# Learners' conceptual resources for kinematics graphs

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# SUMMARY

Various researchers have indicated the importance of graphs in physical sciences and the difficulties that learners may experience with graphs. More specifically, learners' problems with motion graphs have been reported in literature. Learners' difficulty in the application of basic concepts in graphs to solve kinematics graphs problems leads to underperformance in physical sciences. Their ability to handle problems in kinematics graphs is enhanced if they have an effective knowledge base or conceptual resources on graphs.

In South Africa there seems to be a gap between the GET [General Education and Training] and FET [Further Education and Training] band's requirements on graphs. A smooth learning progression is needed. For this reason this study selected to investigate the conceptual resources acquired by grade 10 learners from grade 9 that can be used productively for the learning of kinematics graphs in grade 10. The primary aim of the study was to determine and analyse grade 10 learners' conceptual resources for learning kinematics graphs in physical sciences.

The use of a mixed method approach was considered appropriate for this study. The mixed method depended on the quantitative method to produce precise and measurable data, while a qualitative method was to enhance the understanding of the data produced by the quantitative method. Data obtained by quantitative methods was drawn into tables and graphs, and the consistency in responses determined. Patterns and trends in learners' reasoning were probed with the aid of qualitative method. In the study it was reported that the quantitative data in the form of a questionnaire was completed by 201 learners. Qualitative data was also obtained by interviewing three learners with varying abilities.

The results showed that many learners could answer mathematics questions, but struggled with similar questions in kinematics. The results further showed that the learners did not answer the questionnaire consistently, but their responses depended on the context of the questions. In the interviews learners used everyday applications to explain scientific concepts, instead of using scientific principles. Still, some of the everyday applications may be used as resources for teaching the science concepts.

From the results it can be deduced that learners' conceptual resources can influence their understanding of kinematics graphs in physics. These resources are gained from everyday experiences and previous learning in mathematics and the natural sciences. A constraint is that many learners do not efficiently integrate their mathematics and physics knowledge.

In the study some learners did not transfer their mathematics knowledge to physics, while others could not transfer their physics knowledge to mathematics.

From the results recommendations can be made for the teaching of graphs in the GET band for easier progress into the FET band. The strategy to improve understanding of kinematics graphs is to progressively integrate mathematics and physics from grade nine. Line graphs should be treated in more detail in grade 9 to form proper conceptual resources for kinematics graphs in grade ten.

**Key terms:** Graphs, kinematics graphs, conceptual resources, learner, resources, learning progressions, integrate, natural sciences and physical sciences.

## OPSOMMING

Verskeie navorsers toon die belangrikheid van grafieke in fisiese wetenskappe en die probleme wat leerders daarmee kan ervaar aan. In die literatuur is daar ook spesifiek gerapporteer oor leerders se probleme met bewegingsgrafieke. Leerderprobleme met toepassings van basiese begrippe in die oplos van bewegingsgrafieke lei tot swak prestasie in fisiese wetenskappe. Leerders se vermoë om probleme oor bewegingsgrafieke op te los word verbeter wanneer daar ‘n effektiewe kennisbasis (konseptuele bronne) van grafieke beskikbaar is.

In Suid-Afrika blyk daar ‘n gaping te wees tussen die vereistes m.b.t. grafieke in die AOO en VOO bande. ‘n Gladde leerprogressie word benodig. Die konseptuele bronne wat graad 10 leerders reeds in graad 9 verkry het en wat produktief gebruik kan word in die leer van bewegingsgrafieke, word dus ondersoek. Die primêre doel van die studie was om graad 10 leerders se konseptuele bronne om bewegingsgrafieke in fisiese wetenskappe te leer, te bepaal en te analiseer.

‘n Benadering waarin daar gemengde metodes gebruik is, is geskik geag vir hierdie studie. Die gemengde metode het die kwantitatiewe metode gebruik om akkurate en meetbare data te verkry, terwyl ‘n kwalitatiewe metode gebruik is om die kwantitatiewe data beter te verstaan. Kwantitatiewe data is in tabelle en grafieke voorgestel en die konsekwentheid van hulle antwoorde is bepaal. Patrone en neigings in leerders se redenasies was ondersoek met behulp van ‘n kwalitatiewe metode. Die kwantitatiewe data wat verkry is uit ‘n vraelys wat deur 201 leerders ingevul is, word in die studie gerapporteer. Kwalitatiewe data was verkry deur onderhoude met drie leerders met verskillende vermoëns te voer.

Die resultate toon dat baie leerders die wiskunde vrae kon beantwoord, maar gesukkel het met soortgelyke vrae in kinematika. Die resultate toon verder aan dat die leerders die vraelys nie konsekwent beantwoord het nie, maar dat hul antwoorde afhanklik was van die konteks van die vrae. In die onderhoude het leerders alledaagse toepassings in plaas van wetenskaplike beginsels gebruik om wetenskaplike begrippe te verduidelik. Sommige van die alledaagse toepassings kan tog wel as bronne vir die onderrig van die wetenskaplike begrippe gebruik word.

Uit die resultate kan afgelei word dat leerders se konseptuele bronne hulle begrip van bewegingsgrafieke in fisika beïnvloed. Hierdie bronne is verkry van alledaagse ervarings en voorafgaande kennis van wiskunde en natuurwetenskappe. Die feit dat baie leerders nie hulle wiskunde en fisika kennis effektief kan integreer nie, is ŉ beperkende faktor. In die studie het sommige leerders nie hul wiskunde kennis na fisika oorgedra nie, terwyl ander nie hulle fisika kennis na wiskunde kon oordra nie.

Die resultate kan gebruik word om aanbevelings oor die onderrig van grafieke in die AOO band te maak en so die voortgang na die VOO band te vergemaklik. Die strategie om begrip van bewegingsgrafieke te verbeter, is om progressief wiskunde en fisika kennis vanaf graad 9 te integreer. In graad 9 moet daar meer aandag aan lyngrafieke geskenk word om bruikbare konseptuele bronne vir bewegingsgrafieke in graad 10 te vorm.

**Sleutelwoorde:** Grafieke, bewegingsgrafieke, begripsbronne, leerder, bronne, leerprogressie, integreer, natuurwetenskappe en fisiese wetenskappe.

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| DoE: | Department of Eduction |
| RNCS: | Revised National Curriculum Statement |
| LP: | Learning progression(s) |
| NSC: | National School Certificate |
| CTA: | Common Tasks for Assesment |
| NWU: | North West University |
| CAPS: | Curriculum Assessment Policy Statement |
| GET: | General Eduation and Training |
| FET: | Further Education and Training |
| SAASTA: | South African Agency for Science and Technology Advancement |
| LO: | Learning Outcome |
| AS: | Assessment Outcome |
| QUAN or quan: | Quantitative |
| QUAL or qual: | Qualitative |
| LOs: | Learning Outcomes |
| ASs: | Assessment Outcomes |
| TUG-K: | Test Understanding Graphs in Kinematics |
| NS: | Natural sciences |
| NS1: | Naturalsciences (physical sciences component) |
| NS2: | Natural sciences (life sciences component) |
| ID: | Identification |
| L1: | Learner one |

# CHAPTER 1

# BACKGROUND OF THE STUDY

## 1.1 INTRODUCTION

The ability to work effectively with graphs is a basic skill and a tool of communication needed by scientists (Beichner, 1994:750). The use of graphs in the laboratory is important for developing understanding of topics in physics (Svec, 1999:1; Cothron, Giese & Rezba, 2006:56-78). Beichner (1994:750) indicated that the ability to use graphs correctly is an important gateway to produce expertise in problem solving in science. To further reflect the importance of graphs McKenzie and Padilla (1986:572) are quoted as follows: ‘‘Line graph construction and interpretation are very important because they are an integral part of experimentation, the heart of science‘’. Construction and interpretation of graphs is a conceptual resource that learners need in order to solve kinematics graph problems.

