of the task were understood by the learners. The pilot study also established the average time frame necessary to complete the task. The pilot study was administered at a third school which is also involved in the Catch-Up Programme. Three learners, one of high ability, one of average ability and one of poor ability, were approached to complete the pilot study. All three learners showed good understanding of what was requested of them in the tasks. A time frame for the completion of the SSAT task was established and a schedule was drawn up for the learners of the two participating schools.

The validity of this study is, to a great degree, dependent on how carefully the worksheets were structured in order to avoid ambiguity and how objectively the prompting questions were posed when trying to establish the spatial skills demonstrated by the participants. Care was taken to ensure that the tasks in the instrument were aligned with the Senior Phase and Grade Ten Mathematics curricula. For example, tasks included questions that were relevant to congruency of shapes and objects, as well as questions that tested understanding of vertical height. These topics form an integral part of Geometry in these curricula.

The instrument was also structured in such a way that it gave a more in-depth view of what learners could and could not understand, with explanations from the learners themselves in some cases. This was a far more suitable and valid means of collecting data, as other tests, such as the TIMSS, SAQMEC and TOMA-3 simply indicate a correct or incorrect answer, which gives no insight into what the learner can and cannot understand. The structure of the instrument was also carefully scrutinised to ensure that no questions influenced any others. All interviews were videotaped. The purpose of the audio and video recordings was twofold. Firstly, any commentary by the participants (in either English or isiXhosa) which was not noted in the actual interviews, but which may have enriched the data, could then be transcribed. Secondly, capturing the interviews and being able to replay events as they unfold was an effective form of data triangulation.

3.7 Ethical Issues

The development of a personal code of ethical practice with regard to research, establishes within the researcher a sense of obligation and sensitivity towards the research task, the research community and the research participants (Cohen et al., 2007). According to Winter (2000), the desire to understand and categorise others is implicitly one of power and control. Essentially, we as researchers are reducing the lives of others to a series of explanations and evaluations in order to produce a research output and this requires very careful handling and extreme sensitivity. As a part-time teacher in the Catch-Up programme, I was automatically in a power position relative to the learners. It was essential that I minimize this perceived power position and rather position myself alongside the learners, as an observer and interested person. To this end, the purpose and procedures of the research were clearly explained to all participants from the outset. It was made very clear that I was not there to judge their success or failure at completing the given tasks, but rather to probe their thinking and play an encouraging and nurturing role as a researcher.

Written informed consent was sought and received from all stakeholders in the research process. It was also made clear to all participants that their involvement was voluntary and could be terminated by them at any time during the research process.

The dignity, privacy and interests of the participants were respected and protected at all times and the findings of the research will be made available to the participants if they so desire.

CHAPTER 4 - RESULTS AND ANALYSIS

4.1 Introduction

In this Chapter I report on learner performance in each of the SSAT tasks. As the SSAT test took the form of a qualitative investigation, I report on my emic or insider perspective and describe the observations that I have made during the course of the investigation. As Cohen et al (2007) explain, the purpose of the interpretive paradigm is to understand the “subjective world of human experience” (p. 21).In terms of the interpretive research perspective, I share my understanding of the learners’ experience whilst undertaking the SSAT tasks. I establish which of the six spatial skills the learners were able to demonstrate, both in the textbook type questions, which fall into the A category of subtasks, as well as the real-world context questions, which fall into the B category of subtasks.

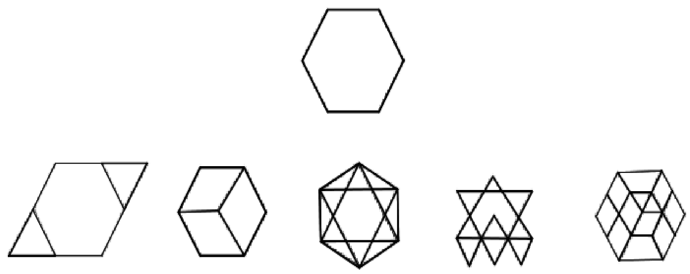
Firstly I present the rubric which was used for each subtask, with the number of learners whose answers fell into each category of the rubric noted below. Where appropriate, I then present the percentage of learners that performed according to each specific category of the rubric. Where the learners could choose from multiple choice, the percentage of learners that selected each choice is then given. Observations are then made with regard to the data collected for each subtask. At the end of each SSAT task, a graph is generated to give a visual comparison of results between the textbook (Subtask A) subtasks and the real-world context (Subtask B) subtasks.

4.2. Figure-Ground Perception Tasks

4.2.1. Subtask A: Hexagon Task

Learners were given a diagram of a hexagon and were then tasked to identify hexagons in five further diagrams. The question was presented to them as follows:

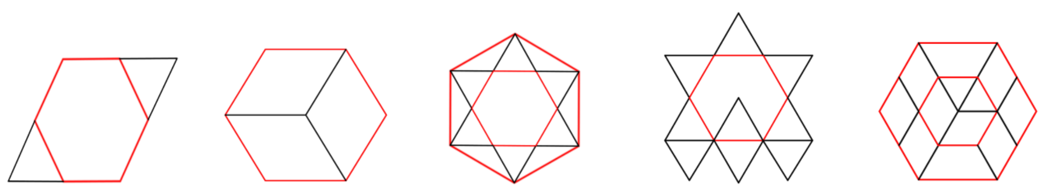
In the diagram below, a hexagon is shown.



1 2 3 4 5

In which of the five labelled diagrams above can you identify a hexagon? Answer:

The diagrams are presented below with the hexagon, or hexagons, in red for easier identification.



1 2 3 4 5

Hexagon Subtask	Unable	Partially Able	Able	Excels
	The learner cannot see the hexagon in any of the diagrams and struggles to verbalise his/her thoughts.	The learner can see the hexagon in one or two diagrams, but is distracted by extra features in the diagrams.	The learner sees at least one hexagon in all the diagrams.	The learner is able to see more than one hexagon in some of the diagrams and is able to discuss other features that appear.
Number of learners to achieve per rubric category	2	28	0	0
% of learners to achieve per rubric category	6.7%	93.3%	0%	0%

The percentage of learners that selected each option is given below. As the learners were able to select more than one option, the total percentage is greater than 100%, but this breakdown gives a clear picture of which hexagons were easier for the learners to identify.

Diagram Number	1	2	3	4	5
% of learners to select each diagram	6.7%	10%	33%	0%	60%

The following observations were made:

- Only four learners out of the 30 selected more than one option. Three of these learners chose diagrams 3 and 5, while one learner chose diagrams 2 and 5.
- The two diagrams that were least selected, i.e. diagrams 1 and 4, are the only two diagrams whose overall gestalt is not representative of a hexagon, despite them both containing hexagons. According to Todorovic (2008), the loss of the visual identity of a shape or pattern can be explained by the Gestalt principles of closure and continuity, whereby the elements of a shape are perceptually integrated with other elements which in turn creates a new visual whole. So it is possible that the learners, when looking at diagram number 1, saw a rhombus or parallelogram containing two small triangles in opposite corners. This may have led them to assume that there could not possibly be a hexagon in the diagram.
- Similarly, when learners observed diagram 4, it is possible that they saw the shape of a star, with extra triangles facing downward from the baseline of the star. The existence of an added triangle facing upward from the baseline of the star into the interior of the hexagon could have distracted them further from being able to identify the hexagon contained in the middle of the diagram.
- Diagram 2 was only selected by 10% of the learners, despite it being a fairly simple diagram without too many internal line segments. While the gestalt of the diagram is clearly that of a hexagon, it is possible that the learners were distracted by the

diagram also being representative of a cube that is oriented at an angle to the vertical axis. As they have all been exposed to 3D objects in the Catch-Up classes, this may explain their interpretation of the diagram. A further possibility is that they saw three rhombi arranged about a central point, as opposed to seeing the entire gestalt.

- Diagram 3 was the second most popular selection, although the orientation of the outer hexagon differs from that of the sample hexagon. However, this diagram was placed directly below the sample hexagon. This may have aided the learners in identifying the inner hexagon, which has the same orientation as that of the sample hexagon.
- The diagram which was selected by the most learners was diagram number 5. The outer hexagon has the same orientation as the sample hexagon, as does the smaller inner hexagon. It is possible that this "double hexagon" could have strengthened the capacity of the learners to identify the shape as a hexagon. However, none of the learners indicated that there was more than one hexagon in the shape.

4.2.2 Subtask B: Animal Identification Task

In this subtask, learners were told that there were hidden animals in each of the photographs. The photographs used were specifically selected as they contained animals in camouflage. However, they were not told that there was more than one animal in photograph number C. The Subtask was posed as follows:

In each of the photographs below, there is a hidden animal. Can you find the animals?

A:

B:

C:

D:

The results of this subtask follow:

Animal Identification subtask	Unable	Partially able	Able	Excels
	The learner cannot see any animals in the photographs.	The learner can discern one or two of the animals in the photographs.	The learner sees all of the animals in the photographs. He /she is not distracted by the background information.	The learner sees all the animals in the photographs and explains the connection between the two questions by referring to looking for objects that are "hidden" by the background.
No of learners to achieve per rubric category	0	14	14	2
% of learners to achieve per rubric category	0%	46.7%	46.7%	6.7%

The following breakdown indicates how many learners were able to identify each of the animals in camouflage:

Photograph	Photo A Giraffe	Photo B Buck	Photo C 3 Frogs	Photo D Spider
Number of learners who selected item	23	16	18 (1 frog) 2 (3 frogs)	28
% of learners to select item	77%	53%	60% (1 frog) 7% (3 frogs)	93%

The photographs represent animals in camouflage. They have adapted to their environment in such a way as to "blend in" to their surroundings and are thus very difficult to spot. This is a powerful survival adaptation which protects them from many predators. According to Todorovic (2008), the loss of visual identity of an object (in this case, the animals) is due mostly to the Gestalt principles of closure and continuity, because some parts of the animals look like parts of the environment and thus take on new visual wholes. So while these animals are not occluded, they have become virtually invisible. The images are all static which makes the animals even more difficult to see, because in reality they would have to move at some point which would assist the observer in identifying them.

The following observations were made:

- In photograph A the giraffe is standing in front of a big tree, the trunk of which is directly behind the animal. The neck of the giraffe therefore looks very much like the tree trunk and thus the animal is difficult to identify. The coat of the giraffe is also mottled brown in colour, much like the trunks of the other trees in the photograph. The shape of the giraffe blends in very well with the environment. The dense scrub at a lower level disguises the thicker chest and abdomen of the giraffe, while the slender neck looks much like any one of the tree trunks that protrude above the scrub.
- In photograph B, the impala's coat is virtually identical in colour to the savannah grass, while the black horns blend in perfectly with the very dark branches of the Acacia trees. It is only the impala's darker back and white underbelly that assist the observer in identifying where it is. The horns and ears seem to jut out from the head of the impala at the same angle that the smaller branches of the trees grow out from the trunk.

- In photograph C, three frogs are very well camouflaged as autumnal leaves. Their colouring is similar to fallen autumn leaves and they have a ridge down the middle of their backs which is representative of the midrib of a simple leaf. The learners were not told that there were three animals in this photograph. However two of the learners were able to spot all three frogs. The rest of the learners must have assumed that there could only be one animal and thus directed their attention to the next photograph.
- In photograph D, a black and white spider rests upon a tree of very similar colouring. The bark of the tree has vertical and horizontal striations, but the legs of the spider radiate out from the cephalothorax and cross the striations of the bark at an angle. This draws the eye of the observer to the spider.

If we compare the responses of the learners to Subtask A and Subtask B of Task 1, the results follow in Figure 4.1.

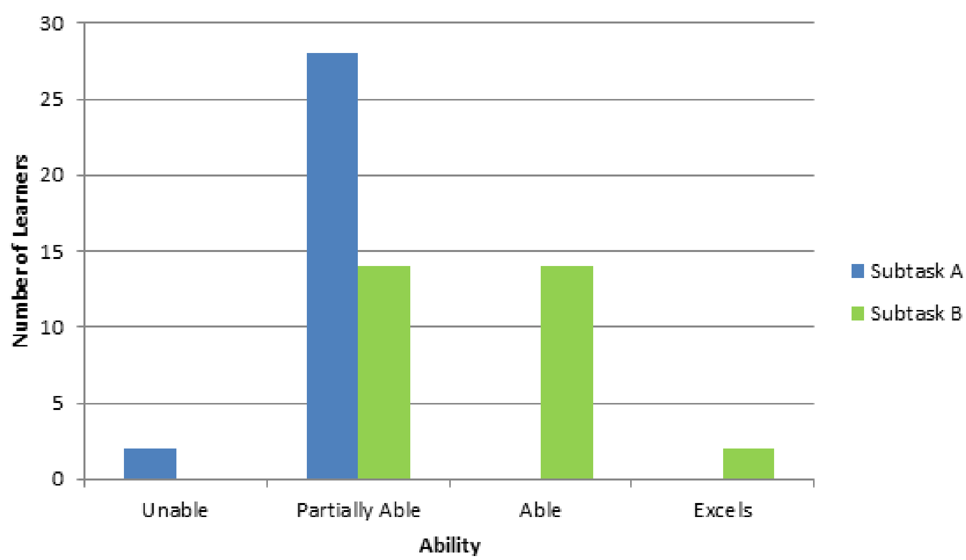


Figure 4.1: Results of Figure-ground Perception Tasks

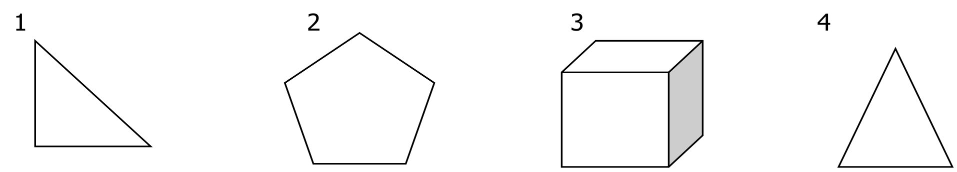
It is very clear that in this task, the performance of the learners was far better in the real-world context format than in the traditional text book format. I elaborate on this in 4.9.1.

4.3 Visual Discrimination Tasks

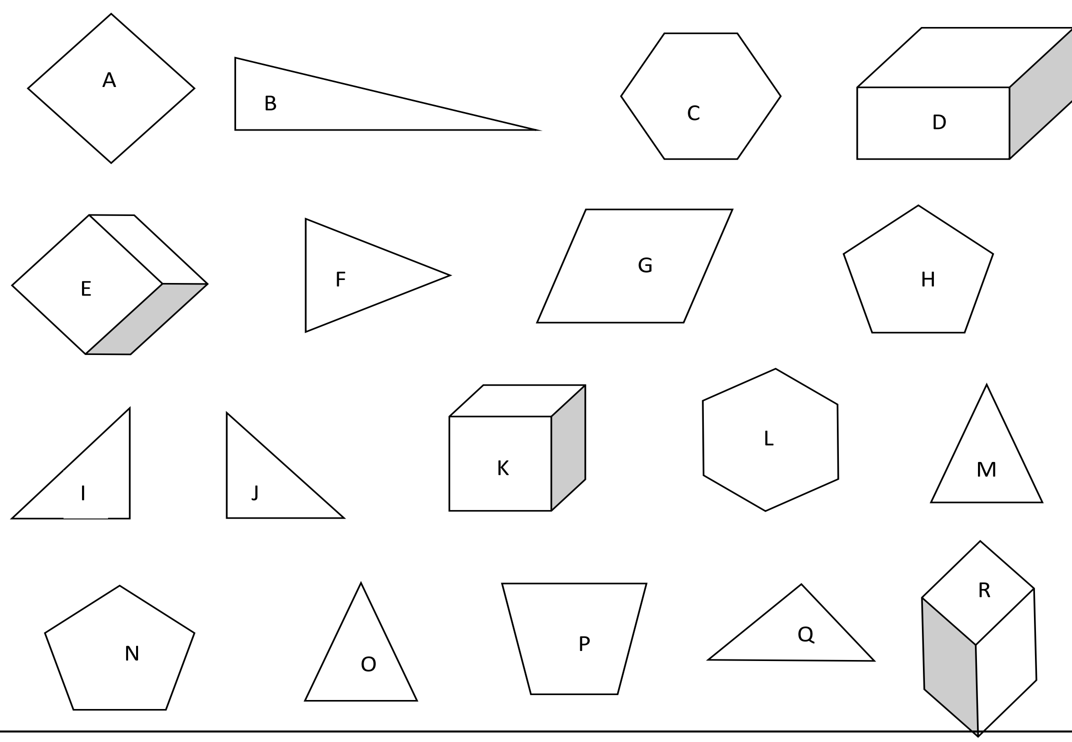
4.3.1. Subtask A: Congruent Shapes Task

This subtask was designed to assess whether the learners understood and were able to verbalise their understanding of the term congruent, as well as whether they were able to visually discriminate between a variety of shapes and classify them according to whether they were congruent to given shapes or not.

Study the four shapes given below and then complete the table by writing the letter of each shape that is identical (congruent) to shapes 1, 2, 3 and 4.



SHAPE	NUMBER OF IDENTICAL (CONGRUENT) SHAPE
Shape 1	
Shape 2	
Shape 3	
Shape 4	



The results of the subtask are as follows:

Congruent Shapes subtask	Unable	Partially Able	Able	Excels
	The learner is unable to discriminate between the shapes sufficiently and is thus unable to categorise them. He/she cannot verbalise the concept of congruency.	The learner discriminates between some of the shapes, for example those with different numbers of sides, but is unable to differentiate between the triangles.	The learner is able to discriminate between all the different shapes and categorises them correctly.	The learner is able to discriminate easily between all the shapes and can verbalise the concept of congruency with ease.
Number of learners to achieve per rubric category	4	19	7	0
% of learners to achieve per rubric category	13.3%	63.3%	23.3%	0%

This question was very revealing in terms of what the learners knew and did not know with regard to several key aspects of Geometry. In order to elucidate I shall analyse the responses to each of the four shapes separately.

The first shape that was given to the learners was a right-angled triangle with the right angle situated on the left hand side between the horizontal and vertical planes. The three triangles that are congruent to it are triangle I, triangle J and triangle Q. After considering the responses of the learners, I have made the following observations:

- The triangle most selected as congruent to triangle 1, is triangle J, which 28 learners selected. This triangle had exactly the same orientation as triangle 1.
- The second-most selected triangle was triangle I, which 21 learners chose. What is interesting is that triangles I and J were placed right next to one another on the task sheet, but triangle I had been reflected about the Y-axis, which meant that the right angle was on the right hand side, between the horizontal and vertical planes. Of the

28 learners who selected J, 8 of them could either not see that triangle I was the same triangle in a different orientation, or they assumed that in order for shapes to be congruent, they MUST have the same orientation.

- Only four learners selected triangle Q as being congruent to triangle 1. This triangle was oriented in such a way that the hypotenuse was placed on the horizontal plane and the right angle was situated in the uppermost vertex.
- The four learners that selected triangle Q also selected both other congruent triangles correctly. They were thus the only four learners to select all three congruent shapes correctly. One learner failed to select any correct shapes.
- The two most popular incorrect choices were shape B (four learners) which is also a right-angled triangle, but with a far longer base and hypotenuse; and shape F (five learners), which is an Isosceles triangle located just above triangle J. The locality of the triangle could perhaps have influenced the learners.
- One learner selected shape A as congruent to triangle 1. Shape A is a square which is oriented away from the horizontal. However, the fact that a learner can confuse a square and a triangle at Grade 10 level is very worrying indeed. This could be indicative of a lack of exposure to the concept of congruency, a lack of exposure to different shapes, or a poor grasp of what was required from the question.

The second shape that was given to the learners was a pentagon, with one side on the horizontal plane. The shapes that were congruent to it were shape H and shape N. The following observations were made:

- The shape that was most selected by the learners (26 in total) was shape N, which had exactly the same orientation as the given pentagon.
- The second-most popular selection was shape H, selected by 21 learners. Again, eight learners that selected shape N with identical orientation to the given shape failed to choose this congruent shape with a differing orientation. Conversely, three learners chose shape H but failed to choose shape N.
- There were 13 learners in total that selected both congruent shapes correctly, without selecting any further incorrect shapes. One learner failed to select any correct shapes.

- The two most popular incorrect choices were shapes C and L, both of which are hexagons. This is worrying on two counts: either the learners were making the assumption that if a shape has more than four sides, it would be the same as the given shape at the top of the question; or the learners were not paying the requisite attention to detail and failed to count the number of sides of the shapes. Either way, the incorrect choices that the learners made seem to indicate that they have experienced less than sufficient exposure to such shapes.
- One learner selected a square, one learner selected a parallelogram and two learners selected a trapezium as being congruent to the pentagon. Once again, insufficient exposure to shapes or failure to understand what the question required could have resulted in such poor selection.

The third shape that was presented was a cube, with its base on the horizontal plane. The shapes that were congruent to it were shape E, with a differing orientation, and shape K, with the identical orientation.

- The most popular shape selected as congruent to shape 3 was shape K. 27 learners selected this shape.
- The second most popular shape to be selected was shape E, which was also congruent to shape 3 but with a differing orientation. 20 learners selected this shape. 10 of the 27 learners that selected shape K failed to select this shape. However, three learners that selected shape E failed to select shape K.
- There were only eight learners in total that selected the two correct congruent shapes with no additional incorrect shapes.
- The two most popular incorrect selections were shape D (nine learners) and shape R (five learners) and shape A (also five learners). Both shapes D and R were rectangular prisms, while shape A was a square. Perhaps the 3D status of the prisms influenced the learners to select them, despite their faces being obviously rectangular. The location of the square directly above cube E, as well as the fact that it had the same orientation as the front face of cube E, may have influenced the learners to select the square.

- Two learners selected the parallelogram as being congruent to shape 3. This is very disturbing as this 2D shape has almost nothing in common with a 3D cube.

The fourth and final shape that the learners were given was an isosceles triangle, with its base on the horizontal plane. Three triangles were congruent to it, namely shape F (rotated 90˚), shape M (identical orientation) and shape O (rotated 180˚).

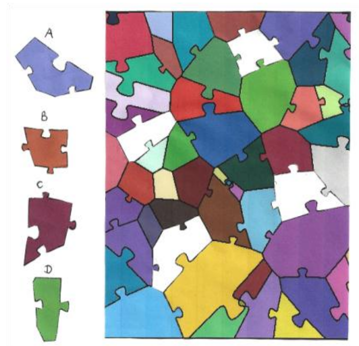
- The most popular selection was shape M, which 26 learners chose. This was the congruent shape that had the same orientation to the given triangle.
- The second most popular correct selection was shape O (18 learners) followed closely by shape F (16 learners). Only two learners that selected shape O failed to select shape M, and only two learners that selected shape F failed to select shape M.
- Only 10 learners selected all three correct congruent shapes, without selecting any further incorrect shapes. One learner failed to select any correct shapes.
- The most popular incorrect shape selected was shape Q, a right-angled triangle. Four learners selected it.
- All the incorrect selections for this triangle were right-angled triangles.

The understanding of the learners with regard to the terminology used in the task will be referred to later, in the section titled “Emerging Themes and Trends”.

4.3.2. Subtask B: Jigsaw Puzzle Task

In this subtask, learners were required to visually discriminate between the four removed puzzle pieces in order to establish which piece would fit into each empty space.

In the jigsaw puzzle below, four pieces have been removed from the puzzle. Write the name of each piece (A or B or C or D) in each of the open spaces in the puzzle in order to finish it. If you think that the pieces are not correct for any of the spaces, explain why.



The results of this subtask are tabulated below.

Puzzle subtask	Unable	Partially Able	Able	Excels
	The learner is not able to discern which puzzle piece should fit into each open space in the puzzle. He/ she is not able to retain the shape of the missing piece and find a suitable open space.	The learner is able to fit one or two of the puzzle pieces but struggles to identify which piece will fit into which open space. He/she can give one or two verbal cues as to the process of fitting puzzle pieces.	The learner manages to fit all the missing puzzle pieces into the open spaces of the puzzle. He/she Is mostly able to verbalise the process of looking for clues to fit puzzle pieces into the correct open spaces.	The learner is easily able to fit all the puzzle pieces into their correct spaces. He/she is able to describe how to look for clues within the task in order to complete it.
No of Learners to achieve per rubric category	0	5	24	1
% of learners to achieve per rubric category	0%	16.7%	80%	3.3%

The following observations were made from the data:

- Of the five learners that were only partially able to complete the subtask, four learners confused puzzle pieces, by placing piece B in the opening for piece C, and vice versa. These two puzzle pieces did have some features in common, such as two adjacent protrusions and two adjacent openings, but their size and shape were sufficiently different that they should not have been confused.

- Most of the learners were able to place all four pieces in their correct openings. However, only one learner was able to verbalise how he studied the shape of the puzzle pieces in order to establish where they would fit. This learner achieved the "excels" status.
- Six of the learners used some form of hand gesture, for example pointing or rotating the finger, in order to assist them in selecting the correct puzzle pieces. I will refer to gestures again later in the chapter.

A comparison of responses to Subtask A and Subtask B of the Visual Discrimination Task is given in Figure 4.2 below:

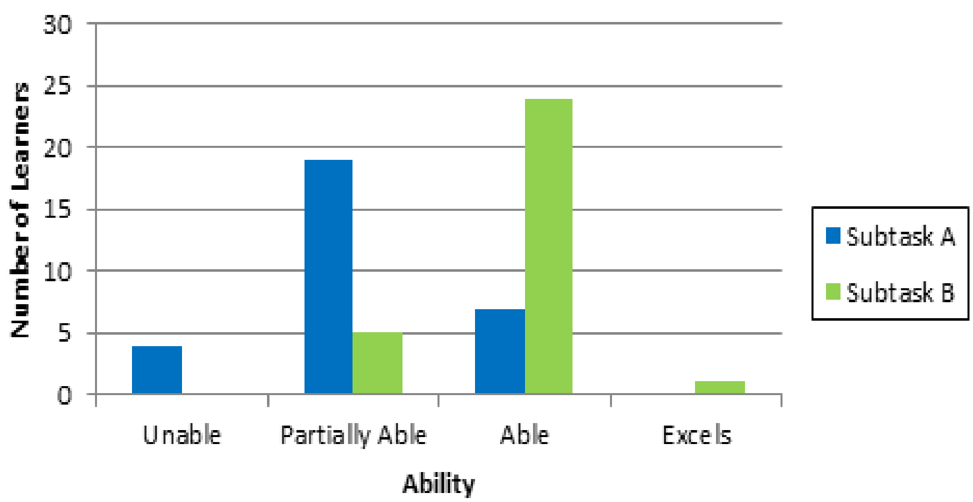


Figure 4.2: Results of the Visual Discrimination Tasks

Once again the learners achieved better results when tackling the real-world context questions as opposed to the text book type questions. I discuss this in 4.9.1.

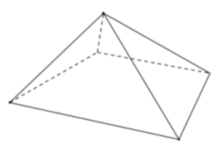
4.4. Spatial Visualisation Tasks

4.4.1. Subtask A: Net Identification Task

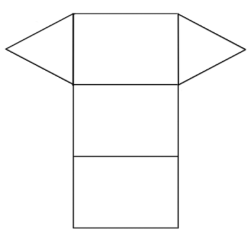
In this subtask, learners were given a diagram of a 3D object to study. They were given four different nets and asked to select the appropriate net for the object if it were unfolded.

<u>Task A</u>

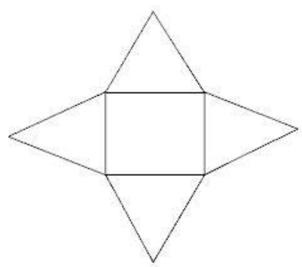
If you unfold this 3D object, what will the net look like?



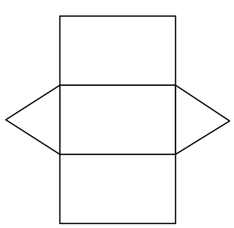
A



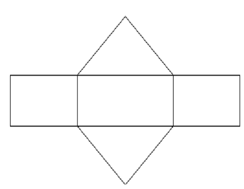
B



C



D



The results of this task were as follows:

Net Identification subtask	Unable	Partially Able	Able	Excels
	The learner is not familiar with nets of 3D objects and is unable to select an option.	The learner attempts to visualise what the net of the object will look like, but chooses either the wrong option or two different options.	The learner can visualize the correct net for the 3D option with an explanation.	The learner chooses the correct net and can identify that two of the other nets will both produce a triangular prism, despite being different in appearance.
No of Learners to achieve per rubric category	1	2	27	0
% of Learners to achieve per rubric category	3.3%	6.7%	90%	0%

The percentage of learners to select each option is as follows:

Diagram	A	B	C	D
% of learners to select diagram	6.7%	90%	0%	0%

Please note that one learner was unable to answer the question at all, resulting in less than 100% of learners appearing in the table.

The learners performed well in this task and the following observations were made:

- The most common explanation that the learners made for their choice was that the shape had four sides/triangles and a square in the middle/ underneath. 14 of the learners made this observation.
- Four learners were able to refer to the 3D object as a pyramid.
- Three learners were unable to verbalise their choices.
- The two learners that selected the wrong option, both selected option A as the correct net.
- One learner was unable to see the 3D shape at all. He suggested that if he moved one vertex, the shape would resemble an envelope. At first he counted four triangles, then later he counted six triangles and a trapezium. He then attempted to extend the sides of the object with a ruler, before stating that he would come back to the task later. He failed to make a selection.
- None of the learners observed that two of the other nets (A and C) would both have formed a triangular prism.

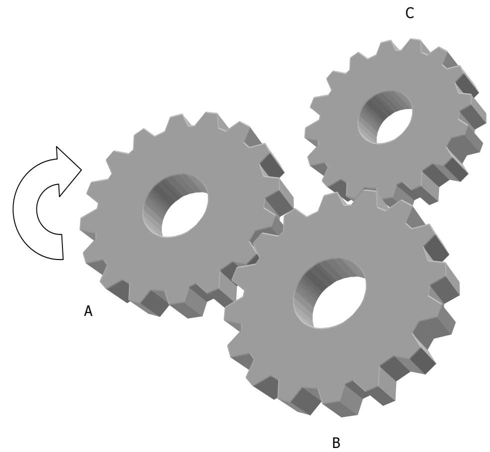
The learners had built nets in class earlier in the year and this may have influenced the outcome of this task.

4.4.2. Subtask B: Cog Movement Task

This task challenged the learners to predict which way cogs would move if linked to a cog that moved in a specific direction.

If cog A spins in the direction shown by the arrow, which way will cog B and cog C spin?

Explain



The results of this subtask were as follows:

Cog Movement subtask	Unable	Partially Able	Able	Excels
	The learner is unable to visualise which way any of the cogs will spin.	The learner visualises that both cogs B and C will spin in the same way, or that all the cogs spin in the same direction.	The learner visualises that cog B will spin anticlockwise and cog C will spin clockwise.	The learner visualises the correct movement of the cogs and can predict the movement of added cogs.
Number of Learners to achieve per rubric category	1	10	4	15
% of Learners to achieve per rubric category	3.3%	33.3%	13.3%	50%

The following observations were made from the data:

- Only one learner was unable to predict the movement of the cogs.

- Fifteen learners were able to correctly predict the movement of cog B and cog C, and correctly predict the movement of imaginary cog D, if it were added in such a way as to touch cog C.
- 17 of the learners used some form of gesture, such as twisting their hands, rotating their fingers or pointing with a pencil to help them visualise the cog movement.
- Two learners drew arrows to indicate the direction of the cog movement.
- One learner stated that all the cogs would move in the same direction, as they were fixed together "like an engine".

The results of Subtask A and Subtask B of Task 3 are indicated in Figure 4.3 below:

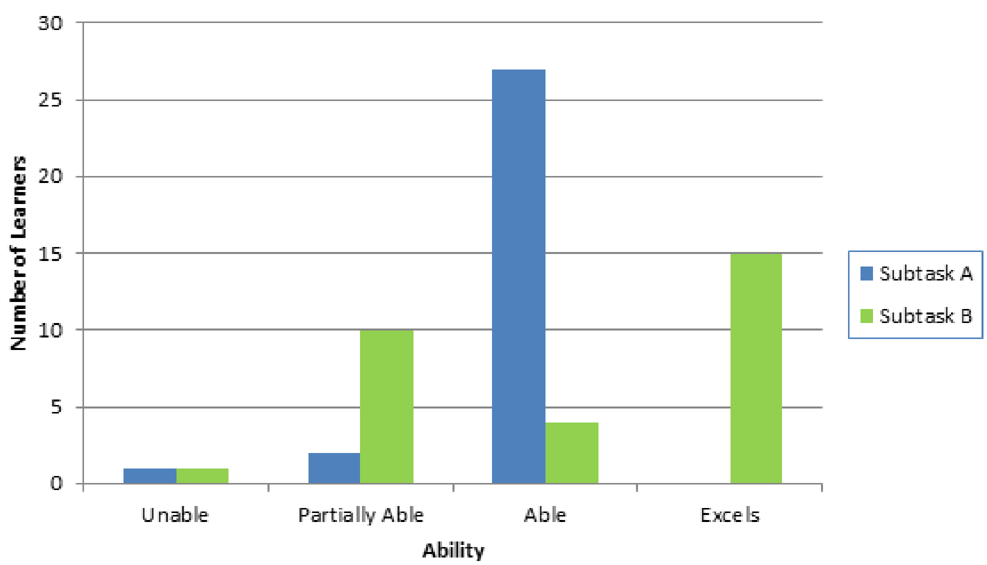


Figure 4.3: Results of Spatial Visualisation Tasks

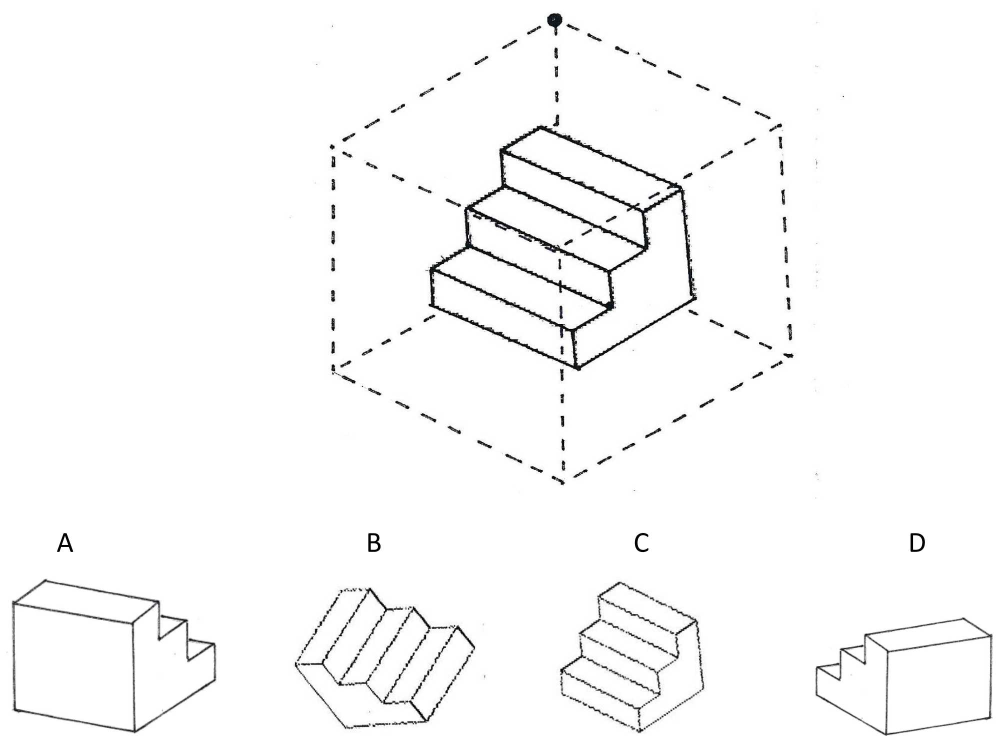
This graph reveals a very uneven spread of ability regarding the two Spatial Visualisation Tasks. Most learners were able to complete the first task satisfactorily, but nobody excelled. In the second task, the majority of learners either partially completed the task, or they excelled at the task.

4.5 Spatial Orientation Tasks

4.5.1. Subtask A: Staircase Orientation Task

The learners were given a 3D staircase and were tasked to change their orientation to view the staircase from above and behind. The staircase was placed in a cubic dotted framework in order to assist the learners.

If you were looking at the stairs from where the black dot is, what would you see? Explain.



The learners answered the question as follows:

Staircase Orientation subtask	Unable	Partially Able	Able	Excels
	The learner is unable to imagine how the stairs would look from another view or angle.	The learner makes an effort to imagine the stairs from another angle, by using words such as “from behind” or “if I walk around the stairs…”, but is confused by the selection of options.	The learner is able to identify the correct orientation of the stairs from the dot.	The learner selects the correct option and is able to explain why the other orientations of the stairs are incorrect.
No of Learners to achieve per rubric category	16	5	0	9
% of Learners to achieve per rubric category	53.3%	16.7%	0%	30%

The percentage of learners to select each of the different options is as follows:

Orientation	**A**	**B**	**C**	**D**
% of learners to select option	30%	3.3%	50%	16.7%

The following observations were made from the data:

- Of the sixteen learners who were unable to imagine what the staircase would look like from a different angle, fifteen of them guessed that the stairs would still look like option C, in other words, the view of the staircase would not change at all. Only one learner thought that it would change to option B.
- Of the five learners that were partially correct, three commented on the difficulty of the question. One commented about being behind the structure, but selected the wrong view from behind, while one learner used the process of elimination, but failed to take option A into account.
- None of the learners chose the correct option without being able to explain why.