Hammer (2000:52) argued that for the productive use of learners’ conceptual resources, the learners should use the resources to build an understanding of science concepts and skills. The term *conceptual resources* refer to the rich variety of knowledge and experience that learners use as they interact with the physical world (Redish & Hammer, 2009:630). These resources are elaborated or refined to scientific knowledge. The conceptual resources of graphs identified in this study can be used to build understanding of kinematics graphs.

Duncan and Hmelo-Silver (2009:607) asserted that learning progressions are bounded by an upper and a lower anchor. In this study the knowledge and skills related to graphs required in grade 10 form the upper anchor. The lower anchor is what learners already know about graphs before entering grade 10, i.e. their resources in terms of knowledge and skills acquired until grade 9.

## 1.2 MOTIVATION AND RESEARCH QUESTIONS

Graphs can be found in many of the natural sciences and physical sciences textbooks used in South African schools. It is therefore apparent that learners should develop graphical skills that include amongst others interpretation of data, drawing of graphs and tables, reading from graphs and interpretation of graphs. These skills are important for understanding sciences and analysis of data for research purposes and should be taught to learners who wish to continue with formal education in order to understand graphs. Graphical skills are also essential for everyday life activities since they are commonly found in reports, periodicals and journals. In

South Africa, grade 9 is the first exit level that serves as a gateway to the world. Learners can end their formal education at the end of grade 9 and they should be able to use the knowledge gained at this level to fend for themselves.

The National Senior Certificate (NSC) physical sciences examination paper, which marks the end of formal secondary education and a requirement to pursue higher or tertiary education, includes questions on graphs. The analysis of the NSC physical sciences paper 1 examination written in 2011 revealed the following with regard to performances on graphs in the North-West province (Department of Education and Training, 2011:7-12):

Question 3, a typical kinematics graph question, was poorly answered. The report indicates that learners struggled when it comes to plotting and sketching graphs for a described motion and interpretation of given graphs. Only about 32% of candidates were able to correctly sketch a velocity versus time graph of a camera dropped from a hot-air balloon moving vertically upwards. About 59% of the total population under consideration was able to identify the dependent variable of a given graph. With regard to questions related to interpretation of graphs, only 19% of the learners who wrote the paper could identify coordinates of plotted points on the graph.

Question 9.3 required learners to calculate the gradient of the graph; only 10% could do so. Questions 10 and 11 were also related to graphs and were poorly answered by candidates (Department of Education and Training, 2011:13).

From the analysis of learners' performance as discussed in the paragraph above, it is clear that graphical literacy is lacking even though it is essential for learners to perform well at the end of their secondary school career. Hence studies such as this one are needed to provide valuable information for natural sciences and physical sciences educators in the GET Band (General Education and Training Band) and FET Band (Further Education and Training Band) to improve the understanding, performance and pass rate in physical sciences.

Graphs are an inherent component of the natural sciences and physical sciences curricula in South Africa. The National Curriculum Statement (NCS) for physical sciences grades 10 to 12 considers graphs as an important process skill (Learning Outcome 1) that contributes to the construction and applications of science knowledge (Learning outcome 2) Department of Education, 2003:24). For example, grade 10 learners are expected to seek patterns and trends in data and represent them in different forms, including graphs (Learning Outcome 1, Assessment Standard 2). With regard to Learning Outcome 2, grade 10 physical sciences learners have to describe different types of motion in words, diagrams, graphs and equations. They must also be able to draw and interpret line graphs of motion. Graphical presentation of relationships between different variables form part of the physical sciences curricula from grades 10 to 12 (Department of Education, 2003:19-38).

Learners' knowledge and skills regarding graphs form an integral part of the Common Tasks for Assessment (CTA) of natural sciences in Grade 9. The CTA is an external assessment tool used for all grade 9 learners in South African schools. Knowledge tested in schools includes among others the translation of tabulated data into graphs, reading data off graphs and making predictions from patterns. Examples of some of the statements that led to questions in the CTA's are:

- Drawing bar graph using data from a given table.
- Posing of questions that require direct reading from a graph. For example using a line graph to determine the weight at a given age.
- Using information from the table to calculate concepts like the resistance of the wire in an experiment.

Mathematics that is learnt in the General Education and Training Band (GET) should also contribute to grade 10 physical sciences learners' resources on graphs. Although mathematics in GET also focuses on other types of graphs, line graphs as representations of functions are only introduced in grade 9. One problem that is encountered is that learners struggle with the transfer of knowledge to new contexts (Bransford, Brown, & Cocking, 2000:235-238). In particular, learners do not readily transfer their mathematics knowledge and skills to the physical sciences class (Molefe, 2006:77).

It is clear from the discussions in the paragraphs above that learners in the GET and FET band are expected to apply their graph skills and knowledge in science. In grades 8 and 9 natural sciences textbooks questions are based on the application of graph skills and knowledge, but the way in which they should be acquired is often not explained. A survey of the available resources provided in mathematics and natural sciences textbooks formed part of this study.

According to the constructivist learning theory, learners build their own knowledge structures through experiences and reflection on the experiences (Bransford, Brown, & Cocking, 2000; Vygotsky, 1978). Teachers should help learners to construct knowledge by providing a conducive environment for learning. Teachers should provide learners the tools such as problem-solving, inquiry-based activities with which to formulate and test their ideas, draw conclusions, inferences and transfer their knowledge to new contexts.

The two constructivist principles of the NCS (National Curriculum Statement) that are of importance for curricula are the principles of learning progression and knowledge integration

(Department of Education, 2003:3). The NCS for physical sciences explains that the integration of knowledge and skills is vital for the attainment of applied competencies because knowledge and skills have to be integrated in everyday life and in careers. Physical sciences must contribute towards promoting an integrated learning of theory, practice and thinking (Department of Education, 2003:3). Learners' ability to integrate their resources formed part of this study.

According to the principle of learning progression (Department of Education, 2003:3), the ability to construct and interpret graphs in the FET Band physical sciences should build on learners' basic knowledge of reading and using graphs in the GET Band natural sciences. The basic graphical skills are learnt in the GET band, the focus is on types of graphs other than line graphs (e.g. bar graphs, circle graphs and histograms).

For effective progression towards an understanding of kinematics graphs in the physical sciences in grade 10, it is therefore necessary to investigate what the learners already know from their studies of natural sciences and mathematics in the GET Band. In this way they can be guided progressively to an understanding of graphs in the FET Band while attention is given to the problems they may encounter.

At the start of the FET band, learners have to work with motion graphs with no or little background knowledge on line graphs. Kinematics graphs, treated in grade 10 physics, are usually portrayed as difficult by learners (McDermott, Rosenquist & van Zee, 1987:504). In their work with a sixth-grade class involved in graphing using explorations related to motion, DiSessa, Hammer, Sherin & Kolpakowski (1991:157) found that one of the problems learners faced was that although learners can do graphing, they do not understand the principles and the use of the graphs. It is important to note what learners' difficulties with motion graphs have been reported in literature (e.g. McDermott, *et al.,* 1987:504; Molefe, Lemmer & Smit, 2005).

According to Beichner (1994:751) learners' difficulty in application of basic concepts in graphs to solve problems leads to difficulty in understanding concepts such as the gradient of kinematics graphs. Their learning problems are enhanced if they do not have an effective knowledge base (or resources) on graphs. Most learners find graphs, especially line graphs, difficult to draw and interpret (Gazer, 2011:195-201). In a study of South African physical sciences learners' mathematics procedural and conceptual knowledge, Molefe (2006:68) found that the section on *Interpretation and application of graphs* had the lowest overall performance. This can be attributed to the fact that the comprehension of kinematics graphs is influenced by learners' prior knowledge and familiarity of graph concepts. The progression of graph concepts from GET Band to FET Band should have a positive effect on understanding of kinematics graphs.

Given the importance of graphs in physics, the difficulties that learners may experience with graphs, the gap that seems to exist between the GET and FET Band's requirements on graphs and the need for learning progression, the primary research question of the study is: What conceptual resources have been obtained in the GET band that can be productively used for the learning of kinematics graphs in grade 10?

The two subsidiary research questions are:

1) Are learners' conceptual resources sufficiently linked and integrated for effective learning of kinematics graphs?