- Nine learners chose the correct option and all of them were able to verbalise their choice. The most commonly used terms were “from the back and the right hand side”.

4.5.2. Subtask B: The Church Window Orientation Task

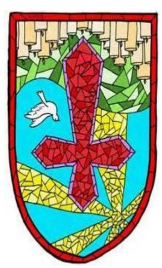
The learners were asked to compare what a church window would look like from inside the church and then from outside the church.

The church in your village has a new stained glass window. If you look at the window from **inside** the church, it looks like this:

If you look at the new window from **outside** the church, will it look like window A, window B or window C, or none of them? Explain your answer.

A

B



C

The results of this question are as follows:

Church Window Orientation subtask	Unable	Partially Able	Able	Excels
	The learner is unable to imagine what the window would look like from the outside.	The learner understands that the window's orientation would have changed, but is not sure which option is correct. The learner may indicate that two options could be correct.	The learner correctly identifies the correct orientation of the window from the outside.	The learner correctly identifies the correct orientation of the window and is able to justify his/her selection.
Number of Learners per rubric category	6	0	0	21
% of Learners per rubric category	20%	0%	0%	70%

Note: Two learners selected the correct option, but stated that the window would not change, in other words their explanations were at odds with their selection. A further learner selected the wrong option, but gave the correct explanation. I have left all three out of the results table.

The following observations were made concerning the data:

- The most commonly used explanation by the learners who excelled at this subtask was that the dove (bird) would change direction, from facing (flying to) the left when looking from inside the church, to facing (flying to) the right when looking from outside the church. Six learners referred to the dove.
- The second-most popular explanations were that the image is mirrored and that you will see the opposite image (four learners).
- Three other terms that were used were "twists", "flips" and "turns".
- Five of these learners used their hands to gesture how the image would change. One learner used his eraser to demonstrate reflection.
- The learners who were unable to imagine how the window would look from the outside were all of the opinion that the window was a fixed feature and could not change. They did not grasp that their own orientation had changed and that this would impact on what they saw from outside.

A graphic summary of the results from the Spatial Orientation subtasks is given in Figure 4.4 below:

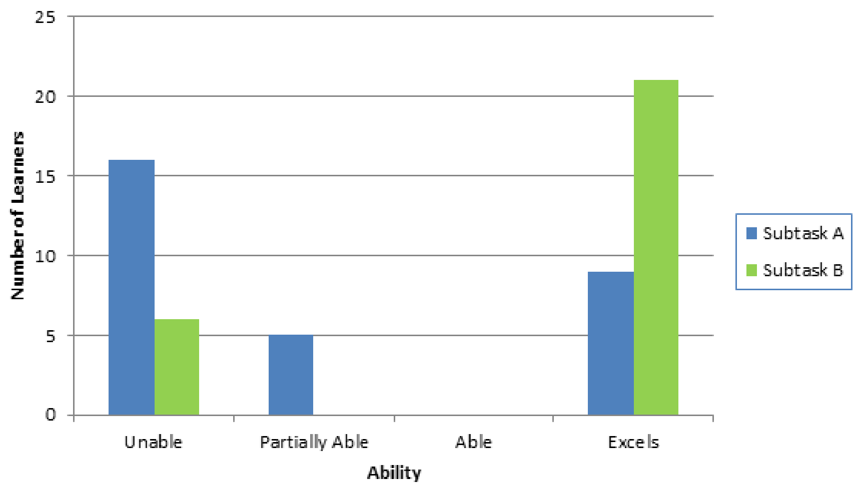


Figure 4.4: Results of the Spatial Orientation Tasks

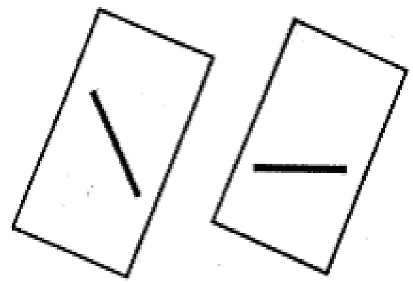
The graph indicates that the learners once again coped far better with the real world context subtasks than text book type subtasks. The majority were able to answer the church window task correctly and give a reasonable explanation for their choice. I discuss this in 4.9.1.

4.6. Spatial Perception Tasks

4.6.1 Subtask A: Vertical Lines Task

This subtask was designed to try to establish what the learners understand by the term vertical.

Cut the two rectangles off the bottom of the page. Cut them out neatly and stick them onto this page so that the lines inside them are vertical.



The results of this subtask follow:

Vertical Lines subtask	Unable	Partially Able	Able	Excels
	The learner does not understand the concept of vertical and is unable to follow the instructions and complete the task.	The learner places one of the rectangles correctly, but this may be indicative of accurate guess work as the second rectangle is incorrectly placed.	The learner completes the task correctly, with both lines inside the rectangles being in a vertical position. He/she is able to verbalise the concept of verticality.	The learner completes the task with ease and is able to explain the difference between vertical and horizontal with examples from nature or real life contexts.
No of Learners to achieve per rubric category	19	3	6	2
% of Learners to achieve per rubric category	63.3%	10%	20%	6.7%

A close inspection of the responses to the subtask revealed the following observations:

- Only two learners were able to correctly align the rectangles so that the lines inside them were vertically positioned, while at the same time being able to differentiate between vertical and horizontal using examples from nature or real life contexts. One learner describes vertical as standing straight like a tree and horizontal as lying down on the ground. The other learner correctly referred to the lights on the braces of the Kowie bridge as an example of vertical lines.

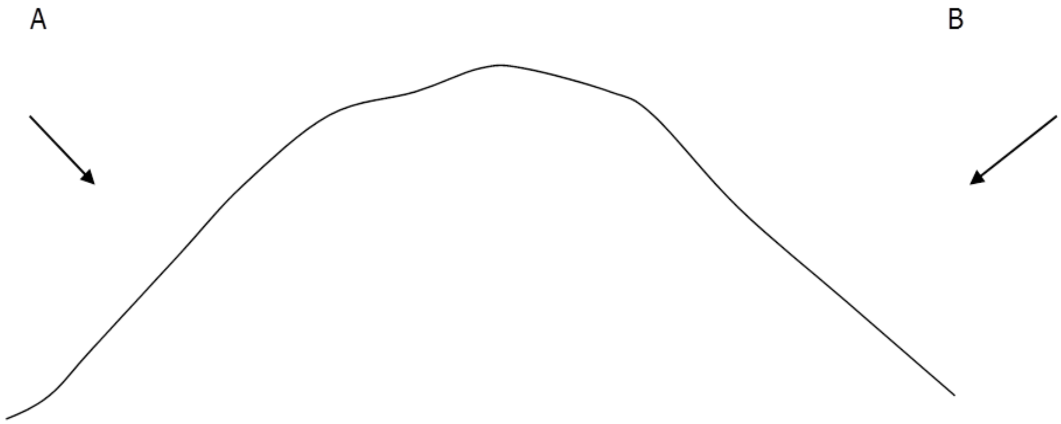
- Six learners were able to position the rectangles correctly so that the lines were vertical. Two of these learners made the association between the Y-axis on the Cartesian plane or graph, and a vertical line. Another learner referred to vertical as “up and down”. The other three learners were unable to verbalise their choice, but because they had positioned both rectangles correctly, still achieved “able” status.
- Three learners placed one rectangle correctly but placed the second rectangle incorrectly. Two of them placed the second rectangle so that the line inside it was horizontal. This could indicate that they are familiar with both terms, but confuse them.
- Nineteen learners were unable to complete the task satisfactorily. Of these learners, thirteen positioned the rectangles so that the lines inside them were neither vertical nor horizontal. Three learners placed both rectangles horizontally, while three learners did not glue the rectangles in place and thus did not complete the task.
- Of the nineteen learners that were unable to complete the task, nine did not understand the term vertical, four said that they could not remember what vertical meant, two learners confused vertical lines with vertically opposite angles, while one learner stated that the lines cross one another and do not run straight (ezihlukeleyo). Two learners confused the terms vertical and parallel.
- Overall, ten learners rotated the shapes several times before deciding where to position the rectangles. Of these 10 learners, three placed them correctly while seven learners placed them incorrectly.

4.6.2. Subtask B: Mountain Task

This subtask was designed to try to establish the learners’ proficiency at recognising verticality and horizontality in relation to the surface of the earth.

Sipho lives in a house halfway up the mountainside. There is a tree halfway up the other side of the mountain.

Draw Sipho's house where arrow A is pointing. Draw the tree where arrow B is pointing.



The tabulated results of this subtask follow:

Mountain subtask	Unable	Partially Able	Able	Excels
	The learner is either unable to accomplish the task, or draws the house and the tree incorrectly, without demonstrating the concepts of horizontal or vertical to the earth's surface. The house and tree are drawn horizontal and vertical to the mountainside respectively.	The learner is confused by the concepts of horizontal and vertical but successfully draws either the house or the tree correctly with regard to the earth's surface. The second drawing is incorrect.	The learner completes the task successfully by drawing the house horizontal to the earth's surface and the tree vertical to the earth's surface.	The learner completes the drawings successfully and is able to expand on the concepts of verticality and horizontality by giving examples from nature or real life contexts.
No of Learners to achieve per rubric category	12	6	12	0
% of Learners to achieve per rubric category	40%	20%	40%	0%

All 30 learners completed this subtask. 12 learners achieved "unable" status for the subtask. The following observations were made with regard their answers:

- Of the twelve learners in this category, eleven learners drew both the house and the tree perpendicular to the mountain. The 12th learner drew both diagrams at the bottom of the page, thus not following the instructions for the subtask.
- Of the 12 learners in the "unable" category, eleven learners drew a house with a small door and two windows, the bottoms of which were much higher than the top of the door. This observation will be discussed later in this chapter.
- The same twelve learners drew trees that were also perpendicular to the mountain. Six of the learners drew trees that had enormous trunks and very small leaf canopies. I shall refer to these trees as "lollipop" trees. One learner drew a tree with

a leaf bigger than the tree trunk and a further learner drew a tree that resembled a leaf.

- All twelve learners demonstrated undeveloped skill with regard to drawing simple structures. The diagrams were immature.
- All of the learners in the “unable” category drew the house and the tree touching the sides of the mountain, with the exception of the learner that did not follow the instructions and drew the diagrams at the bottom of the page.

Six learners achieved the “partially able” status, as they were able to draw one of the two diagrams required for the subtask.

- Four of the six learners drew the tree correctly, while two of the learners drew the house correctly.
- Of the six houses drawn, four had low doors and high windows. One had no windows at all, while one was drawn in good proportion. This last house was drawn on stilts, which allowed for it to remain horizontal to the surface of the earth.
- Of the six trees drawn, two resembled lollipops, one had exposed roots and two lay almost flat against the mountainside.
- Of the six learners in this category, only one demonstrated satisfactory drawing skills for the age group. The rest were considered to be immature.
- All six houses and four of the trees touched the sides of the mountain.

12 learners achieved “able” status for the mountain subtask. They therefore drew the houses horizontal to the surface of the earth and not the mountainside, while the trees were drawn perpendicular to the surface of the earth, and not the mountainside.

- Of the 12 houses, nine were drawn with a low door and high windows. Two had no detail. One house was drawn with the top of the door aligned with the tops of the windows. One house was drawn on stilts.

- Of the trees drawn, three resembled lollipops. One of these had exposed roots. Two further trees were simple outlines with no detail.
- Seven of the houses drawn made contact with the side of the mountain on one edge, while five did not quite touch the mountainside. They were termed “floating” houses.
- Five of the trees drawn made contact with the mountain on one side, while seven of them did not. These were termed “floating” trees.
- Two of the 12 learners in this category showed average drawing skills, while the balance of the learners drew immature drawings.

The results of Subtask A and Subtask B of Spatial Perception are presented in Figure 4.5 below.

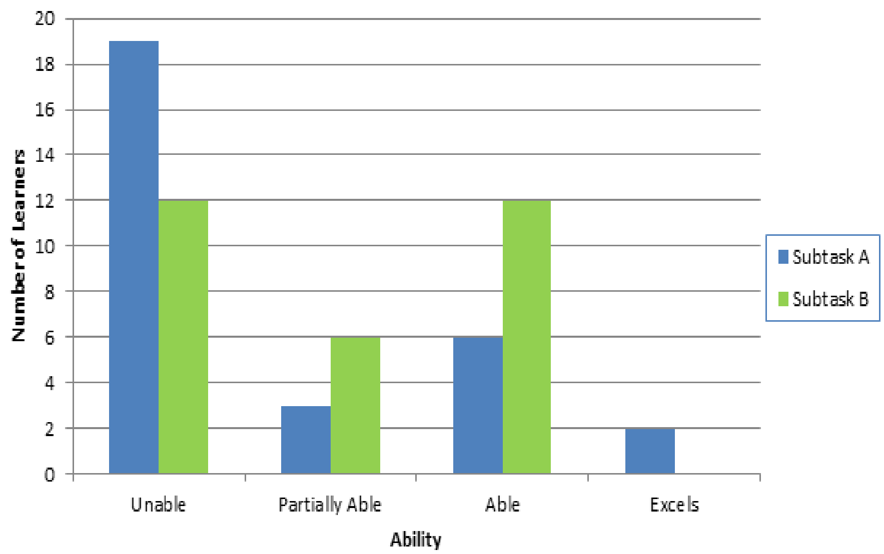


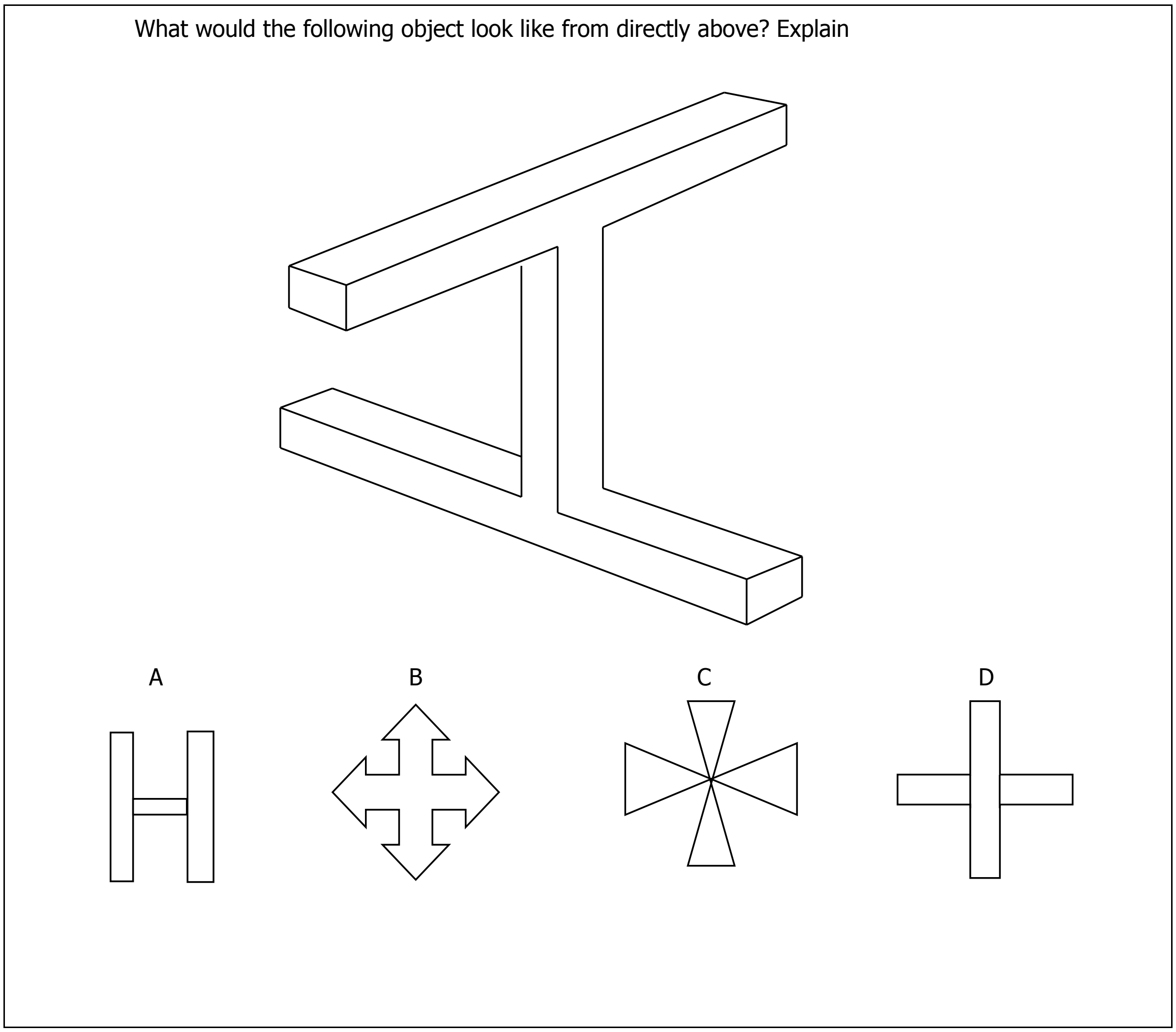
Figure 4.5: Results of Spatial Perception Tasks

This graph demonstrates that more learners were unable to complete subtask A than subtask B, which means that on average, more learners were partially able or able to complete the real-world context question (Task B) than Task A. However, none of the learners achieved “excels” status in Task B, as they were unable to expand on the concepts of verticality or horizontality in real world contexts.

4.7. Perspective Tasks

4.7.1 Subtask A: Geometric Shape Task

This subtask was designed to establish whether the learners could imagine an object in its entirety from a different perspective.



The answers to this subtask were assessed as follows:

Geometric Shape subtask	Unable	Partially Able	Able	Excels
	The learner is unable to see that the object is 3D or is unable to see the object from another perspective.	The learner makes an attempt to view the object from a different perspective but is unsure which view option to select.	The learner is able to complete the task and selects the correct view option.	The learner completes the task with ease and is able to verbalise why the other options are not applicable.
No of Learners to achieve per rubric category	13	0	5	12
% of Learners to achieve per rubric category	43.3%	0%	16.7%	40%

The following observations were made from the data:

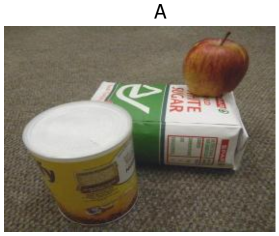
- Of the 13 learners that were unable to see the shape from another perspective, all thirteen of them selected option A as the correct answer.
- Seven of these learners alluded to some form of movement, either turning, twisting or squeezing, in order to make the shape look like the H in option A. This lends weight to the supposition that they have in fact not changed their own perspective at all, but rather have manipulated the shape in some way in order to change the perspective of the shape.
- No learners chose options B or C.
- Five learners chose option D without verbalising the reason behind their choice.
- 12 learners selected option D and justified their choice. Of the 12 learners, six referred directly to being above the shape and seeing a cross. Four others referred to straight lines going in “opposite directions” in order to form a cross. One learner used the process of elimination to select the correct answer. None of them used the word “perpendicular” when referring to the two sets of lines or beams in the diagram.

4.7.2 Subtask B: Household Items Task

This subtask was designed to challenge the learners to have imagined moving from one perspective of a structure or object in its entirety to another perspective of the same structure or object. In this subtask, everyday items were used as opposed to specifically geometric shapes or objects.

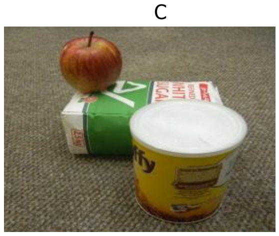
If you look at these items from the opposite side of the table, what will you see? Explain.

A

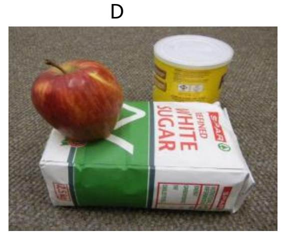


B

C



D



E

F

The results of this subtask follow:

Household Items Subtask	Unable	Partially Able	Able	Excels
	The learner is unable to imagine the scene from a different perspective.	The learner tries to imagine the scene from the opposite side, but is confused by the differing options.	The learner is able to imagine the scene from the opposite side and selects the correct photo.	The learner completes the task easily and is able to discuss how perspective can change in other real life contexts.
No of Learners to achieve per rubric category	2	9	7	12
% of Learners to achieve per rubric category	6.7%	30%	23.3%	40%

The following observations were made:

- Two learners were unable to imagine the scene from a different perspective and chose option E, which is identical to the original scene.
- Nine learners tried to imagine the scene from the opposite side, but chose an incorrect option. Seven of these learners chose option A, in which only the coffee had been shifted from the background to the foreground. One learner chose option C, in which the apple and coffee were correctly placed but the sugar was in the original position, and one learner chose option D in which the apple and coffee had swopped sides but the sugar was still in the original position.
- Seven learners selected B as the correct option, but were either unable to give a reason, or were only able to justify their choice by referring to one item in the scene. One of these learners used hand gestures to strengthen the choice.
- Twelve learners were able to make the correct choice and substantiate that choice by using two or more items in the diagram, and refer to evidence such as the sugar sign being reversed, etc. Of these learners, five used hand gestures to demonstrate their thought processes.

A summary of the results for Subtask A and Subtask B for Perspective follows in Figure 4.6.

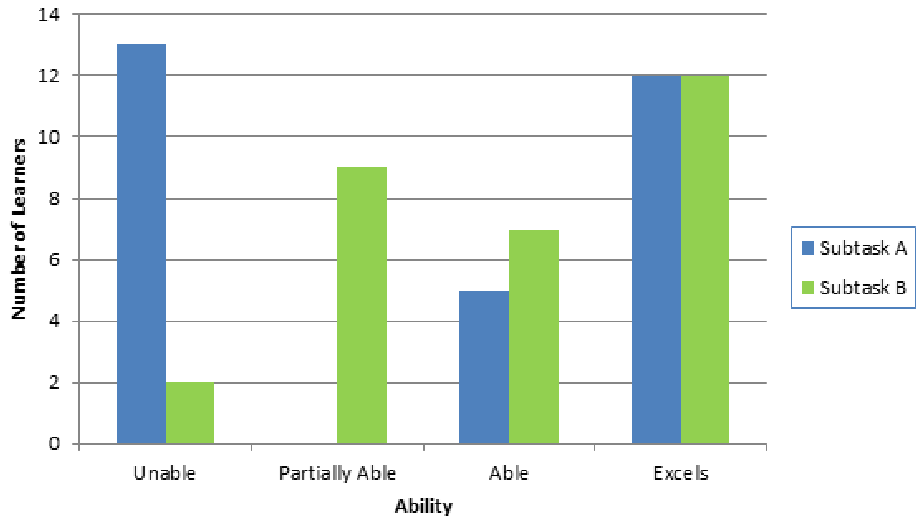


Figure 4.6: Results of Perspective Tasks

Once again, more learners were unable to perform the text book type task than the real world context task. On average, more learners were partially able or able to achieve success when doing the real world context tasks. I discuss this in 4.9.1.

4.8. Summary of Results

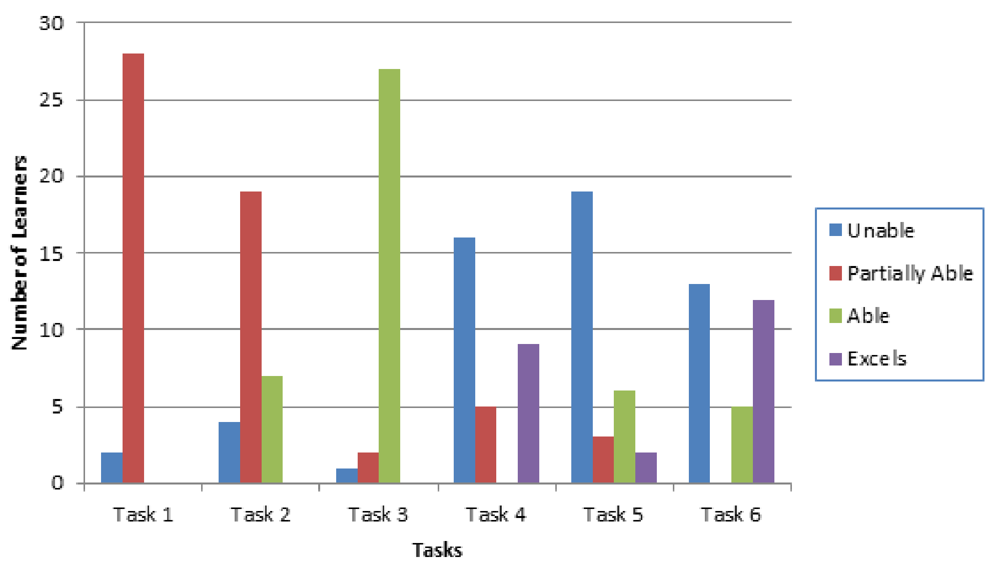


Figure 4.7: Summary of Subtask A Results

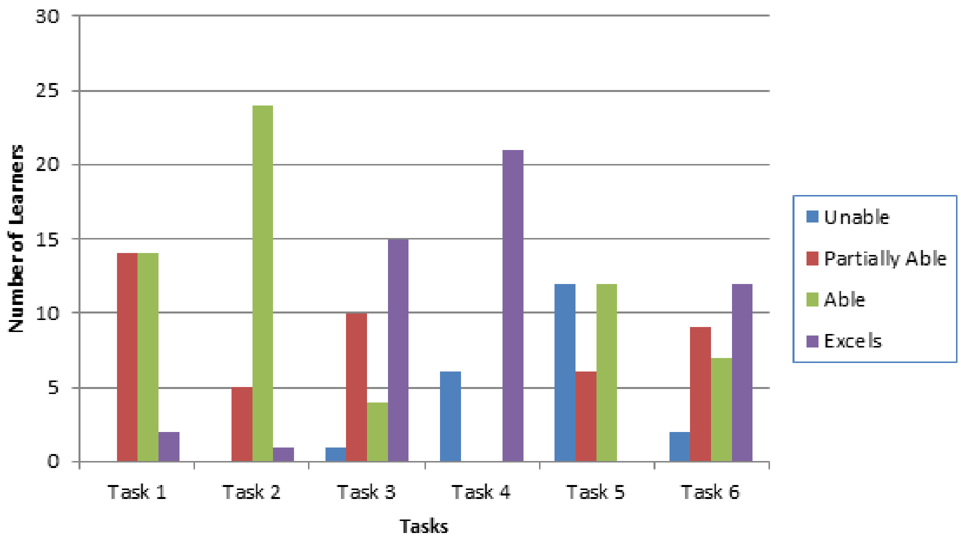


Figure 4.8: Summary of Subtask B results

When we compare the Task A performance in Figure 4.7 with the Task B performance in Figure 4.8, we notice the following:

- In the A tasks, learners achieved the “unable” status 55 times. In the B tasks, they achieved this status 21 times.
- In the A tasks, learners achieved “partially able” 57 times, while in the B tasks they achieved this status 44 times.
- In the A tasks, learners achieved “able” status 45 times, while in the B tasks they achieved this status 61 times.
- In the A tasks, learners achieved “excels” status 23 times, while in the B tasks they achieved this status 51 times.

It is thus very clear that the learners fared far better with the real-world context questions, as opposed to the text book type questions. This poor performance in text book type questions may be one of several reasons why learners perform poorly in this section of Mathematics. However, their substantially better performance in real-world context questions give us the assurance that they do demonstrate at least some of the spatial skills required in order to perform certain mathematical tasks. This augurs well for possible future remediation strategies to improve these skills and thus improve performance in Mathematics generally and Geometry in particular. This observation is discussed further in 4.9.1 below.

4.9 Emerging Themes and Trends

On closer inspection of learner responses in all six sets of tasks, some trends began to emerge. These are highlighted below:

4.9.1 Textbook Type Subtasks vs Real-World Context Subtasks

The rationale behind setting two distinct sets of tasks was to examine whether the format of text book questions could be a factor in poor Geometry performance. By setting text book type tasks as well as real-world context tasks, the learners were given the opportunity to demonstrate spatial skills in one format or another. This would give some indication as to whether the learners demonstrated these skills in two formats, one format or not at all.

It is clear from the results that the learner performance in the Subtask B tasks, which were the real-world context tasks, far outstripped their performance in traditional text book type questions. While this is disconcerting on the one hand, as learners need to be able to comprehend and interpret traditionally structured questions for Matric examination purposes, on the other hand it is reassuring, and as it is a clear indication that the learners do indeed possess these spatial skills.

A possible explanation for their greater achievement in the real-world context tasks could be founded in the Piagetian theory of schemata, which he described as intellectual structures that people use to organise and classify events and information according to common characteristics (Wadsworth, 1989, p. 11). Throughout childhood, the learners are accessing and assimilating more and more information about everyday items such as sugar and coffee and fruit, cogs such as those on a bicycle, puzzles, church windows, and pictures of wild animals, and then assimilating these data into their existing schemata for these items. The schemata thus become more and more complex and differentiated.

On the other hand, however, the learner will have very limited schemata that pertain to 2D shapes and 3D objects in Mathematics textbooks, as his/her exposure to such items and information is strictly limited to a short lesson in the school environment from time to time. Thus the real-world items, diagrams or photographs seem less intimidating to the learners as they have far more assimilated knowledge of them and feel comfortable when manipulating images of them mentally. It is far easier, for example, for them to imagine themselves walking around a table to look at a bag of sugar from the opposite side, than it is to imagine moving around a 3D shape to see what it would look like from the other side, as this is not likely to ever have happened in their real-world experience and therefore their schemata for these 3D shapes are undeveloped.

Their ability to mentally rotate shapes and work with other spatial concepts in real-world contexts is also reassuring as this leads one to believe that future remediation strategies are a viable option for further spatial skills development.

4.9.2. Lack of Exposure to 2D Shapes and 3D Objects

In Task 1, learners were given an example hexagon and asked to identify further hexagons in five given shapes. Although the hexagon appeared in all five given shapes (and twice in two of them) none of the learners could identify a hexagon in more than two of the shapes. However, what was of greater concern was that two of the learners counted the sides of the sample hexagon in order to establish how many sides a hexagon should have. A third learner selected shape number three as his answer because "it have 13 sides and they are not equal". It is very apparent that he did not understand the question, despite assuring me that he did, or that he had no idea what a hexagon is.

In Task 2, learners were required to classify congruent shapes. One learner classified a square as a right-angled triangle, while ten learners classified pentagons and hexagons as being congruent. One learner classified a trapezium as being congruent to a pentagon and five learners could not differentiate between a square and a cube. Nine learners classified right-angled triangles as being isosceles triangles and two learners could not differentiate between any of the shapes mentioned.

In Task 3, one learner was unable to recognise that the object in the illustration was a 3D square pyramid. He first identified a shape containing four triangles, then later saw the diagram as a shape that contained a trapezium and six triangles. He could not imagine how the shape would collapse into a net.

According to the Department of Education's Mathematics CAPS Statement for the Senior Phase (South Africa. DBE, 2011a), learners in Grade Nine should be able to distinguish between equilateral, isosceles and right-angled triangles. They should further be able to define and distinguish between parallelograms, rectangles, squares, rhombi, trapezia and kites. In terms of

3D objects, they should be able to define the five Platonic solids in terms of faces, vertices and edges, recognize and describe the properties of spheres and cylinders, and use nets to build cubes, prisms, pyramids and cylinders (pp. 27 – 28). It must be assumed therefore that by the time the learners reach Grade 10, these criteria have been met. Sadly, this is not the case, as evidenced above. Not only do the learners confuse 2D shapes with one another, but they are also unable to differentiate between 2D and 3D shapes. There are always many factors at play when learners fail to achieve crucial benchmarks in mathematics development, but when they fall short as a group, one has to assume that they have not received sufficient exposure to the material.

How the learners are exposed to the material is also of concern. I refer back to Clements & Battista (1992), who state that a child's representation of space cannot be a passive "reading off" of his/her spatial environment, but rather it requires construction by actively manipulating that spatial environment. There is a plethora of evidence proving that active, hands-on engagement with a variety of manipulatives ranging from maps to construction toys to geoboards, will improve spatial skills (Del Grande 1990; Hill, Corbett & St. Rose, 2010; Newcombe, 2006). At the beginning of this section I related learner errors in three separate tasks. The first task assessed figure-ground perception, the second assessed visual discrimination and the third assessed spatial visualisation. According to the typology of Newcombe & Shipley (2012), all three of these tasks are assessing the intrinsic characteristics of the 2D shapes and 3D objects. The first two are static and the third is dynamic, which in this case meant mentally unfolding a 3D object into a net and mentally rotating cogs. Learning about these intrinsic characteristics of geometric shapes and objects forms a substantial portion of the Geometry syllabus in both the Intermediate and Senior phases of education. It is thus almost inconceivable that learners in Grade Ten have such a poor understanding of these characteristics.

A possible explanation may be that teachers in many of our public schools are severely under-resourced and do not have the budget required for equipping their classrooms adequately in order for the learners to engage in the necessary activities that would develop both their spatial skills and a better understanding of the intrinsic characteristics of shapes and objects. While there are many cost effective and user friendly resources that could be used for this purpose, teachers may feel apprehensive about using such resources without specific training in this constructivist approach to teaching and learning.

A further consideration is that many of the older South African teachers in previously disadvantaged communities received education training that is deemed today to be substantially less than adequate. Some of them were employed as Mathematics teachers despite having no Mathematics teaching qualifications, but simply because they were willing to try to teach it. Such teachers perhaps feel insecure with regard to the content of the Mathematics syllabus, and thus tend to adhere rigidly to the "knowledge transfer" style of teaching, guided by a textbook and discouraging any form of dialogue that may expose their mathematical weaknesses, as opposed to the more recent constructivist approach that allows for the learners to actively participate in the construction of Mathematics or Geometry knowledge. Learners have therefore passively received abstract information about 2D shapes and 3D objects without engaging with any material or manipulatives. This kind of knowledge acquisition is very difficult to retain and may have contributed to the poor understanding of basic concepts that learners exhibit today.

4.9.3 Congruency

In the same task as above, where learners had to classify congruent shapes, only seven learners out of the group of 30 learners were able to do so. Nineteen of the learners were able to correctly classify some of the shapes, and four learners were not able to complete the task at all. There was also a huge discrepancy between the answers given. While six learners did not differentiate between obviously different shapes such as squares and cubes or hexagons and pentagons, other learners only listed as congruent those shapes that held exactly the same orientation as the shapes in the example, thus failing to note several other shapes that were also congruent but held differing orientations.

French (2004) states that learners' first thoughts about congruence are based upon the intuition that two shapes fit exactly on top of each other (p. 55). Thereafter, learners move on to measurement of the shapes and exploration with the properties of the three transformations, i.e. translating, reflecting and rotating. In superimposing one shape on top of another and transforming them in multiple ways, the learners begin to acquire a grasp of the concept of congruency. Only after these concepts become concretised can the learners then use reason to prove that two shapes are congruent.

French (2004) relates an observation he made in a lesson in which the teacher had given the 12 year old learners the task of illustrating and naming all the different types of triangles they could think of. One boy named two triangles as they appear in Figure 4.9.

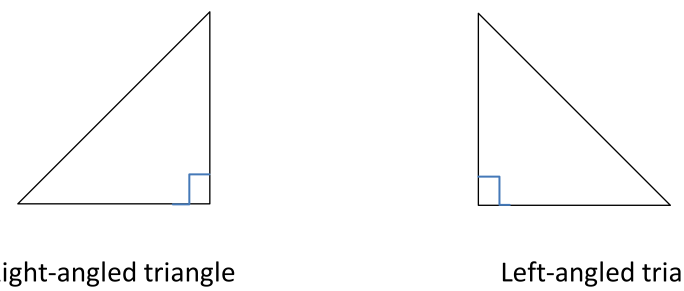


Figure 4.9: Naming triangles

This response, while quite logical, reveals a fundamental problem that learners face when developing the concept of congruency: if one shape *looks* different from another, how can they possibly be the same? This dilemma, in the context of a Geometry problem, could possibly unfold as follows:

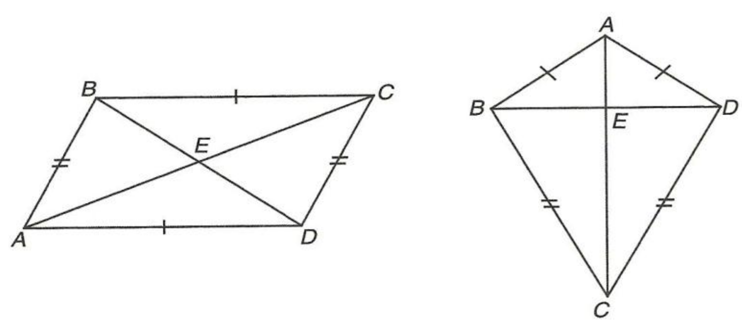


Figure 4.10: Congruent triangles within parallelograms and kites

The questions pertaining to the diagrams in Figure 4.10 could be posed as follows: In parallelogram ABCD, prove that triangle ABD is congruent to triangle CDB. Alternatively, a question pertaining to the kite could be presented as follows: In kite ABCD, prove that triangle BEC is congruent to triangle DEC.