2) How can the learning progression for graphs be enhanced from the GET to the FET band?

## 1.3 AIM, OBJECTIVES AND HYPOTHESIS OF THE STUDY

### 1.3.1 The aim

The primary aim of the study is to determine and analyze learners' conceptual resources for learning kinematics graphs in grade 10 physical sciences.

### 1.3.2 The objectives

The objectives of the study are to:

Identify the conceptual resources related to graphs that grade 10 physical sciences learners have obtained in their studies of natural sciences and mathematics in the GET Band. Statistically analyze the coherence and integration of the learners' resources. Make recommendations for smooth learning progression of graphs from natural sciences in the GET Band to physical sciences in the FET Band.

### 1.3.3 Hypothesis

The hypothesis is as follows: Grade 10 learners have not acquired adequate conceptual resources needed to solve kinematics graph problems. These resources are not coherent, i.e. learners do not apply knowledge consistently in different problems. Learners do not efficiently integrate knowledge from different contexts, e.g. mathematics and physical science. They do not apply their knowledge of graphs from mathematics in physical sciences to enhance their understanding of kinematics graphs.

## 1.4 DELIMITATION

The area of study was restricted to grade 10 learners who take physical sciences as a subject in the Potchefstroom town of Tlokwe Area Office in the North West province of South Africa. Seven schools in the identified area were used in the study, of which one was used for the pilot study. The financial implications and distance made it impossible to include more schools. Since the learners were from different cultures and from different places in the country, the results gave a good indication of South African grade 10 learners' conceptual resources for learning kinematics graphs.

## 1.5 THE IMPORTANCE OF THE STUDY

As alluded to in the introductory paragraphs, graphical literacy should be one of the priorities in schools and should be taught in the GET band. Learners' prior knowledge should be identified and build upon. This research study may add some impetus in identifying the conceptual resources that can assist educators to guide learners to develop graphical literacy skills. The resource is then progressively developed into scientific skills that can be used to solve kinematics graph related problems so that learners in grade 12 can handle questions related to graphs with ease.

The way in which teachers assist learners to progress in graph work from a lower to the upper level (Friel, Curio & Bright, 2001:143) is important. The teacher should understand the concepts that the learners possess before exposure to new knowledge and this study can assist in this regard. The study provides a framework that educators could use to better understand and predict many of their learners' resources and difficulties in graphs.

The results have value for the science learners of the participating schools. The knowledge gained through the study enhances the learning and teaching of physical sciences at the schools. McDermott *et al.* (1987:513) concluded by saying "literacy in graphical representation often do not develop spontaneously and therefore intervention in the form of direct instruction is needed". Understanding learners' resources can assist in the design and implementation of effective instruction in kinematics graphs.

## 1.6 METHOD AND DESIGN OF THE RESEARCH

The study commenced with a literature review in order to obtain an understanding of relevant research findings with regard to learning requirements and problems related to kinematics graphs. Study material was obtained from the following:

- Grade 9 and 10 Natural Sciences, Physical Sciences and Mathematics textbooks that were used in South African schools at the time the empirical study was conducted.
- Available databases of the Ferdinand Postma Library (North-West University Potchefstroom campus), e.g. JSTOR.
- Current publications on the subject of study in scientific and educational journals (local and international).

Mixed method design was used in the study. This included the use of quantitative and qualitative techniques to collect and analyze the data. Whereas qualitative research generates rich, detailed data that contribute to in-depth understanding and description of the context, quantitative research reaffirms the objectivity and reliability of the study (Leedy & Ormrod, 2010:96).

Qualitative research was used because the study focused on a natural setting (Grade 10 classrooms) that should help to identify and describe the existing learning resources and problems with reference to graphs (Leedy & Ormrod, 2010:97,135-137). In qualitative research, several methods could be used to collect data. These include interviewing, direct observation, documents, use of personal experience and use of visual materials (Denzin and Lincoln, 2008:34), but in this study interviewing was applied.

The quantitative research design of this study can be characterized as descriptive. A descriptive research design involves identifying the characteristics of an observed phenomenon or survey and possible correlation among phenomena (Leedy & Ormrod, 2010:182). The purpose for using a descriptive research design was to determine grade 9 learners' conceptual resources and the extent of coherence and integration of the resources.

The research instrument used was a questionnaire that was compiled, validated and the data processed with the aid of the Statistical Consultation Services at the North-West University. 201 learners participated in responding to the questionnaire (Appendix A). The response to the questions was coded and attached (Appendix E). Three learners with different abilities were selected for interviews based on the results of the questionnaire. They were interviewed in the comfort of their homes. The researcher conducted interviews and processed the data under the guidance of the study supervisor.

This study forms part of the project ''Design research in Physical Sciences Education'' with ethical clearance application number: NWU-00017-10-52. Permission for this survey was requested from the North West Department of Education (Appendix B). This was followed by a request for approval from the Principals of the participating schools (Appendix C) to use the learners for the study. Consent was obtained from the learners (Appendix D). Request for permission written by researcher (Appendix F).

The identity of the selected schools and learners who participated in the study will remain confidential. The names of the learners were not mentioned in the research results. The participants were not subjected to any risks. Instead, the research led to knowledge acquisition and improvement in their academic performance.

## 1.7 TERMINOLOGY

The key words used are: graphs, kinematics graphs, and conceptual resources, learner, resources, learning progression, knowledge integration, natural sciences and physical sciences. In this study secondary school and high school refer to a school that has grades 8 to 12 learners.
Teachers and educators are used interchangeably, as well as learners and students.

## 1.8 STUDY OUTLINE

The study consists of seven chapters. Chapter 1 provides the study background, introduction, the research questions, and hypotheses, aim, objectives and delimitation of the study.

Chapter 2 gives a review of literature on learning, constructivism, conceptual change, conceptual resources and learning progressions.

Chapter 3 deals with literature review of graphs in natural sciences, physical sciences and mathematics as conceptual resources for learning kinematics graphs. The chapter includes the importance, types, and features of graphs.

Chapter 4 provides a comparative analysis of graphs in South African secondary school textbooks. The limitations and influence of textbooks on conceptual resources for comprehending kinematic graphs were identified.

Chapter 5 describes the research design and methodology. It consists of the approach and methodology employed as part of the project. The strategies and the instruments used to collect and analyzed the data are highlighted in this chapter. Particular problems encountered in the course of the research are highlighted. The method used for sampling the population is also addressed in this chapter.

Chapter 6 deals with the results and discussion of the research results. The results were presented and discussed within the context of the research objectives. This chapter provides the results and analysis of the empirical study.

Chapter 7 highlights the conclusion and recommendations made from the research.

# CHAPTER 2

# LITERATURE REVIEW ON LEARNING, CONSTRUCTIVIST LEARNING, ALTERNATIVE CONCEPTIONS, CONCEPTUAL RESOURCES, AND LEARNING PROGRESSION

## 2.1 INTRODUCTION

Learners' quest to learn is met with many challenges while challenges faced by educators are how to relate and build on learners' existing knowledge, selecting the pathway in which instruction and assessment should follow. These challenges can be overcome by the utilization of learners' existing conceptual resources. According to Hornby (2006:894) learning is the gain of knowledge or skill by studying, from experience, and from being taught. Learning involves progression, that is the pathway along which instruction and assessment is expected to proceed (Heritage, Kim, Vendlinski, & Herman 2009:30).

Hence this chapter starts with a literature survey of learning (see paragraph 2.2) and the constructivist learning theory (paragraph 2.3). This is followed by a discussion of ways to deal with learners' conceptual problems that enhance the learning of physics, namely alternative conceptions and conceptual change (paragraph 2.4) and learners' conceptual and epistemological resources (paragraph 2.5). Finally attention is paid to definition and importance of learning progressions (paragraph 2.6) and approaches to learning progressions (paragraph 2.7). The chapter ends with a summary (paragraph 2.8).