The learner may note that in the first instance, one triangle is the right way up and the other triangle is upside down. Because the two triangles do not look identical to one another, the learner may assume that they cannot be congruent, not realising that a simple transformation (in this case a rotation) would reveal that the two triangles are indeed identical to one another. This may result in cognitive conflict (Adey & Shayer, 1994), as the learner must assume that the triangles have to be congruent, despite not looking that way, because the question has asked that the congruency be proven. Some learners may opt to leave the question out as they would rather attempt something that makes more sense to them.

In the second instance, the learner may assume that the first triangle faces left and the second triangle faces right, so therefore, once again, they cannot be congruent. In this case a simple reflection would reveal that the two triangles are in fact congruent. As we have observed above, cognitive conflict may arise and the question may be left out.

Had these learners been exposed to a constructive learning approach in Geometry, they would have actively worked with these and other triangles and a variety of other shapes and objects, by tracing, drawing, measuring, cutting out and transforming them until their schemata for working with such shapes and objects were developed enough for them to be able to mentally rotate or reflect triangles when the need arose. We are reminded here that Pederson (1983) defined Geometry as a skill of the eyes and the hands, as well as the mind. If only the eyes have seen shapes, but hands have not drawn them or cut them out or flipped them over, then the skills will not have been effectively acquired.

It thus becomes apparent that the learners who completed the SSAT test have been woefully underexposed to working with and manipulating shapes in order to establish a better understanding of the concept of congruency. The CAPS document for Senior Phase Mathematics iterates that in Grade Nine, learners should be able to establish the minimum conditions for congruent and for similar triangles (South Africa: DBE 2011a, p. 28). With their understanding of the concept of congruency being fragile at best and their ability to visually discriminate between shapes in need of much development, it is to be expected that this section of the Geometry syllabus will remain very challenging for them.

4.9.4 Vertical and Horizontal

In a traditional Spatial Perception task, learners were given two rectangles to cut out. Each rectangle contained a straight bar. Learners were tasked to glue the rectangles down in such a way that the bars inside them were in the vertical position. Of the 30 learners attempting the task, nineteen of them were unable to complete it as nine of the learners did not know the meaning of the word vertical, while four learners admitted that they could not remember what the word vertical meant. Two learners thought that vertical referred to vertically opposite angles and a further two learners confused vertical and parallel. A further three learners partially completed the task, by placing one bar vertically and the other horizontally, but this was clearly guesswork as they were not sure which was which. Of the 30 learners, only two were able to give the correct definition of the word vertical.

In the CAPS document for Senior Phase Mathematics, learners in Grade Nine should "*be able to perform transformations with points, line segments, and simple geometric figures on a co-ordinate plane, focusing on reflection in the X-axis or Y-axis, translation within and across quadrants, and reflection in the line y=x*" (South Africa. DBE, 2011a, p. 29). If the learners are unable to distinguish between horizontal and vertical when perceiving space, it follows that all work with reflections is under threat of being misinterpreted. Furthermore, vertical height is an essential measurement when working with area of triangles and parallelograms and the misinterpretation of such could become very costly to the learner.

A second Spatial Perception task, which involved drawing a house and a tree on the side of a mountain, also revealed much about the learners' understanding of the concepts of vertical and horizontal. According to Piaget et al. (1960), there are four stages of development in spatial thinking. The first is the sensori-motor stage from 0 – 2 years, when babies and young children observe features in a topological way. The second stage is called the pre-operational stage and occurs from 2 – 7 years, when children start to represent spatial features through drawing and modelling. Their topological thinking is still very prevalent and they are unable to comprehend such ideas as the horizon. The third stage is called the concrete operational stage, from seven to 12 years. This is when children slowly start perceiving and representing objects from different perspectives. They begin taking vertical and horizontal relationships into account when they draw. The fourth and final stage is called the formal operational stage, from 12 – 18 years, when complex geometric concepts of plane geometry are understood and used.

McNally (1975) illustrates how children ranging from four to 10 years co-ordinate horizontal and vertical planes. They were asked to draw liquid in a tilted jar on a table, and people, trees or houses on a hillside. The diagram below clearly indicates how spatial thinking matures, from topological thinking at the top, to concrete operational at the bottom. Wadsworth (1989) concurs by stating that when five and six year olds draw a house and a tree on the side of a hill, they draw them perpendicular to the hill and only by age eight or nine are they able to coordinate the hill and the plane of the earth and thus draw the objects perpendicular to the surface of the earth.

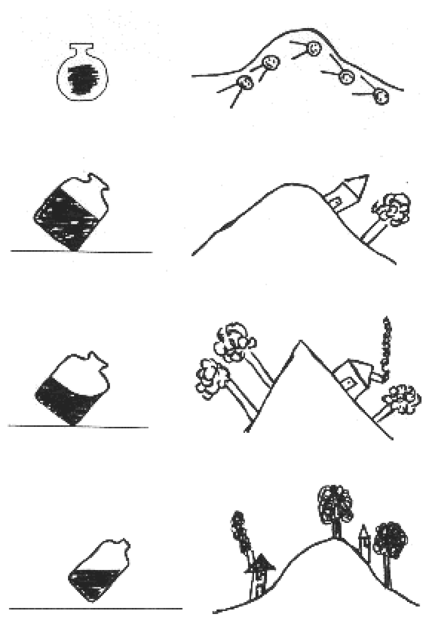


Figure 4.11: Illustration of the development of the co-ordination of horizontal and vertical planes (Source: McNally, D. (1975)).

It can therefore be assumed that the children who drew the diagrams at the top of Figure 4.11 were younger, while the children who drew the diagrams at the bottom of Figure 4.11 were older. I now wish to bring attention to the diagrams below, which were drawn by the learners who completed the SSAT test. The learners were all in Grade ten, so their average age at the time of the test was assumed to be 16 years of age.

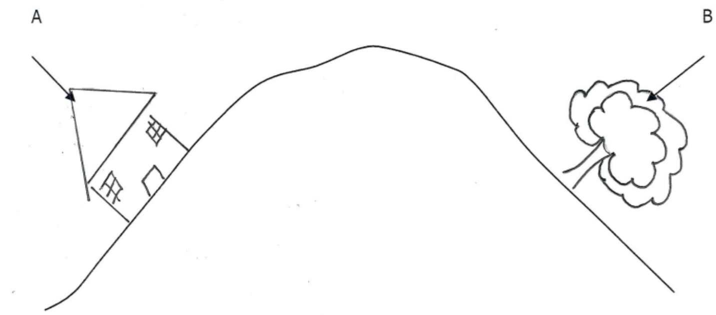


Figure 4.12: Diagram from the “unable” category

Figure 4.12 resembles a typical drawing by the learners from the “unable” category. 11 of the learners produced such drawings, where both the house and the tree are perpendicular to the mountainside and not the earth’s surface. In this drawing, the windows of the house are very high relative to the door, which is typical in drawings of children far younger than this age group.

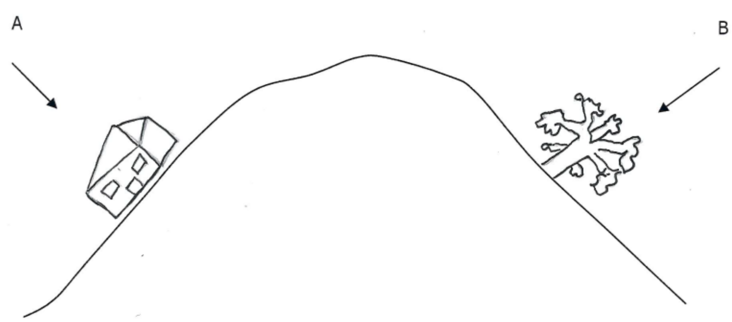


Figure 4.13: Diagram from “unable” category with house in 3D

This drawing demonstrates the same lack of horizontal and vertical perspective. However, the learner has made an effort to draw the house in three dimensions. The tree is also somewhat more elaborate than in Figure 4.12.

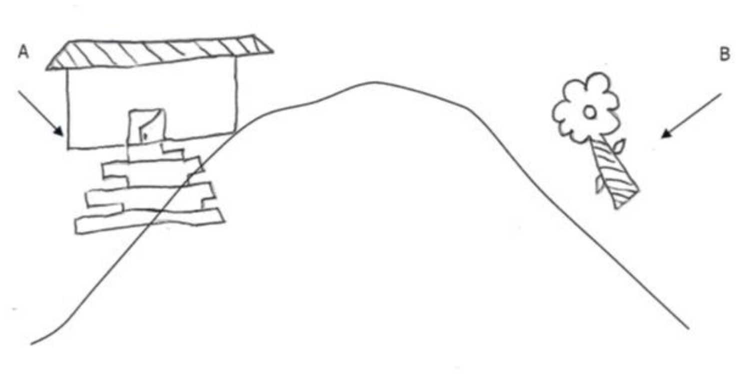


Figure 4.14: Diagram from “partially able” category

This drawing is typical of the learners who were partially able to complete the task. In this case, the house was drawn perpendicular to the earth, but the tree was not. The tree resembled a flower and lay almost flat against the surface of the mountainside.

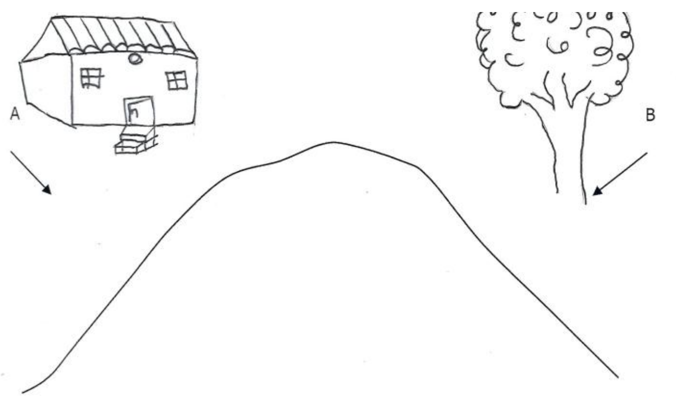


Figure 4.15: Diagram with “floating” objects

In this diagram, both the house and the tree were correctly drawn relative to the earth’s surface. However, it is drawn “floating” and does not touch the surface of the mountainside. Five learners drew floating houses, and seven learners drew floating trees. This may be a another manifestation of the term “cognitive conflict”, coined by Adey & Shayer (1994), which they describe as an event or observation which the student perceives to be in conflict with earlier knowledge. The learners have assimilated the horizontal and vertical perspectives, but are still unsure as to how to demonstrate them in terms of the angles of the mountainside, thus they avoid the issue by placing the diagrams slightly above the mountainside.

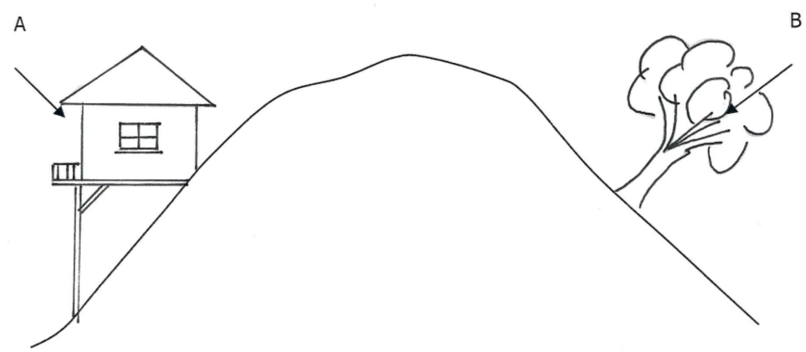


Figure 4.16: A further example of partial Spatial Perception

In the diagram above, the learner has demonstrated a certain artistic creativity in order to marry the concept of verticality to the concept of building on a mountainside. While the drawing of the house indicates spatial perception, the drawing of the tree does not. It is still perpendicular to the mountainside.

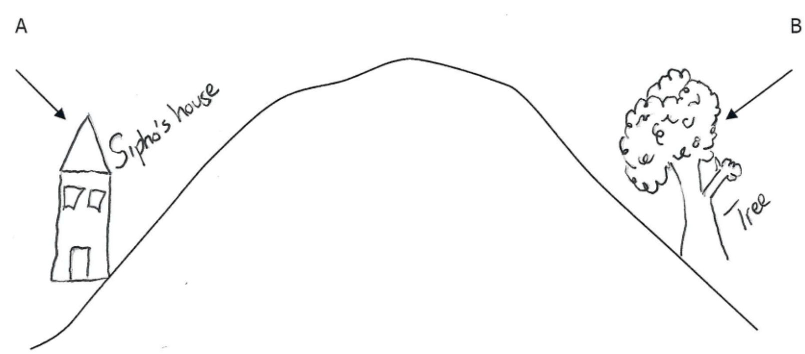


Figure 4.17: Diagram from the "able" category

This figure is representative of most of the learners who were able to complete the task satisfactorily. At least one corner of the house and tree make contact with the mountainside, and both drawings are perpendicular to the surface of the earth. While the diagrams are immature, the concept of spatial perception is understood.

Vygotsky (1978) states that drawing and all other forms of representation are built on a foundation of verbal speech. Dyson (1983) concurs by saying that oral language precedes and is a bridge to graphic representation. Perhaps then it should not be surprising that learners who are taught Mathematics in a second language will struggle to express their understanding either verbally or graphically.

4.9.5 Orientation of Objects and Orientation of the Observer

Task 3, the spatial visualisation task, required the learners to imagine how a 3D object would look after a mental adjustment. Task 4, the spatial orientation task, and Task 6, the perspective task, required the learners to be able to imagine a structure or a scene from a different perspective. In general the learners coped far better with the spatial visualization tasks in both the traditional and the real-world context formats. 25 learners were able to complete subtask A correctly, while 27 learners completed subtask B task correctly.

However, the spatial orientation and perspective tasks were more challenging. Learners struggled to imagine what a structure or a group of items would look like if they, the observers, had to change their personal orientation and look at these objects from elsewhere. One question showed a stained glass window in a church with a cross in the middle, a dove on the right and a sun on the left. The learners were tasked to select from three possibilities, what the window would look like if one looked at it from outside the church. Nine learners stated that there would be no change at all. As one learner stated, "*because this window is not going anywhere….it stayed like this. When you are outside you are going to see that thing you see inside*."

This brings to mind Piaget & Inhelder's theory of topological primacy, and specifically the Three Mountains Task, in which young children are requested to construct a view of three mountains from the perspective of a doll sitting opposite them. All of the children constructed the view from their own perspective, as they had not yet developed a "global" system of reference, which is a basic prerequisite for constructing projective relations (Clements & Battista, 1992).

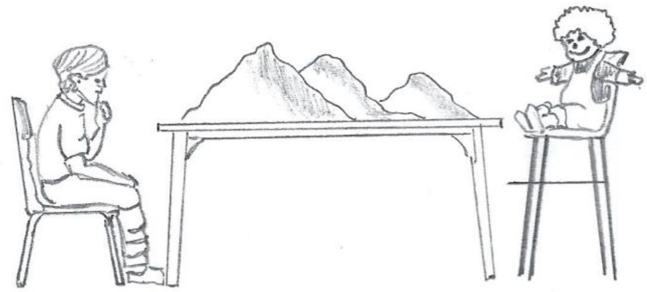


Figure 4.18: Piaget's Three Mountains Test

In Table 2 on page 21 a summary of Newcombe & Learmonth's milestones in the development of spatial skills (2005) is given. According to them, children of six to nine years begin developing perspective and mapping conventions. By the age of nine to 10 years, children should be able to take perspective even when frames of reference conflict. By the age of 12, children should be able to demonstrate spatial coding on a par with those of an adult. According to these milestones, a learner in secondary school should have developed the full range of spatial skills required to tackle perspective tasks.

The unfortunate reality is that too many learners in the group were unable to complete these tasks with any understanding of perspective. This does not bode well for success in transformation Geometry, where the learners are required to reflect and translate shapes and objects around various axes and accurately predict the location of a shape after it has undergone transformations. Graphic representation of inverse functions will also be a challenge.

4.9.6 Terminology

The lack of understanding of basic mathematical terminology and the inability of learners to verbalise what they understand by certain terms remain enormous challenges. Learners were given the option to define these terms in isiXhosa if they preferred. However, it is apparent that the following concepts were not understood as explanations could not be given in either language.

Congruent shapes	Seven learners stated that congruent shapes are the same as each other.
	One learner stated that they can change shape but are the same.
	One learner said they are not the same, but have the same qualities or the same structures, or something like that.
	Nine learners said that they are similar shapes.
	10 learners could not answer or were not sure.
Vertical	Three learners could correctly describe what vertical means – standing up straight and horizontal is lying down.
	13 learners could not remember or could not answer.
	Two learners described them as horizontal lines.
	10 learners did not know.
	Two learners said that they are vertically opposite angles.

According to French (2004), the word similar can be a potential source of confusion as it implies a certain sameness, when used in everyday contexts (p. 90). So in everyday language, two shapes could be called similar if they both have four sides and equal angles. This applies in isiXhosa too. The term “ziyafana” implies that things are “alike”, but not necessarily identical. The correct term for things that are identical to each other is “yinto enye” which translated means “one and the same thing”. However, the mathematical use of the word similar is far more rigid and requires that shapes be in proportion with one another too. Renne (2004) explains this by stating that often learners lack the appropriate vocabulary to distinguish clearly between shapes or compare them in an orderly way.

Empirical data shows that lack of language competency impedes progress in geometric understanding (Feza & Webb, 2005). This becomes apparent when one refers to the table above. Two assumptions can be made from the information in the table. Firstly, the concepts of congruency and similarity cannot be sufficiently understood if learners define congruent shapes as shapes that are similar to one another. In Geometry, these two concepts are quite different from one another. Secondly, if only three out of 30 learners are correctly able to define the term vertical and the rest are unsure of its meaning, it may follow that as many learners are unsure of the term horizontal. The understanding of these two terms is essential for the understanding of co-ordinate Geometry and all work relating to the X and Y axes.

4.10 Conclusion

Despite several very worrying results that have emanated from this study, the results of the spatial skills as tested in the real world context questions are somewhat reassuring, as they clearly indicate that most learners assessed in the SSAT instrument possess many of the spatial skills required for success in Geometry. These skills simply need to be practised and developed. According to Sorby (2007), engineering students who had demonstrated a lack of spatial skills and who then completed a spatial skills remediation programme, showed statistically significant gains in their spatial skills performance and these gains were long term. The programme consisted of a verbal introduction to the relevant skill, followed by building with snap cubes, sketching constructions, modelling 3D shapes on computers and using hand held items whenever possible. Athebe & Schäfer (2010) mention the importance of foregrounding the necessity of teaching basic geometric terminology in school mathematics. The type of programme mentioned above, together with regular workshops to address terminological weaknesses, could substantially enhance the performance of our learners in Geometry.

CHAPTER 5 - CONCLUSION

5.1 Introduction

In Chapter 4 the results of this study were discussed at some length. In this final chapter I revisit the most important findings that arose from the study. Thereafter, I discuss the significance of this study and also the limitations of the case study. Recommendations are then made and avenues for further research are discussed. I conclude with a personal reflection.

5.2 Findings

This study emanated from observations made regarding bench mark tests that learners who were involved in the Catch-Up programme completed on a biannual basis. On studying the results of these tests, it was noted that the sections of Mathematics that were particularly poorly answered, were those that were spatial in nature. For example, questions with 2D or 3D diagrams, questions with graphs and questions that involved area or volume were consistently weakly answered. This led to the assumption that poorly developed spatial skills may be a significant factor in the poor mathematics performance of the learners.

There are many closed pen and paper tests to establish mathematical ability across a range of mathematical skills. However, there was no known spatial skills assessment instrument that allowed for one-on-one interaction between the learner and the assessor. Furthermore, spatial skills had been assessed using traditional text book type questions with right or wrong answers, with little attempt being made to understand what the learner understood or not.

The aims of this study were twofold: Firstly, to design a spatial skills assessment instrument which would allow for an open and interactive engagement between the researcher and the learner. In this way the researcher could pose suitable questions in both English and isiXhosa in order to establish the extent of understanding of each learner. Secondly, this assessment tool, called the Spatial Skills Assessment Tasks, was then implemented in two schools which were already involved in the Mathematics Catch-Up Programme.

The findings of the SSAT instrument are many and complex and are discussed at some length in Chapter 4. However, I feel it necessary to highlight some of the major findings which impact substantially on the performance of the learners.

5.2.1 Traditional Text Book Questions vs Real-World Context Questions

Learners performed substantially better in the real-world context questions as opposed to the traditional text book type questions. It is assumed that they were less intimidated by the real-world questions, with which they also seemed more familiar. Their demonstration of spatial skills suggests that a remediation strategy to further strengthen these skills is worth considering.

5.2.2 Lack of Exposure to 2D Shapes and 3D Objects

Learners in Grade 10 Mathematics should easily be able to differentiate between a range of 2D shapes and 3D objects. It is very disconcerting, therefore, that the majority of the participating learners were unable to distinguish between some of the standard 2D quadrilaterals and polygons as well as confuse some 2D shapes with 3D objects. The syllabus covers this section of work very thoroughly throughout the senior phase and the ability to categorise and differentiate between 2D shapes and 3D objects is accepted as understood by the time the learner reaches Grade 10. Their failure to achieve in this part of the SSAT leads one to believe that either the learners have been substantially underexposed to the work over a period of years in their schooling, or that the language pertaining to this section of work is not sufficiently understood, or both.

5.2.3 Congruency

The learners failed to understand this section sufficiently and many assumed that two shapes need to hold the same orientation in order to be congruent. Terminological misinterpretation also plays a role in the poor performance of the learners, who confuse two mathematical terms that have vastly differing meanings in Mathematics, as being the same thing, i.e. similar and congruent.

5.2.4 Vertical and Horizontal

The concepts of vertical and horizontal are very poorly understood by most of the learners in the study. These concepts were assessed in two different ways in the SSAT, one of which required the learners to cut out rectangles and paste them in such a way that the bar inside them was vertical; the other required them to draw a house and a tree on the side of a hill. Responses to both questions were indicative of extremely weak conceptual and terminological comprehension.

5.2.5 Orientation of Objects and Orientation of the Observer

The inability of some learners to “flip” or rotate an image mentally was highlighted in subtasks 4A and B. This underdeveloped spatial skill is likely to impact negatively on learners’ success with regard to congruency tasks if they are unable to see that two triangles with differing orientations can, in fact, be congruent if one of them were to be reflected or rotated. Further, when learners work with volume and surface area of 3D objects, not all faces are shown in diagrams and the learner needs to be able to re-orientate the shape mentally in order to find required measurements. Once again a lack of exposure and hands- on activities in lower grades could be partially to blame.

5.2.6 Terminology

The common thread woven throughout and linking all aspects of the SSAT study has been that of learners who are not sufficiently au fait with the language of teaching and learning (in this case English). Added to this is the extra challenge of learning, understanding and assimilating the language of Mathematics, and specifically in this case the language of Geometry.

One might assume that it is the responsibility of the teachers to educate the learners in the “language” of the subject that they teach, but the problem is far more deep-seated and complex than this. Four common scenarios in South African classrooms are:

- An English speaking teacher teaching Mathematics to both first and second language English speakers;
- A second language English speaking teacher teaching Mathematics to both first and second language English speakers;
- A second language English speaking teacher, whose first Language is, for example, isiXhosa, teaching Mathematics to second language English speakers, whose first language is also isiXhosa; and
- A second language English speaking teacher teaching Mathematics to second language English speakers, whose home language is different from that of the teacher.

These teachers face enormous challenges. Not only do they need to identify the linguistic demands of the instructional context and plan activities to teach the natural and formal language of textbooks (Dale & Cuevas, 1992), but they also have to take into account the cultural and socioeconomic differences that will surely impact on the potential success of the learners. Further, the temptation to revert to home language instruction in the case of scenario 3 above in order to clarify certain concepts, becomes overwhelming, especially when faced with word problems that add to what Paas et al. (2003) have termed “extraneous cognitive load” suffered by the learners. Not only are they grappling with a language in which they are not entirely fluent, but are also attempting to solve a Mathematics problem that may or may not have been correctly interpreted. In scenario 4, depending on the language proficiency of the teacher, he or she may very well be experiencing this extraneous cognitive load as well.

Tragically, very few of our qualified Mathematics teachers in South Africa have received sufficient, if any, instructional support in order to mitigate the challenges and demands that they face when teaching the subject to second language Mathematics learners.

5.3 Significance of the Study

Success in school Mathematics, as evidenced in learner performance in national and international assessments such as SACMEQ, TIMSS and now the ANA’s, remains elusive. These tests repeatedly report that the standard of Mathematics education in our country is dire. However, whilst these tests are termed “diagnostic”, they are designed as closed pen and paper tests, usually with multiple choice answers, that only reveal a correct or incorrect end answer. It thus follows that the only diagnosis that can be given once the tests are complete, is that the learners either can, or cannot, do a particular section of Mathematics. These tests say very little about the underlying skills and abilities that are apparently lacking.

This study therefore sought to expand on the spatial shortfalls of the learners by designing and implementing an interactive open assessment instrument that would expose which spatial skills the learners demonstrate when doing Geometry and which spatial skills are underdeveloped, thus providing a more comprehensive assessment of learner performance in Geometry.

The Spatial Skills Assessment Tasks (SSAT) instrument was thus structured in such a way as to test each spatial skill which is considered important for success in Geometry in two ways – with a traditional text book type question and then with a real-world context question, in order to establish whether the learners are merely intimidated by traditional tasks but are capable of demonstrating spatial skills, or whether they simply cannot perform tasks that are spatial in nature at all. There is no literature on another such assessment tool being available in South Africa.

This approach is significant for two reasons: Firstly, the interactive relationship between the researcher, the instrument and the learner revealed information that would possibly never have come to light in a standard bench mark test. This allowed the researcher a tremendous insight into the conceptual understanding of all the learners that participated in the study. Secondly, questions were posed to the learners that allowed insight into their understanding of certain mathematical and geometric terms. This gave the researcher a glimpse of the multitude of challenges that face learners of Mathematics, and Geometry in particular, when attempting to study it in their second language.

5.4 Limitations of the Study

This study came about as a result of the MTEP programme being launched by the FRF Mathematics Chair at Rhodes University in the Eastern Cape. As the MTEP teachers had spent much time catching up lost or untaught concepts to the learners, they were left with little time to implement the new concepts in teaching that had emanated from their contact sessions. The Catch-Up Programme was thus launched, which sought to place selected Mathematics teachers in participating schools in afternoon sessions to spend time catching up the lost and untaught concepts. I was the Catch-Up teacher in two of these schools.

As a relationship of trust and mutual respect was required between the learner and the teacher in order to maximize the impact of the SSAT instrument, only the learners from the two schools at which I taught formed the case study, which meant that the study was limited to 35 learners initially, but which was later reduced to 30 learners.

Another limitation was that the SSAT test was only implemented in one part of the Eastern Cape, which makes extrapolation of the results to national level unreasonable, despite evidence of the same problems being nationwide. A sample study would ideally have to be implemented in each of the nine provinces in order to lend the findings more weight.

A third limitation was that both schools are peri-urban schools in previously disadvantaged communities. This may impact further on their understanding of their second language, as they may not all have access to media, social media or libraries which could aid their linguistic development.

5.5 Recommendations

The task of improving Mathematics performance in general, and specifically achievement in Geometry, is daunting. However, there is much that can be done which will ultimately impact positively on the general attitude towards Mathematics, as well as achievement in Mathematics.

An enormous challenge which we face is that many of our Mathematics teachers in South Africa have received less than adequate training in the field of Mathematics education. However, due to a shortage of qualified Mathematics teachers, they are obliged to teach the subject. In my experience there is little or no support for them from the Department of Education and in my interactions with teachers, many of them feel overwhelmed by the challenges they face when trying to teach the subject. Further, in my experience, the in-service training of the DoE, when it does take place, is less than satisfactory and does not tackle the challenges that these teachers face on a daily basis. Instead, it usually takes the format of a lecture, with very little or no interaction with the material. That is why I believe the MTEP programme hosted by the FRF Mathematics Chair of the Education Department of Rhodes University was ground-breaking and effective. Mathematics was taught conceptually and not procedurally and a constructive approach was adopted at all times. The feedback from the teachers (CoPF Report, 2014) was overwhelmingly one of empowerment and understanding on a far deeper level than before. It is this type of programme that needs to be rolled out for our teachers across the country.

Teacher confidence is an essential tool in equipping learners with the appropriate skills for achieving in Mathematics. Many teachers are under- or not qualified (Mji & Makgato, 2006) and those who are perhaps teaching Mathematics in their second or third language, will often adhere rigidly to the textbook for fear of making errors or being misunderstood, as they lack the confidence to develop their own lessons. The text books themselves focus too little attention on the importance of learners doing hands on activities, thereby constructing their own spatial knowledge. More time and text book space should be dedicated to the development and enhancement of spatial skills, as so many careers in our modern society are based on such skills.

This constructivist approach has had enormous success, particularly in the development of knowledge of 2D shapes and 3D objects (Hill, Corbett & St. Rose, 2010). The learners, by playing, cutting, measuring, rotating, overlapping, drawing and comparing a range of these shapes and objects, expand and develop their Geometry and spatial schema to the point that a strong foundation is laid for further extension in the learning area. Teachers thus need to feel confident enough to move away from the rigidity of the text book and “onto the carpet” as it were, in order to interact with the learners in experimental play and spatial concept development.

Attention should at all times be paid to using spatial and directional language so that the learners are sensitised to this language at a young age. Directive language, such as closer, further, higher, lower, above and below, away from and towards, etc. should be commonplace in primary school Mathematics lessons so that the subtleties and nuances of the language of Mathematics be diminished as learners become more proficient in their linguistic understanding. By the time the learners enter high school, they would have built up a sound knowledge of important spatial concepts and the relevant language to describe them.

A further recommendation is made in light of the current situation in our secondary schools. Grade eight, nine and ten learners are clearly woefully underequipped to deal with the challenges of the Geometry syllabus is it stands. An intensive intervention is required in order to develop their spatial skills sufficiently. According to Newcombe (2006) spatial cognition is malleable and spatial thinking can be improved by effective technology and education. If both teachers and learners could participate in an after- hours programme such as the Catch-Up programme that specifically targets the development of spatial skills and the appropriate terminology to interpret and describe these skills, their performance in Geometry and the spatial sections of Algebra (such as graphs) could be dramatically improved.

5.6 Avenues for Further Research

The malleability of spatial skills has been mentioned more than once. Authors have also referred to the long term benefits of intensive training programmes to improve these skills (Newcombe, 2006). A natural extension of this study would then be the design and implementation of a

Spatial Skills Enhancement Programme, designed in such a way as to be user friendly, cost effective and easy to implement. It could possibly take the following format:

- An initial assessment of the spatial skills of a learner or group of learners, using the SSAT;
- The implementation of a sustained and intensive after hours programme that consists of a series of hands-on activities such as construction blocks, puzzles, tangrams, rubic cubes, brain teasers, maps, Cartesian planes, dolls and Lego pieces. Each item will be linked to several activities which are designed to improve one or more of the spatial skills that are considered essential to success in Mathematics and particularly in Geometry. These are the skills assessed in the SSAT;
- All the necessary items and instructions would form part of a kit, which would be portable so that several teachers in one school could share it;
- The teachers themselves would also need to participate in the programme, in order to enhance their own spatial skills; and
- After the intervention programme of intensive skills enhancement training, the SSAT could be used to re-assess the learners in order to establish the effects of the training programme.

I would recommend that this type of programme be implemented before the learners reach secondary school, or at the latest in their first year of secondary school. If the programme were to be proven successful, funding could be sought for the production of more kits and training on a larger scale.

> "*Spatial literacy is as important a goal as traditional literacy is. We need to invest our resources and efforts accordingly.*"

Newcombe, N. S. (2006) A Plea for Spatial Literacy.
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5.7 Personal Reflection

When I embarked on this journey at the beginning of 2013, I had no idea what a Masters study entailed. When encouraged to read as much as I could about my chosen theme, the realisation dawned on me that this adventure was not only far bigger than anticipated, but would also be a life changing experience.

The most difficult challenge for me was not all the reading, which I thoroughly enjoyed, but writing the very first sentence. I kept all the initial drafts of my proposal and when I look at them now, I appreciate how far I have come on this journey.

None of this would have been possible, of course, if it were not for Professor Marc Schäfer. He is a remarkable educator and his insight and tremendous support were invaluable.

5.8 Conclusion

This final chapter contained a brief summary of the findings of my research. This was followed by what I deem to be significant about this study and also a few limitations of the study. My recommendations are then made and possible avenues for further research are entertained. I conclude with my personal reflections.

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APPENDICES

APPENDIX 1: LETTERS OF PERMISSION FROM SCHOOL PRINCIPALS

APPENDIX 2: DATA FROM BENCH MARK TESTING 2011 – 2014

APPENDIX 3: SSAT TEST

Appendix 1: Letters of permission from school Principals

19 Somerset Street
Grahamstown
6140
02 October 2013

Attention: The Principal
[redacted]

Dear [redacted]

Re: Request to conduct research for completion of Masters thesis in Mathematics Education

The main thrust of the FRF Mathematics Chair has been the MTEP (Mathematics Teacher Enrichment Programme) in which teachers from participating schools attend Mathematics contact sessions which are conceptual in nature as opposed to curriculum-driven. This programme is proving to be most beneficial and greatly enjoyed by all those who attend the sessions. However, a drawback has been that the teachers have had little time to implement their newly acquired skills in the classroom as they spend so much time trying to catch up the Mathematics backlog which seems to be present in many schools.

In order to counter this problem, the Catch-Up programme was initiated in 2011, whereby Mathematics teachers offer their services to the learners of participating schools in an after hours programme, in order to identify backlogs and try to catch up accordingly. In order to establish which aspects of the curriculum are more problematic and whether the catch-up programme is impacting on the backlog at all, learners from participating schools are required to write bench mark tests at the beginning and at the end of each year. These bench mark tests have revealed that the backlog stretches across all sections of the Mathematics syllabus, but also that some sections, such as Geometry, are noticeably weaker than others. The weakest sections in all the bench mark tests are those which are spatial in nature.

It was therefore decided that for my Masters thesis, I would design and administer an instrument which would reveal more about the spatial skills that the learners demonstrate when attempting to solve Geometry problems. The results of this test would then give us guidelines for future remediation strategies when teaching Geometry.

As I have been involved in the Catch-Up programme at [redacted] for the past three years and I am familiar with both the staff and learners there, I humbly request your permission to conduct my research with the current Grade 10 learners. This research will be conducted after school hours and will take the form of a set of twelve tasks which each learner will complete. The learners will do these tasks individually with me present. Each session will be audio-and videotaped in order to capture all data. I must emphasise that the anonymity of each learner will be safeguarded and no data will be made available to anybody other than me and my supervisors. Learners will not be identified by name and their privacy and wellbeing will be prioritised at all times throughout the test. If a learner does not wish to participate in the research, he or she is free to say so without any consequences whatsoever.

I would be very grateful if you were to agree to my request, as I firmly believe that the results of such research will go some way to clarifying problems that learners face in Geometry. This in turn would allow us to focus on suitable remediation programmes in the future.

I look forward to hearing from you in this regard.

Yours faithfully
Jane Cowley

I, [redacted] the Principal of [redacted]l in [redacted], hereby grant Mrs Jane Cowley permission to conduct her research at requested in the letter of request above.

Signature: ____________________

Date: 09/10/2013

19 Somerset Street
Grahamstown
6140
02 October 2013

Attention: The Principal
[redacted]l
[redacted]

Dear [redacted]

Re: Request to conduct research for completion of Masters thesis in Mathematics Education

The main thrust of the FRF Mathematics Chair has been the MTEP (Mathematics Teacher Enrichment Programme) in which teachers from participating schools attend Mathematics contact sessions which are conceptual in nature as opposed to curriculum-driven. This programme is proving to be most beneficial and greatly enjoyed by all those who attend the sessions. However, a drawback has been that the teachers have had little time to implement their newly acquired skills in the classroom as they spend so much time trying to catch up the Mathematics backlog which seems to be present in many schools.

In order to counter this problem, the Catch-Up programme was initiated in 2011, whereby Mathematics teachers offer their services to the learners of participating schools in an after hours programme, in order to identify backlogs and try to catch up accordingly. In order to establish which aspects of the curriculum are more problematic and whether the catch-up programme is impacting on the backlog at all, learners from participating schools are required to write bench mark tests at the beginning and at the end of each year. These bench mark tests have revealed that the backlog stretches across all sections of the Mathematics syllabus, but also that some sections, such as Geometry, are noticeably weaker than others. The weakest sections in all the bench mark tests are those which are spatial in nature.

It was therefore decided that for my Masters thesis, I would design and administer an instrument which would reveal more about the spatial skills that the learners demonstrate when attempting to solve Geometry problems. The results of this test would then give us guidelines for future remediation strategies when teaching Geometry.

As I have been involved in the Catch-Up programme at [redacted] School for the past two years and I am familiar with both the staff and learners there, I humbly request your permission to conduct my research with the current Grade 10 learners. This research will be conducted after school hours and will take the form of a set of twelve tasks which each learner will complete. The learners will do these tasks individually with me present. Each session will be audio-and videotaped in order to capture all data. I must emphasise that the anonymity of each learner will be safeguarded and no data will be made available to anybody other than me and my supervisors. Learners will not be identified by name and their privacy and wellbeing will be prioritised at all times throughout the test. If a learner does not wish to participate in the research, he or she is free to say so without any consequences whatsoever.