## 2.2 LEARNING

Learning is defined as an act of gaining knowledge (Hornby, 2006:894). From the constructivist perspective, learning involves activities that lead to learners constructing their own theories, by building on their prior knowledge (Driver, Asoko, Leach, Mortimer & Scott; 1994:6, Bybee, Powell & Trowbridge, 2008:4). This statement is in agreement with the theoretical framework that states that learners construct new ideas or concepts based upon existing knowledge (Bruner, 1969). Learners relate well to learning when they are given the opportunity to construct their own theories and ideas through constructive scientific activities guided by their prior knowledge. That means activities developed from learners' existing knowledge can lead to effective, long lasting learning.

Vakalisa (2004:5); Barkley, Cross and Major*,* (2005:12) contend that learning involves interpretation of new knowledge, which is guided by existing knowledge, that is, resources that the learners have and bring to the class. They further indicate that such new knowledge should be connected to the learners' prior knowledge in a creative and flexible manner.

Even though learning takes place when learners take responsibility of their own learning and construct new understanding based on their previous experience (Georghiades, 2000:120), learning and mastering of science needs the assistance and guidance of adults or others (Vygotsky, 1978:86). This is confirmed by Driver *et al.* (1994:6) namely that learners cannot discover new knowledge through their own empirical enquiry. In addition learners should be engaged in social interactive activities about the problems or tasks in order to construct scientific understanding of concepts.

Learners come to the classroom with their own concepts, theories and ideas, which should be skillfully integrated with the new concepts to achieve effective learning (Driver *et al*., 1994:9). However, Smith, Wiser, Anderson, and Krajcik (2006:2), claim that many scientific ideas are not comprehensible to learners with reference to their existing ideas and concepts. Smith *et al*. (2006:3-6) continue to argue that difficulties learners have in understanding science is due to the inability to restructure their existing ideas. They maintain that learning requires restructuring of existing knowledge, which is difficult to do. Still, Redish and Hammer (2009:630) argues that learners have a rich variety of knowledge and experience that could be used to develop and be refined towards learning science conceptions.

Wilson and Scalise (2006:648) defined learning as conceptualized progress towards higher levels of competence as new knowledge is related to existing restructured knowledge and a deeper understanding is developed which takes the place of earlier understandings. On the other hand, Ranson, Martin, Nixon and Mckeown (1996:12-13) define learning as a process of discovery that produces new understanding, this leads to changes in existing understanding to act as a basis for elaboration of knowledge.

Linking existing knowledge and understanding with new knowledge and understanding, fosters a meaningful progressive understanding. In this way learning kinematics graphs should follow a meaningful sequential route, which will make learning kinematics graphs easier. Learners should be provided with encouraging environment that enables them to relate existing knowledge to new knowledge as well as modifying the existing understanding of concepts with the new knowledge as suggested by (Ranson *et al.,* 1996:11-24). Learning can take place when learners discover new concepts and can modify and develop earlier existing knowledge or ideas into a much deeper and complex understanding.

## 2.3 CONSTRUCTIVIST LEARNING THEORY

There are different theories on learning, one of these is constructivism. According to Barkley *et al.* (2005:28) constructivism is a learning philosophy that asserts that learners construct their own understanding of new ideas. Constructivism is a modern learning theory that is based on several premises (Novodvorsky, 1997:242). The first premise states that learners' construct knowledge in their mind, the second premise states that students bring their previous knowledge and experience into the classroom and the third premise is that learning is a lifetime process. Learning is not limited to a specific phase or stage in the individuals' life, but an incessant process that does not take place in stages. The main point here is that learning is a continuous process that takes place in the mind of an individual.

The constructivist philosophy views learning as a building up of knowledge and concepts constructed by the learner (Driver *et al.*, 1994:5; Barkley *et al.,* 2005:28) as oppose to the view of transferring knowledge from one person (the teacher) to the other (learner). The latter view means the teacher as the active participant and the learner the dormant receiver in the learning and teaching process. Abbott (2002:13) ascertains that a model of learning that will produce expertise is to give learners, especially the younger ones, more help and direction whereas Duffy and Cunningham (1996:2-10) emphasize that learners should construct their own understanding of new knowledge.

Jacobs (2004:46) explains constructivist theory with emphasis on learners' active involvement in acquiring and constructing their own knowledge. Still, learners should be assisted to construct meaningful l knowledge that can be useful in their own lives.

The viewing of science as a process that requires learners to critically and skilfully find solutions to problems, active learning however encompasses problem-based learning. Bruner's theories emphasize the significance of classifying learning. Hence learning under the constructivist premise has been categorized in this study under the following sub headings: problem-based learning, inquiry-based learning, cooperative learning/ collaborative learning, discovery learning and active learning.

### 2.3.1 Problem-based learning

Problem-based learning is a constructivist theory in the sense that learners participate actively in constructing their own knowledge. Learning initiated by creating real-world problems that are used to motivate learners to identify concepts, theories, and principles, needed to solve the problem is associated with problem–based learning (Duch, Groh & Allen, 2001:6). In support of this principle, Barkley (2005:169) states that, providing learners with challenging, solvable problems is an important motivating strategy.

The problem-base approach addresses desirable outcomes such as the ability to demonstrate effective communication skills, think critically and work effectively in groups (Duch *et al.,* 2001:7). These outcomes are in accordance with the natural sciences and physical sciences learning outcomes of the South African Curriculum (Department of Education, 2002b; Department of Education, 2003:12-15).

According to Overton (2003:259) problem-based learning is well established in many science-based disciplines such as medical education, and engineering because of the under listed benefits:

- Produces better –motivated learners.
- Develops a deeper understanding of the subject.
- Encourages independent and collaborative learning.
- Develops higher order cognitive skills.
- Develops a range of skills including problem-solving, group work, critical analysis and communication.
- Provides information on how to proceed with inquiry into a problem.

### 2.3.2 Inquiry-based learning

Liberman (2009:22) mentioned that inquiry–based learning is a form of constructivist approach. It characterizes different cultures and encourages learners to develop their own personal meaning with an open mind. Inquiry-based learning involves students questioning, investigating, verifying and producing new questions not in a linear way but more of a circular, intertwined approach which reveals the truth and principles of a lesson (Svinicki & McKeachie, 2000:282; Liberman, 2009:22-23).

Inquiry-base teaching and learning of science involve active construction of meaning. Staten (1998:28) study reveals that learners who were given the opportunity to create their own meaning using questions in between assisted them to build their own circuits. After the learners have built their own and shared with the teacher and the class how they did it, the teacher then explains and show learners how to build the circuit. The teacher explains and gives correct explanations to their inaccuracies and misconceptions.

According to Liberman (2009:55) ''our philosophy of what learning should accomplish determines our methodology''. If we really consider that education should teach our children how to reflect and formulate their own conclusion while exposing them to things they might not know existed, then we have to think about the efficiency of constructivist inquiry-teaching. Liberman (2009:22) confirms by saying ''constructivists believe that the purpose of education is to let students discover their own truth whereas inquiry-based teaching is based on the belief that truth is absolute''.

As learners try to find meaning through inquiry they should be able to work cooperatively with other members of the class.

### 2.3.3 Cooperative learning / Collaborative learning

There are two schools of thought for cooperative and collaborative learning. On the one hand one school of thought maintains a clear distinction between cooperative and collaborative learning. The other school of thought holds the view that cooperative and collaborative learning have similar meaning and therefore the two terms are interchangeable (Barkley *et al*., 2005:5). However both emphasize the importance of learners working in small groups with the aim of achieving a common objective. In this study cooperative and collaborative learning will be used interchangeably.

In cooperative learning, emphasis is placed on cooperation and therefore interdependence of group members (Gawe, 2004:209). Cooperative learning involves ''promotive interaction'' in which learners encourage the achievement of other members of the group while working on their own achievements in order to accomplish group goals. The learners help each other and ensure that all members of the group understand and learn the same content cooperatively (Gawe, 2004:209) while working together to solve a problem or reach a common goal. Springer, Stanne and Donovan (1999:42) indicated that learners who learn in small groups achieve better academic standards, develop favourable attitude towards learning and excel in SMET (Science, Mathematics, Engineering and Technology courses or subjects). In chapter one of Johnson, D., Johnson, R and Holubec (2008:5-6) states that students benefit more when they work in pairs or small groups than when they work individually. This implies that learners can understand concepts better if they work in small cooperative groups during the process of teaching and learning.