I would be very grateful if you were to agree to my request, as I firmly believe that the results of such research will go some way to clarifying problems that learners face in Geometry. This in turn would allow us to focus on suitable remediation programmes in the future.

I look forward to hearing from you in this regard.

Yours faithfully
Jane Cowley

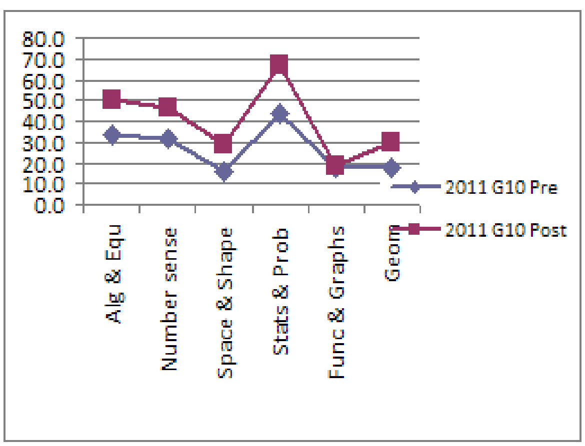
I, [redacted], the Principal of [redacted], hereby grant Mrs Jane Cowley permission to conduct her research at requested in the letter above.

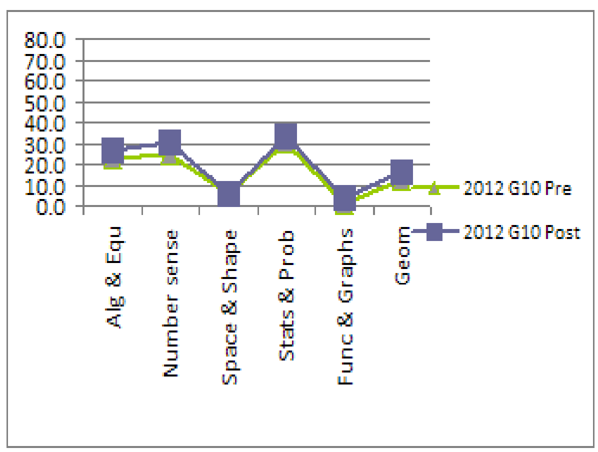
Signature: ______________________

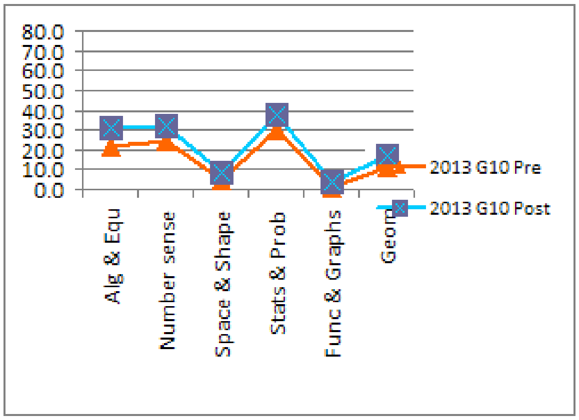
Date: 07/10/2013

APPENDIX 2: Data from bench mark tests 2011 – 2014

	Alg & Equ	Number sense	Space & Shape	Stats & Prob	Func & Graphs	Geom
2011 G10 Pre	33.3	31.5	15.5	44.0	17.9	17.6
2011 G10 Post	50.0	46.5	28.5	66.8	19.0	29.4
2012 G10 Pre	22.5	24.9	5.6	30.6	0.7	12.5
2012 G10 Post	26.5	30.2	5.7	33.8	4.2	16.3
2013 G10 Pre	22.0	24.5	4.6	29.9	1.1	11.6
2013 G10 Post	30.8	32.4	8.9	37.9	3.8	17.2
2014 G10 Pre	16.5	19.1	3.8	27.4	3.1	12.2
2014 G10 Post	23.0	25.0	8.0	30.0	9.0	20.0
Marks per section	**16**	**13**	**13**	**10**	**8**	**10**






80.0
70.0
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Alg & Equ
Number sense
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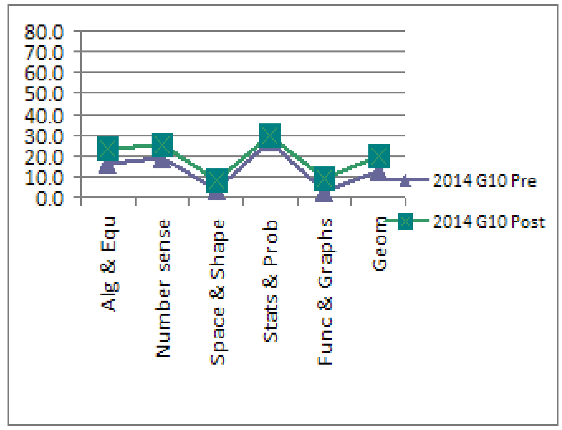
Geom
2013 G10 Pre
2013 G10 Post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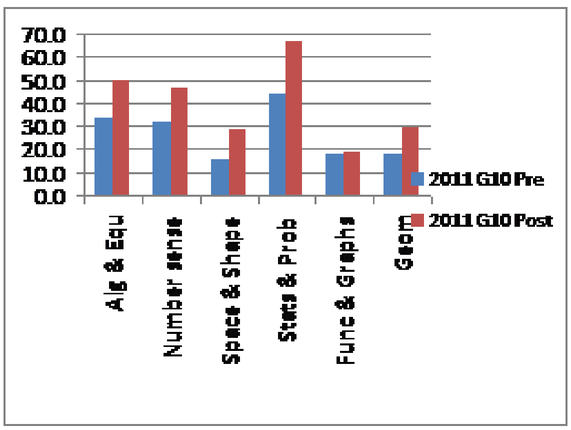
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2011 G10 Pre
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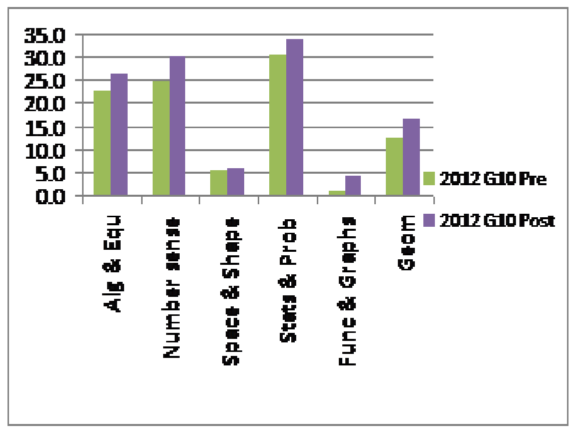
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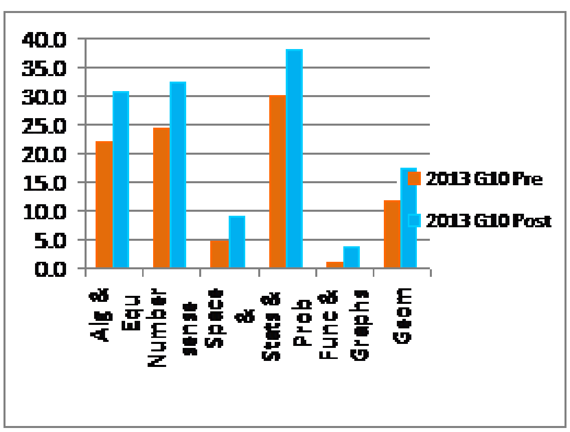
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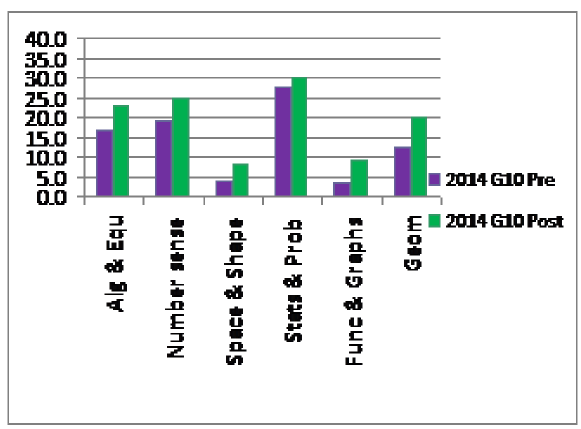
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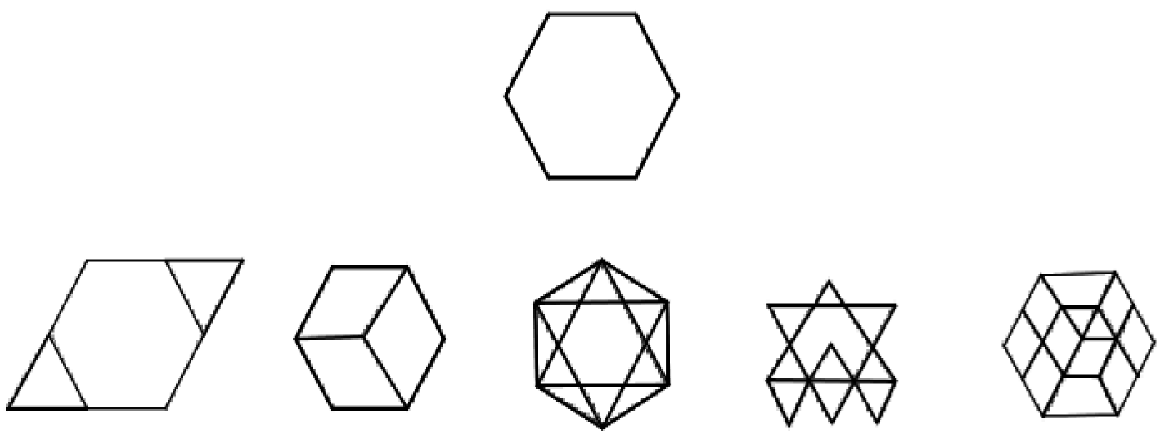
2014 G10 Pre
2014 G10 Post

APPENDIX 3: SSAT Test

Figure -Ground Perception Tasks

Subtask A

In the diagram below, a hexagon is shown.



In which of the five labelled diagrams above can you identify a hexagon?

Answer:

Subtask B

In each of the photographs below, there is a hidden animal. Can you find the animals?

A:

B:

C:

D:

Rubric for Figure-Ground Perception Tasks

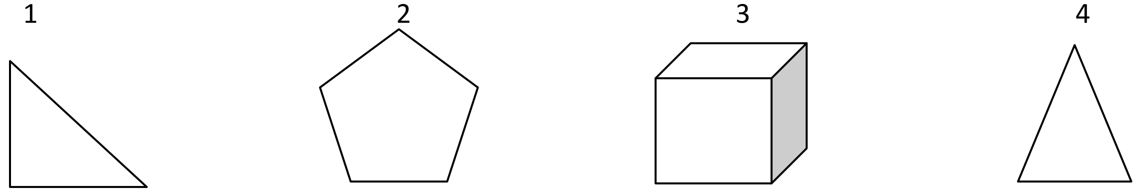
Figure-Ground Perception Task	Unable	Partially Able	Able	Excels
Hexagon subtask	The learner cannot see the hexagon in any of the diagrams and struggles to verbalise his/her thoughts.	The learner can see the hexagon in one or two diagrams, but is distracted by extra features in the diagrams.	The learner sees at least one hexagon in all the diagrams.	The learner is able to see more than one hexagon in some of the diagrams and is able to discuss other features that appear.
Animal Identification subtask	The learner cannot see any animals in the photographs.	The learner can discern one or two of the animals in the photographs.	The learner sees all of the animals in the photographs. He /she is not distracted by the background information.	The learner sees all the animals in the photographs and explains the connection between the two questions by referring to looking for objects that are “hidden” by the background.

Visual Discrimination Tasks

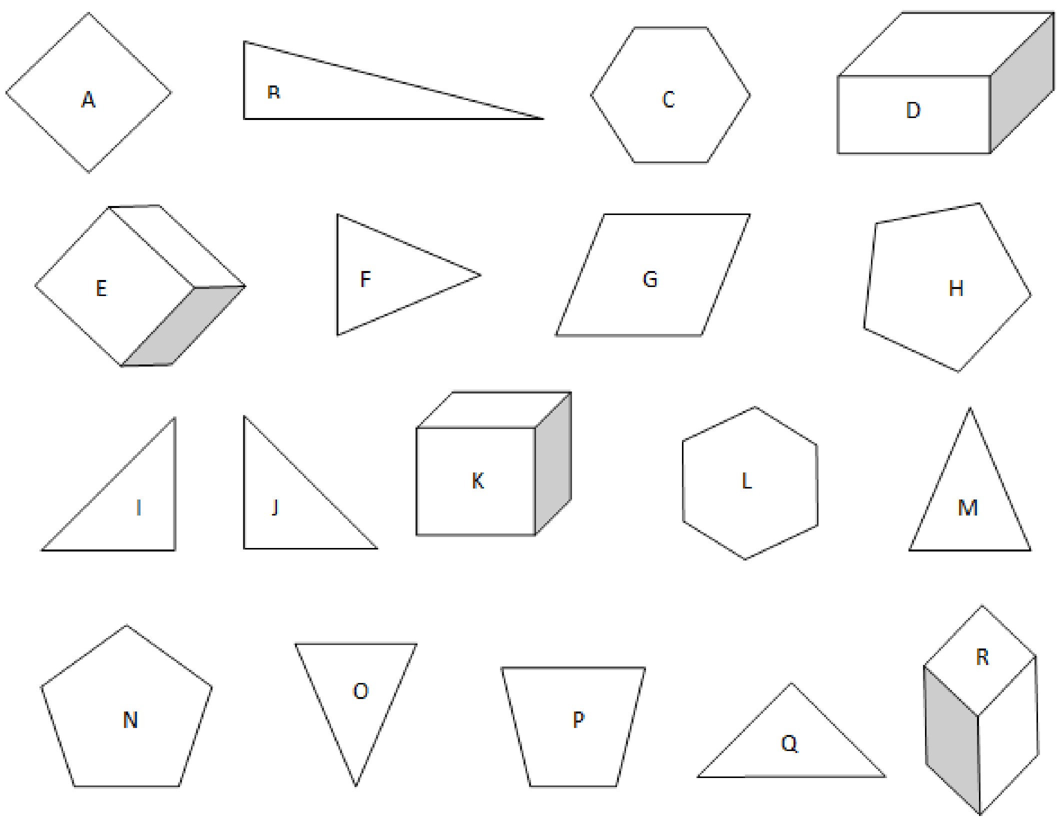
Subtask A

Study the four shapes given below and then complete the table by writing the letter of each shape that is identical (congruent) to shapes 1, 2, 3 and 4.

1 2 3 4

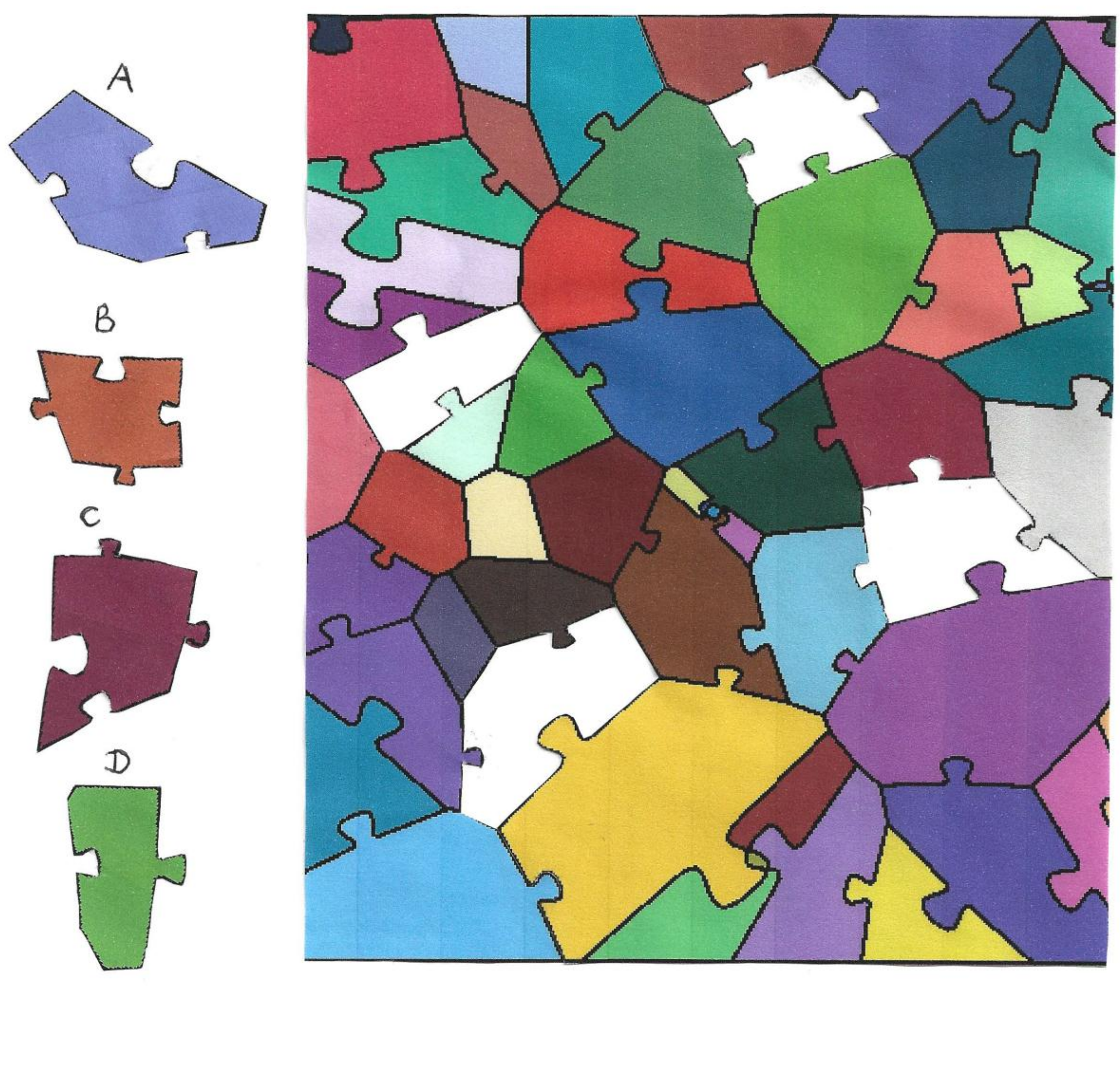


Shape	**Number of Identical (Congruent) Shape**
Shape 1	
Shape 2	
Shape 3	
Shape 4	



Subtask B

In the jigsaw puzzle below, four pieces have been removed from the puzzle. Write the name of each piece (A or B or C or D) in each of the open spaces in the puzzle in order to finish it. If you think that the pieces are not correct for any of the spaces, explain why.



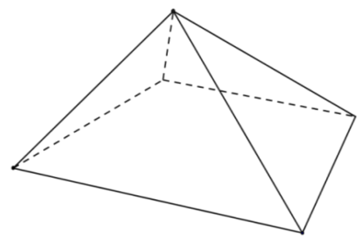
Rubric for Visual Discrimination Tasks

Visual Discrimination Task	Unable	Partially Able	Able	Excels
Congruent Shapes Subtask	The learner is unable to discriminate between the shapes sufficiently and is thus unable to categorise them. He or she cannot verbalise the concept of congruency.	The learner discriminates between some of the shapes, for example those with different numbers of sides, but is unable to differentiate between the triangles.	The learner is able to discriminate between all the different shapes and categorises them correctly.	The learner is able to discriminate easily between all the shapes and can verbalise the concept of congruency with ease.
Puzzle subtask	The learner is not able to discern which puzzle piece should fit into each open space in the puzzle. He / she is not able to retain the shape of the missing piece and find a suitable open space.	The learner is able to fit one or two of the puzzle pieces but struggles to identify which piece will fit into which open space. He or she can give one or two verbal cues as to the process of fitting puzzle pieces.	The learner manages to fit all the missing puzzle pieces into the open spaces of the puzzle. He/she Is mostly able to verbalise the process of looking for clues to fit puzzle pieces into the correct open spaces.	The learner is easily able to fit all the puzzle pieces into their correct spaces. He or she is able to describe how to look for clues within the task in order to complete it.

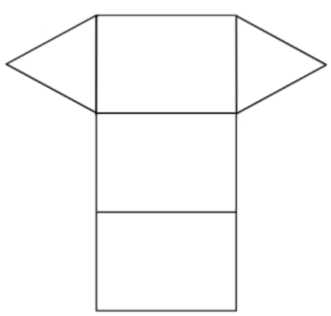
Spatial Visualisation Tasks

Subtask A

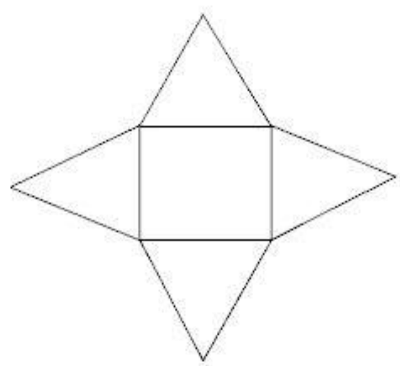
If you unfold this 3D object, what will the net look like?



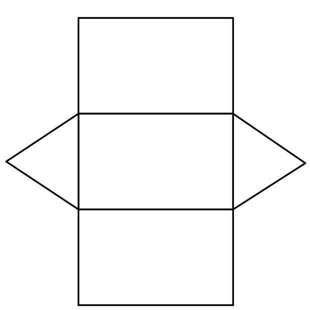
A



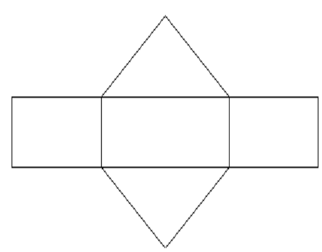
B



C



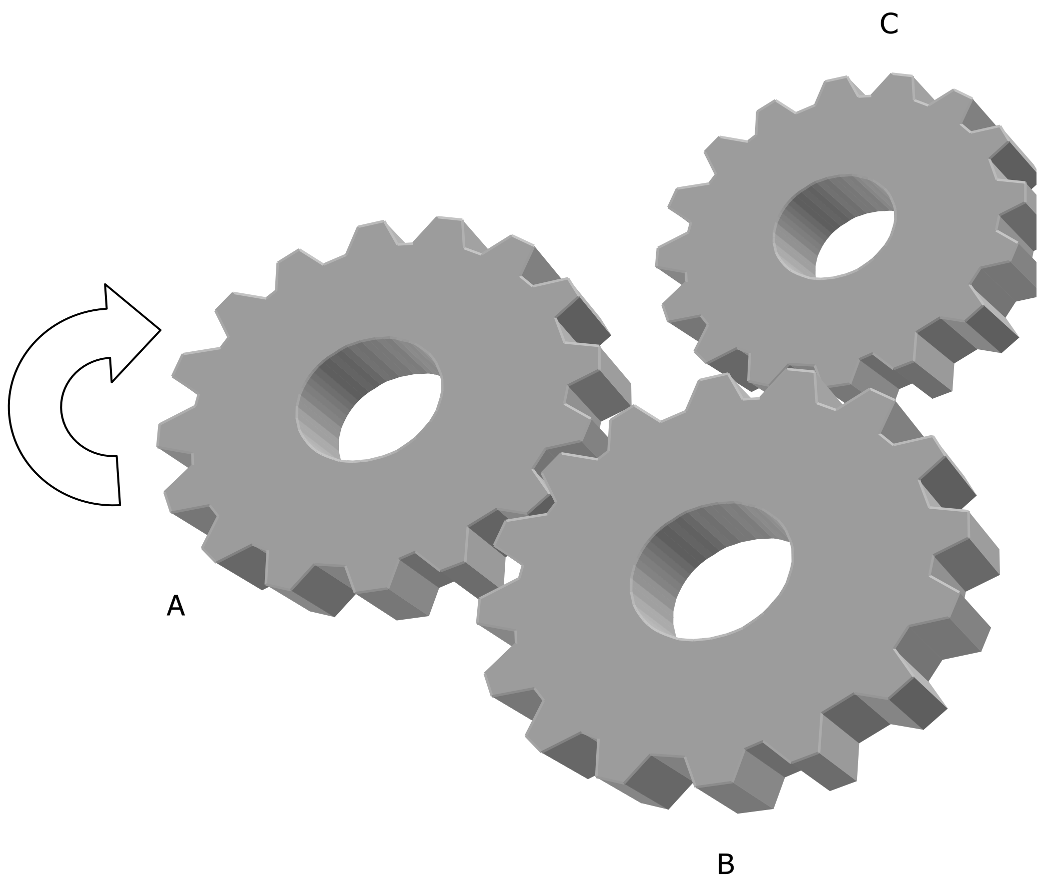
D



Subtask B

If cog A spins in the direction shown by the arrow, which way will cog B and cog C spin?

Explain



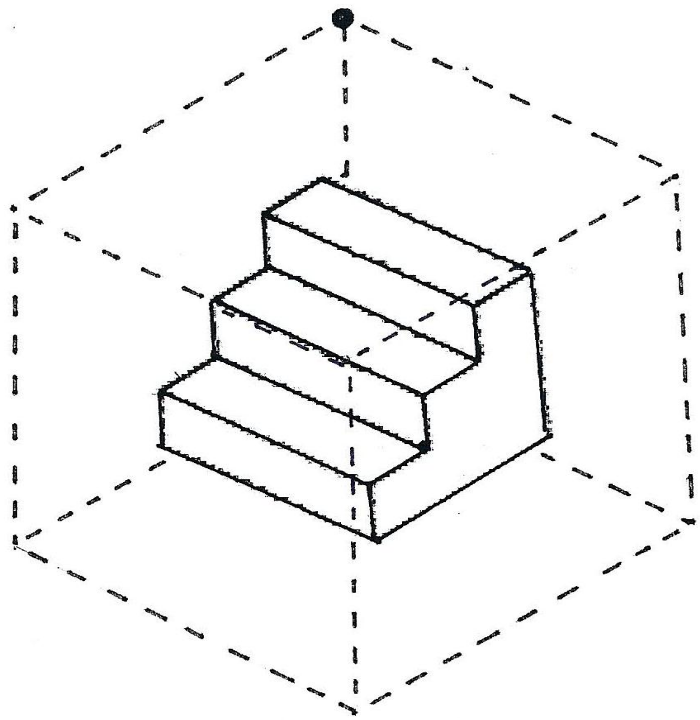
Rubric for Spatial Visualisation Tasks

Spatial Visualisation Task	Unable	Partially Able	Able	Excels
Net Identification subtask	The learner is not familiar with nets of 3D objects and is unable to select an option.	The learner attempts to visualise what the net of the object will look like, but chooses either the wrong option or two different options.	The learner can visualize the correct net for the 3D option with an explanation.	The learner chooses the correct net and can identify that 2 of the other nets will both produce a triangular prism, despite being different in appearance.
Cog movement Subtask	The learner is unable to visualise which way any of the cogs will spin.	The learner visualises that both cogs B and C will spin in the same way, or that all the cogs spin in the same direction.	The learner visualises that cog B will spin anticlockwise and cog C will spin clockwise.	The learner visualises the correct movement of the cogs and can predict the movement of added cogs.

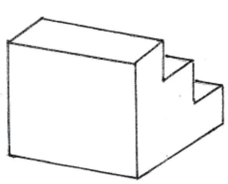
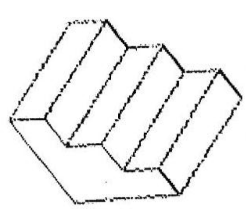
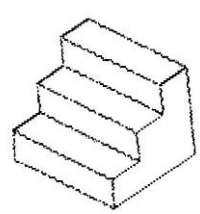
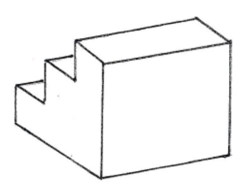
Spatial Orientation Tasks

Subtask A

If you were looking at the stairs from where the black dot is, what would you see? Explain.



A **B** C D

Subtask B

The church in your village has a new stained glass window. If you look at the window from **inside** the church, it looks like this:

If you look at the new window from **outside** the church, will it look like window A, window B or window C, or none of them? Explain your answer.

A

B

C

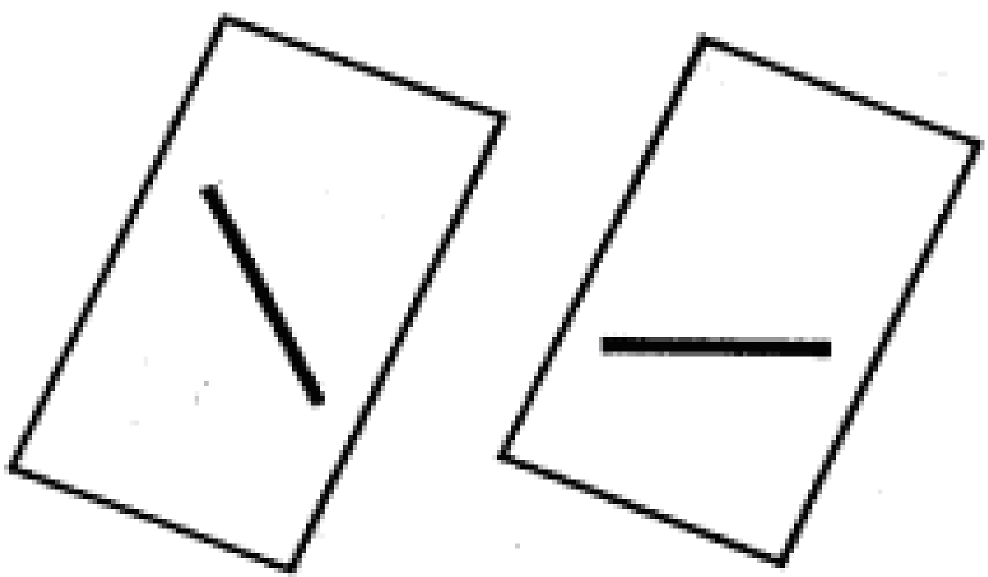
Rubric for Spatial Orientation Tasks

Spatial Orientation Tasks	Unable	Partially Able	Able	Excels
Staircase orientation subtask	The learner is unable to imagine how the stairs would look from another view or angle.	The learner makes an effort to imagine the stairs from another angle, by using words such as “from behind” or “if I walk around the stairs…”, but is confused by the selection of options.	The learner is able to identify the correct orientation of the stairs from the dot.	The learner selects the correct option and is able to explain why the other orientations of the stairs are incorrect.
Church window orientation subtask	The learner is unable to imagine what the window would look like from the outside.	The learner understands that the window’s orientation would have changed, but is not sure which option is correct. The learner may indicate that two options could be correct.	The learner correctly identifies the correct orientation of the window from the outside.	The learner correctly identifies the correct orientation of the window and is able to justify his/her selection.

Spatial Perception Tasks

Subtask A

Cut the two rectangles off the bottom of the page. Cut them out neatly and stick them onto this page so that the lines inside them are vertical.

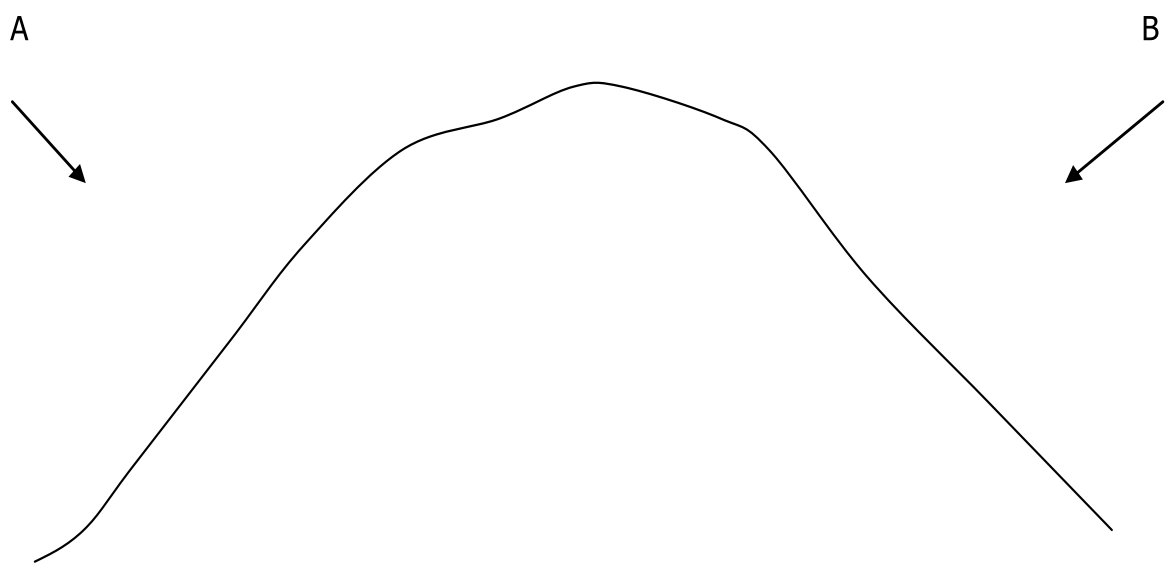


Subtask B

Sipho lives in a house halfway up the mountainside. There is a tree halfway up the other side of the mountain.

Draw Sipho's house where arrow A is pointing.

Draw the tree where arrow B is pointing.



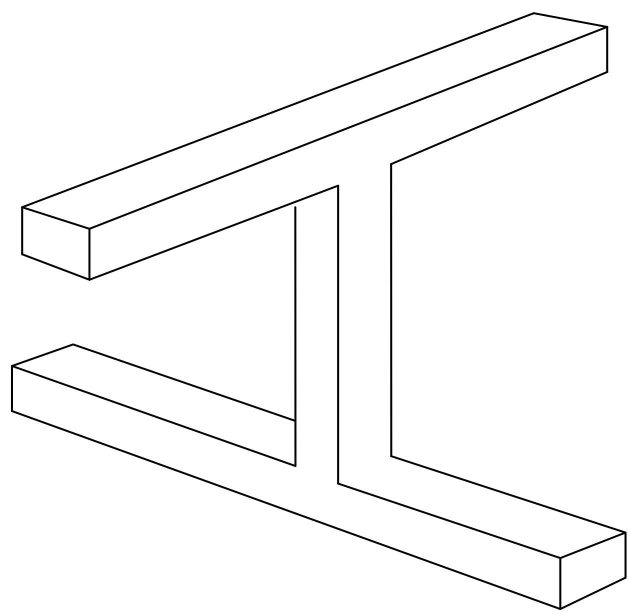
Rubric for Spatial Perception Tasks

Spatial Perception Task	Unable	Partially Able	Able	Excels
Vertical Rectangles subtask	The learner does not understand the concept of vertical and is unable to follow the instructions and complete the task.	The learner places one of the rectangles correctly, but this may be indicative of accurate guess work as the second rectangle is incorrectly placed.	The learner completes the task correctly, with both lines inside the rectangles being in a vertical position. He is able to verbalise the concept of verticality.	The learner completes the task with ease and is able to explain the difference between vertical and horizontal with examples from nature or real life contexts.
Mountain subtask	The learner is either unable to accomplish the task, or draws the house and the tree incorrectly, without demonstrating the concepts of horizontal or vertical to the earth's surface. The house and tree are drawn horizontal and vertical to the mountainside respectively.	The learner is confused by the concepts of horizontal and vertical but successfully draws either the house or the tree correctly with regard to the earth's surface. The second drawing is incorrect.	The learner completes the task successfully by drawing the house horizontal to the earth's surface and the tree vertical to the earth's surface.	The learner completes the drawings successfully and is able to expand on the concepts of verticality and horizontality by giving examples from nature or real life contexts.

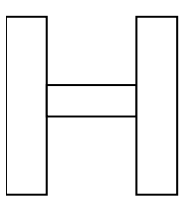
Perspective Tasks

Subtask A

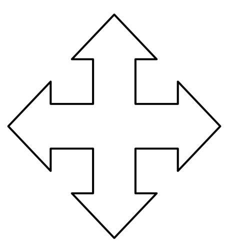
What would the following object look like from directly above? Explain.



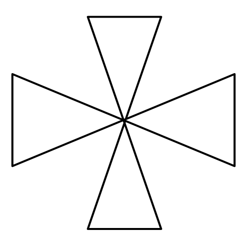
A



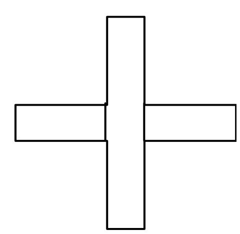
B



C



D



Subtask B

If you look at these items from the opposite side of the table, what will you see? Explain.

A

B

C

D

E

F

Rubric for Perspective Tasks

Perspective Task	Unable	Partially Able	Able	Excels
Geometric Shape subtask	The learner is unable to see that the object is 3D or is unable to see the object from another perspective.	The learner makes an attempt to view the object from a different perspective but is unsure which view option to select.	The learner is able to complete the task and selects the correct view option.	The learner completes the task with ease and is able to verbalise why the other options are not applicable.
Household Items subtask	The learner is unable to imagine the scene from a different perspective.	The learner tries to imagine the scene from the opposite side, but is confused by the differing options.	The learner is able to imagine the scene from the opposite side and selects the correct photo.	The learner completes the task easily and is able to discuss how perspective can change in other real life contexts.