In collaborative and cooperative learning, learners are taught to work with other learners in small groups or pairs (Barkley *et al*., 2005:4) focusing on open-ended tasks (Brufee,1993:1) and creating opportunity for them to learn teamwork skills needed in real life situations (Barkley *et al*., 2005:10). It is intentional, well structured, equal contribution by learners, and finally meaningful learning takes place (Barkley *et al*., 2005:4). As learners work together they should acquire skills and discover new concepts.

### 2.3.4 Discovery learning

Discovery learning is an inquiry-based type of learning theory that takes place in problem solving situations. In this case the learner draws on his or her own prior knowledge and existing knowledge to discover facts and relationships and new concepts to be learned (Bruner, 1969:20-21; Bybee *et al.,* 2008:120). Learners are more likely to remember and understand concepts and knowledge discovered on their own. Svinicki and McKeachie (2011:283) confirms this stance by saying discovery lessons seeks to create knowledge that is owned by the learners due to their active involvement in discovering the knowledge.

The discovery learning is however contrary to the views of Driver *et al*. (1994:6) who claim that learning cannot be discovered through the learners' own empirical enquiry. The ideas of Driver *et al*. (1994) and Bruner (1969) can be combined. That is for effective discovery learning guidance and support should be provided. That is, learning is the active struggling of the learner to find understanding of concepts. This implies that learning takes place when learners discover meaning to issues. Therefore the questions and investigations that guide the discovery process should be relevant to the learner.

### 2.3.5 Active learning

Active learning consists of techniques that present learners with challenges. It gives learners opportunities to discuss the meaning of activities with others and it requires hard work (Silberman, 1996:6-7). Active learning is therefore an umbrella term that refers to several models of instruction that directs the responsibility of learning on a learner as the active participant (Silberman, 1996:7). Cohn, Atlas and Ladner (1994:201) describes active learning, as ''any form of learning in which the learning program has some control over the inputs on which it trains.''

Active learning is the composite of many teaching methods that engage learners in meaningful learning activities involving critical thinking in the classroom (Prince, 2004:1). It emphasizes development of skills and values (Bonwell and Eison, 1991:5-13) which leads to improvement of learners' achievement (Wilke, 2003:218).

Active learning was promoted by authors such as Bonwell and Eison, Ebert-May, Brewer, Allred in the 1990's. Bonwell and Eison (1991:4-7) popularized this approach to instruction. They preached the use of active learning in order to promote effective transfer of learning rather than lecturing.

Wilke (2003:208-220) illustrated the benefits of active learning as promoting effective learning by:

- advancing the view that science is a process and not a set of facts to memorize,
- promoting a belief in the learners' own ability to learn about any subject (self-efficacy),
- shifting the responsibility of learning away from the teacher to the student,
- giving more value to the learning experience because the learner has done the work,
- giving learners' more opportunities to develop confidence.

## 2.4 ALTERNATIVE CONCEPTIONS AND CONCEPTUAL CHANGE

As learners become actively involved in the learning process they make use of their previous concepts. According to Lucariello (2010), learners already have some pre-instructional knowledge about a topic or concepts before they come to class to be taught. What is more, the constructive theory states that the prior knowledge or concepts the learners bring to class, as well as their experience affect the way they construct new knowledge (Grayson, Anderson & Crossely, 2001:611).

### 2.4.1 Alternative conceptions

When preconceptions are consistent with the concepts in the assigned curriculum and in agreement with scientists ideas, learners' preconceptions are called *anchoring conceptions* (Zietsman & Clement, 1997:62). Learning, in such cases, is much easier. It becomes a matter of conceptual growth, enrichment, or adding to learners' knowledge. More often, teachers find themselves teaching concepts that are difficult for their learners to learn because these learners' preconceptions are inconsistent with the concepts being taught. In these cases, preconceptions are termed *alternative conceptions* or misconceptions (Lucariello, 2010:1; Grayson, 2004:1126).

Studies show that learners' previous concepts that affect their understanding can be correct or incorrect, and therefore influence how they learn new scientific knowledge and concepts. The concepts that differ from the scientific meaning are described in different ways by different researchers as misconception, preconceptions, alternative frame works, explanatory systems and alternative conceptions (Grayson, Anderson & Crossley, 2001:613). However, from the learners' point of view these views and concepts are coherent, logical, and important, even though they differ from the accepted scientific explanation (Nakhleh, 1992; Özmen, 2004:148).

Alternative conceptions influence current and future learning, thus making it difficult for learners to acquire the correct knowledge. Lucariello (2010:2) suggested the use of learners' correct conceptions as a bridge between the new concept and the alternative conceptions to overcome the difficulty to learn the new concept. Lucariello (2010:3) further stated that several effective instructional strategies have been identified in achieving conceptual change. For example, teachers have to present new concepts as high-quality and logical instructional strategy. This can then lead to conceptual change.

Grayson (2004:1127) used instructional strategy of concept substitution to address two conceptual difficulties in electric circuits. Conceptual substitution according to Grayson (2004) is a strategy that builds on learners' correct intuitions into useful building blocks to overcome conceptual difficulties and to help them undergo a process of conceptual change.

### 2.4.2 Conceptual change

Georghiades (2000:120) reveals that words like 'knowledge restructuring' and 'principal change', have been used by various authors to define conceptual change but they all carry the implication that learners' conceptual structures are replaced by more complex ones. Georghiades' definition of conceptual change requires the existence of conception A, in order to establish conception B by changing the former. Smith, Blakeslee, and Anderson (1993) define conceptual change as the ''meaningful building of prior knowledge and learning of concepts which involves realigning, reorganizing or replacing learners' prior conceptions to accommodate new ideas''. In order to bring about a conceptual change, the educator has to build upon learners' simple existing knowledge to form complex scientific concepts.

Planinic, Krsnik, Pecina and Susac (2005) contends that learners come to the classroom with conceptual difficulties and for a meaningful learning of physics to become apparent, educators have to assist the learners to overcome these difficulties in order to stimulate conceptual change. Planinic *et al.* (2005) analyzed four techniques that can be used to encourage conceptual change. These techniques were identified as: cognitive conflict, concept substitution, Socratic dialogue, and bridging analogies. Their explanations to these techniques are:

- Cognitive conflict is highly intellectual, can motivate learners and can also cause frustrations.
- Concept substitutions do not support critical thinking and reasoning. It is easier for learners but it is not suitable to all alternative conceptions.
- Socratic dialogue is useful when learners work in groups or pairs. It builds on learners' existing knowledge and promotes reasoning. But it takes too much of the teacher's time and effort.
- Bridging analogies are accepted easily by learners but have no bearing on all the alternative conceptions to bring about a conceptual change.

Heckler and Sayre (2010:768-769) use simple conceptual multiple choice questions for both pre-testing and post-testing to find out how much learners understanding change over a period of instruction. Their findings indicate that topics that seem to relate to one another may interfere with learning, understanding and recall of other topics. They illustrated an example in their study by the use of interference involving vector and scalar quantities in electromagnetism (electric field $E$ and electric potential $V$).

## 2.5 LEARNERS CONCEPTUAL AND EPISTEMOLOGICAL RESOURCES

Learner's resources are the relevant knowledge and strengths that they bring to a learning situation and serves as the foundation on which new knowledge can be built (Hammer, 2000:52-53; Redish & Hammer, 2009).

### 2.5.1 Conceptual resources

The term, conceptual resources, refers to the rich variety of knowledge, reasoning and experience that learners use as they interact and make sense with the physical world (Hammer, 2000:56; Redish & Hammer, 2009:630). Hammer (2000:52) supported the productive use of learners' conceptual resources from which they can build an understanding of science concepts and skills. Hammer also emphasized the need for educators to understand learners' conceptual resources. It is important for educators to understand the resources learners bring to class in order to understand physical phenomenon and concepts, so that instructions will have direct practical benefit.

The resources learners come to class with can be classified as the simple understanding which can be developed step by step into a more complex sophisticated understanding. For effective learning of science these resources should be elaborated or refined to scientific knowledge.

### 2.5.2 Epistemological resources

Epistemological resources is the beliefs and theories that learners' possess about the nature of knowledge and learning which have effect on their understanding of the nature of knowledge and how it is obtained (Hammer, 2000:56; Hammer & Elby, 2003:55-58). Hammer emphasized the importance of epistemological resources students have for understanding knowledge and learning.

Reiner and Gilbert (2000:489) identified three epistemological resources relating to their study on 'thought experiment': conceptual-logical inferences, visual imagery and bodily-motor experience. Integration and analysis of these three epistemological resources gives a broad representation of the learners' ideas (Reiner & Gilbert, 2000:504).

The results of their study indicated that the unconscious process of thought triggers the inner knowledge acquired from the structures and events in our imaginary world; this generates new knowledge.

### 2.5.3 Influence of learners' resources

Nieuwoudt and Beckley (2004:347) state that teachers should take into account the NCS principle of integration. This implies that teachers should guide learners to use their pre knowledge and skills from different learning areas to solve problems connected to scientific concepts.

Friel *et al.* (2001:142) posited the need for a well-thought-out and detailed treatment by educators of what learners need to know, use and understand graphs in various subject areas and across stages or grade levels of schooling. The knowledge, understanding and skills of learners must become deeper and wider over time as they progress from one grade to the next (Department of Education, 2002a:13). In each school phase (or grade) learners have to build upon the knowledge that has been learned in the preceding phase. The learners also have to be prepared for what they will learn in the following phases (or grades).

## 2.6 DEFINITIONS AND IMPORTANCE OF LEARNING PROGRESSIONS

Researchers identified the occurrence of gradual development and understanding of simple to complex scientific concepts as tools called learning progression (LP). Learning progression is a sequence of conceptual understandings that develop from inexperienced ideas and misunderstandings learners bring to the class to scientifically accepted explanations (Duschl, Schweingruber & Shouse, 2007:213-216).

### 2.6.1 Definitions and characteristic of learning progressions

Learning progression has been described and defined by many different researchers. Wilson and Bertenthal (2006:48); Wilson, Zesaguli & Anderson (2006:4) describe Learning progressions as ''descriptions of successively more sophisticated ways of thinking about a topic that can follow one another as children learn about an investigative topic over a broad period of time''. Smith *et al.* (2006:2), Duschl *et al.* (2007:214), Alonzo and Steedle (2008:392), Schwarz, Reiser, Davis, Kenyon, Achér, Fortus, Shwartz, Hug & Krajcik (2009:637), and Salinas (2009:2) highlighted different procedure and content used. Salinas (2009:2) defines LP as "typical successive and interconnected steps in a person's thinking, skills and knowledge that start from simple to complex understandings, advancing toward more sophisticated ways of thinking''.

Stevens, Shin, Delgado, Krajcik and Pellegrino (2007:9) defined LP as ''strategic development of understanding isolated knowledge and forming connections between ideas related to core scientific concept''. Duschl *et al*. (2007:214) see LP as a ''sophisticated ways of thinking about a topic that follow one another successively as children learn a topic over a broad span of time.'' While some researchers like Smith *et al*. (2006:2) see LP as ways of reasoning based on conceptual changes of the research content, other researchers like Stevens *et al.* (2007:3-4) base their definition on the topics of instruction in the classroom.

Hence there are varying and similar definitions in literature regarding LP in the context of curriculum, others within the school, or grades or within a topic. Duncan and Hmelo-Silver (2009:606-607) pointed out that most researchers agree to the following commonalities among researchers of progression:

- Progression is over larger time units (time frame).
- Progression is deepening of ideas and level of sophistication (conceptual framework).
- Progression is change in terms of what learners can do over time (performances).
- Progression is based on research on student learning (research work).

### 2.6.2 Importance of learning progressions

Learning progression is a very important aspect of teaching and learning. The under listed points are brief summary of the importance of LP. Learning progression provides a coherent path that learning can follow, by building on the understandings learners bring to the classroom (Schwarz *et al.,* 2009:634-654). Learning progression is believed to bridge the gap between curriculums; instruction and assessment which intent to bring about transformation in science education (Duschl et al., 2007:213-214).

Steedle and Shavelson (2009:699) believe that LP has the prospects to improve teaching and learning. In support of that, Smith et al., 2006:6, Corcoran, Morsher and Rogat (2009:9) and Swarat, Light, Drane and Park (2009:2) mentioned the importance of LP with reference to instruction and assessment as stated below:

- LP provides a more understandable basis for setting standards that are related to instruction and are achievable by learners (Corcoran *et al.*, 2009:9).
- LP provide information for designing assessment and curriculum design (Swarat *et al.,* 2009:2) that are aligned with what students need to progress (Corcoran *et al*, 2009:9).
- It informs how learners develop and understand scientific concepts (Smith *et al*., 2006:6).

This information helps LP to improve teaching, learning and assessment. Since teaching situations vary one cannot stick to one approach in developing learning progressions. Just as there are diverse definitions of LP, so are different approaches for developing and assessing learning progressions used by researchers.

## 2.7 APPROACHES TO LEARNING PROGRESSIONS

The teaching approach by Bruner (1966) is still applicable with learning progression of today, in the sense that the level of a concept or skill area becomes more sophisticated each time it is revisited within specific time intervals. Bruner's theory suggests that a learner is capable of producing an intended result successfully when faced with new material if the new material follows a progression through enactive, iconic and symbolic representation. Bruner represented these three modes as follows (Bruner, 1966:11):

- The enactive representation – the action-based
- Iconic representation – the image-based
- Symbolic representation – language-based

Bruner's work also suggests that a learner is capable of learning any material so long as the instruction is organized appropriately even though this is in contrast to the beliefs of Piaget and other stage theorists. Piaget saw the child as constantly creating and recreating his own model of reality, going through different stages of development, achieving mental growth by integrating simpler concepts into higher-level concepts at each stage (Piaget, 1972).

Vygotsky (1978) however identified LP in terms of mental functions when he differentiated between higher and lower mental functions conceiving the lower or elementary mental functions to be those functions that are genetically inherited by natural mental abilities. In contrast, he saw higher mental functions as developing through social interaction. The higher mental function development is socially and culturally influenced.

Wilson and Scalise (2006:648) also saw LP as competency development when they emphasized that ''learning is conceptualized as progress toward higher levels of competence, new knowledge is linked to existing knowledge and deeper understandings are developed''. More intense understanding takes the place of the shallow understandings. This approach can be described as a *substitution reaction.*

Salinas (2009:3) also identified two approaches to learning progressions which are: Escalated and landscape approaches. A discussion on landscape approach followed by escalated approach is elaborated in the next sections (2.7.1 and 2.7.2).

### 2.7.1 Landscape Approach to learning progressions

'Landscape' is a word constructed to describe learning progression (Salinas, 2009:7). A landscape approach presents the relations among different content areas by describing mechanisms that relate to facts and interpretation of the content or skills. These trends and relationships show connections necessary for students to advance to higher levels of learning.

A landscape approach first defines knowledge and skills that learners need to acquire and handle, followed by the identification of supporting resources, support and ideas that will help learners reach the desired level of understanding. The relationship between content and skills are represented progressively. Finally, evidence is gathered to support and monitor the learners' progress (Salinas, 2009:8). The above points describing the landscape approach to learning progression, is in line with the four interrelated guiding principles of Learning progressions (LP) by Hess (2008:3). These principles are listed as follows:

- Available research is used to process and develop LP.

- LP has clear evident binding threads that have coherent important core concepts.
- LP promotes increased understanding from simplicity to complexity.
- A well planned assessment is used for advancement of LP.

The Hess LP guiding principles is demonstrated by Salinas in the form of an iterative process as indicated in the diagram (figure 2.1) below. *Iterative process*, according to Salinas, is a continuous process, which is interrelated and repeated over and over again.

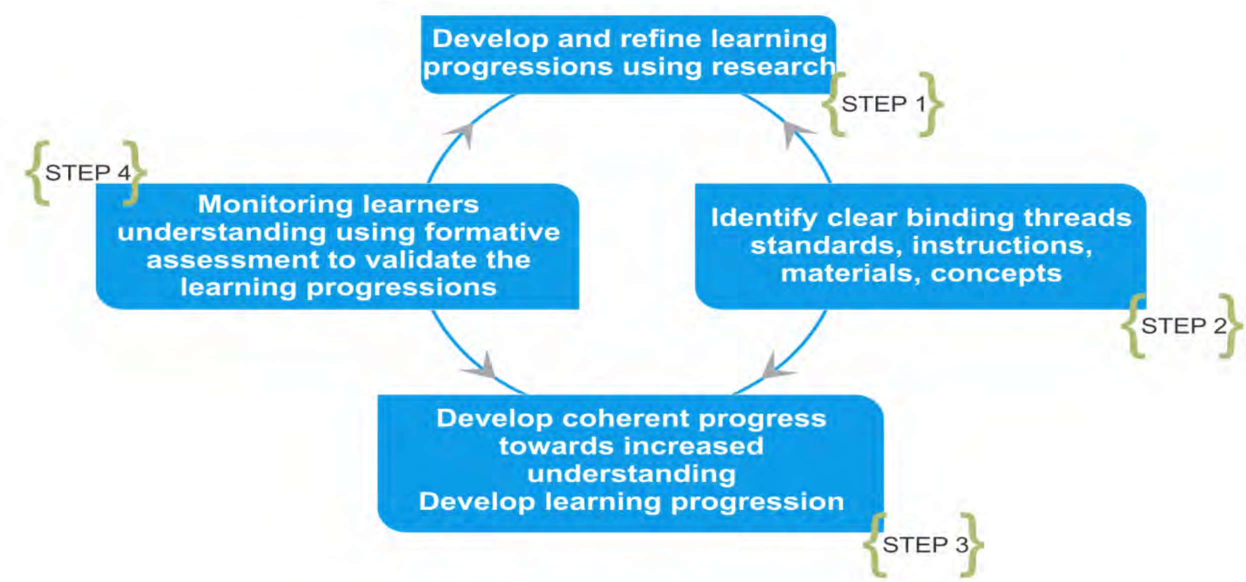



**Figure 2.1: Graphical representation of iterative process focused on developing, refining and validating LP. (Source: Hess, 2008:7)**

According to Hess (2008:3-7), there are four steps that are interconnected in learning progressions:

Step 1 – Develop and refine a learning progression using research

Research is to be done on specific content. The focus is more on how curriculum develops rather than how learning develops. Hess identified three types of research that can be used in teaching learning progressions.

- Cognitive research provides how learning occurs generally.
- Content-specific research gives guidance and how conceptual understanding develops.

- Action research supports how to use formative assessment in the class or school to refine, develop or ‘fill in gaps’ in the curriculum.

Step 2 – Identify clear binding threads

Identify standards, instructions, materials, concepts which constitute the big ideas. ‘The big ideas mean ‘’essence’’ of important concepts and essential processes.’ They are the binding threads that connect learning across the different grades and over the teaching and learning period between and within a phase or instructional time. These binding threads make measurement of progression possible.

Step 3 – Progress towards increased understanding

LP defines the pattern of development towards increased understanding. The pattern of development does not develop along a single straight pathway. However, the process of development of understanding is demonstrated when learning from an unrefined novice understanding is transferred to content concept and more refined expert scientific thinking and reasoning.

Step 4 – Monitoring learners understanding using formative assessment to refine and validate learning progressions.

LP provides opportunities for monitoring the use of summative assessment across the different grades. Summative assessment is preceded by a well-designed formative assessment which includes teacher observations, tasks that require application of knowledge understanding, and critical thinking. Formative assessment reveals how learners reason which shows how their understanding develops.

Apart from the iterative process the resulting landscape approach to LP can be presented as a visual representation as shown in the diagram (figure 2) below.

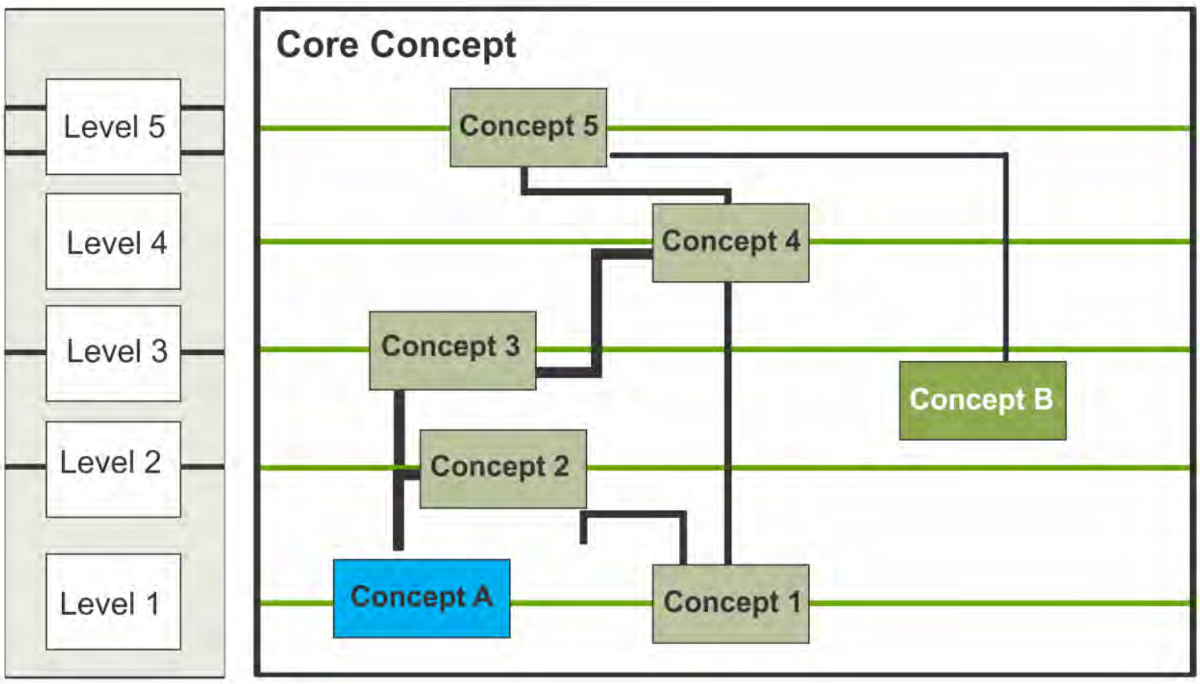



**Figure 2.2: Visual representation of the landscape approach to learning progressions. (Source: Salinas, 2009:9)**

The landscape approach preserves the societal expectations organized around the core concepts or ''big ideas'', which will enhance students' advancement to a higher level of learning. Hess (2008) used the landscape approach to design, describe and construct learning progressions. The approach used by some researchers conforms to the landscape ideas while other researchers do not categorically align themselves to this approach.

Catley, Lehrer and Reiser (2005:6-8) report on the application of a learning progression on students' understanding of evolution as a subject, identification of "big ideas" and development of core evolutionary concepts and its related learning performance. The topic molecular basis of heredity, Roseman, Caldwell, Gogos and Kurth (2006:2), portrayed the application of LP of different fields of study linking LP to biology and science literacy.

Roseman *et al*. (2006:1) used project 2061 which suggests that a learning progression leads to a coherent understanding of the two main functions of DNA. Project 2061 is a project developed by the American Association for the Advancement of Science. The project focuses on creating connections between science standards and learning progressions. It has assessment items to monitor students' progress with the hope to promote efficient learning. The study also focuses on improving upon the coherent understanding of the two functions of DNA in a learning progression. The process of improving the progressions according to Roseman *et al*. (2006:2-4) involves four stages namely:

- The classification of the learning goals based on what is suitable for students to learn from earlier grades to higher grades.

- The clarification of each idea, boundaries determined in terms of knowledge and technical terms.

- The use of available research involving interviews and questions to determine common ideas students have e.g. different proteins do different work. They found that students cannot give a single function of protein.

- The development of multiple choice assessment items for testing student misconceptions and assessment for monitoring students' learning path.

In a work dealing with a similar concept, Smith *et al*. (2006:4) however found that the National Science Education Standards do not provide connections between standards at different levels in the curriculum. They designed a learning progression for K2 to K5 on matter and atomic-molecular theory and assessment tasks in the following four steps:

- They initially selected and worked around two big ideas.
- This was followed by connecting the standards to practical research results about children.
- They then connected the concepts to learners' knowledge.
- Finally, they constructed assessment tasks on matter and atomic-molecular theory to monitor learning.

The landscape approach provides a learning progression that is characterized by what the learners are expected to learn because a logical learning progression is developed first. The escalated approach presents explanation about how learning progresses in the development of learners. The evidence of what learners know is used to develop the learning progression (Salinas, 2009:5).

### 2.7.2 Escalated Approach to learning progressions

The Escalated approach uses the idea of escalation as increasing in learning intensity and an improvement from a lower level to a higher level of learning (Salinas, 2009:3). This approach, framed around a main domain or ‘big idea” (Salinas, 2009:3) is organized around central concepts and principles of a discipline (Smith *et al.,* 2006:5). It further showed how those big ideas are elaborated, interrelated and transformed with classroom instruction. The approach also specifies how those big ideas can take place in specific practices for learners to use them in meaningful ways. The escalated approach is an analytical component that hypothesizes the progression which is followed by tracing the development of the learners’ ideas.

A number of other research work has been done on the escalated approach on different fields of study including work done by Smith *et al*. (2006) process of building (LP) for matter and atomic–molecular theory; Mohan, Chen, and Anderson (2009) worked on LP of learners’ understanding about the carbon cycling in socio-ecological systems; Alonzo and Steedle (2008) developed LP in force and motion with special focus on the use of ordered multiple choice items and open ended items for assessment.

There are two underlining learning levels governing the escalated approach namely; lower and upper anchors.

#### *2.7.2.1 Lower anchor*

Salinas (2009:5); Mohan *et al.* (2009:675) perceived lower anchor as the information or knowledge recognized about learners reasoning on specific concepts as they enter school. Lower anchor is the previous knowledge and skills learners bring to class (Duncan & Hmelo-silver, 2009:607).

#### *2.7.2.2 Upper anchor*

The upper anchor is defined as the expectations that society has (e.g. science standards) about students’ knowledge and understandings when they finish formal education, meaning high school or college (Salinas, 2009:5; Mohan *et al.,* 2009:676). According to Alonzo and Steedle (2008) the upper anchor is the concepts learners are expected to understand using standard or available cognitive science research to define it. They used this understanding to define the top level (upper anchor) of the learning progression.

### a) The iterative process of the escalated model

The iterative process as illustrated in figure 2.3 describes how assessment results are used to describe learners’ knowledge as they progress. Research based on learning progression or use of existing research on learners’ progression is the initial step, after which assessment items are designed and developed. These assessment items are used to evaluate learners' level in the progression. The responses are used to revise the progression and assessment items. This process informs how learning progress and demonstrate progression in understanding in the context of learning.

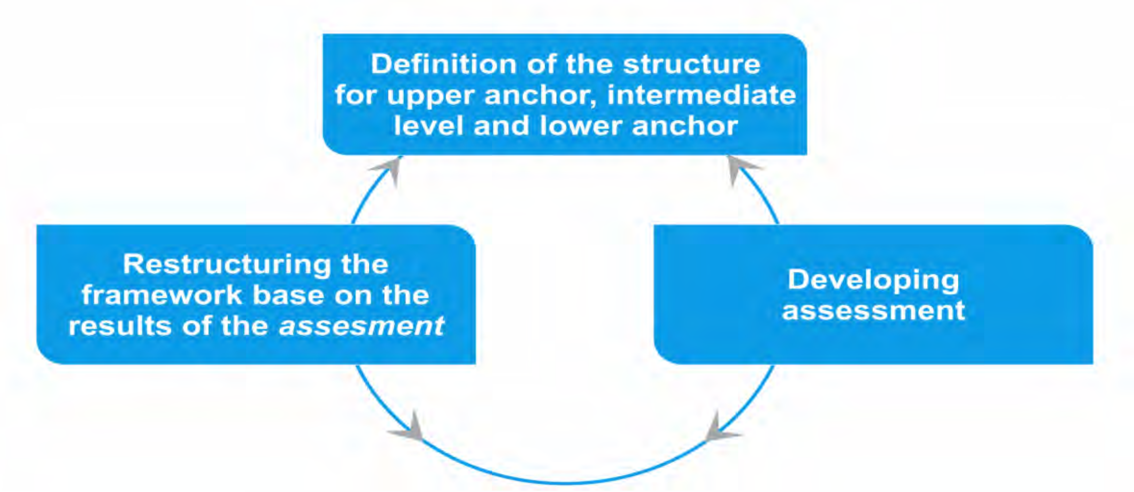



**Figure 2.3:** **Iterative process focused on description of students learning progress according to the escalated model of LP. (Source: Salinas, 2009:6)**

#### *2.7.2.3 Application of escalated approach*

Mohan *et al.* (2009:680) developed an initial hypothetical framework defining upper anchors, lower anchors and intermediate (transitional) levels. The intermediate level is a level between the lower and upper anchor as illustrated in the diagram (figure 2.4) below. They developed assessments based on the framework. They used the results of the assessments to redefine the framework, which led to new assessments. They completed three full cycles of designing frameworks and developing assessments.

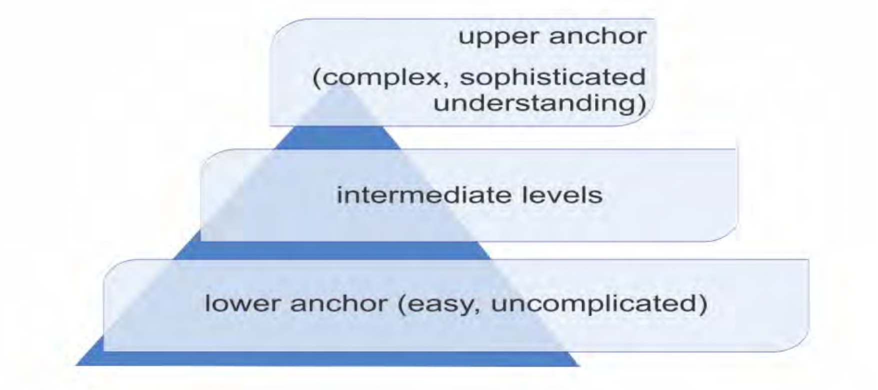



**Figure 2.4: Visual representation of the escalated approach to learning progressions. (Source: Salinas, 2009:6).**

The goal of Mohan *et al.* (2009:675,680) was to ensure that learning progression capture how the understanding of ecological carbon cycling develops among learners taking science courses from upper elementary through to high school. The scientific account of carbon transformation that leads to the understanding of global environmental issues defines the upper anchor. Two intermediate phases were defined and the lower anchor defines the informal accounts of the natural processes in plants and animals. Their interest in developing a learning progression was due to the desire to educate students and adults to be knowledgeable in environmental sciences. As illustrated in the preceding paragraphs, it is clear that escalated and landscape approaches have been used by different researchers.

### 2.7.3 Comparison of the escalated and landscape approach

The escalated approach is descriptive in nature and has strong empirical characteristics whereas the landscape approach is more of expectation guided in nature with strong analytical characteristics (Salinas 2009:12). Below are the differences between the two approaches as suggested by Salinas:

- The escalated approach is more flexible than the landscape approach.
- Escalated approach presents connection within a specific content, while the landscape approach represents connections among different content domains.
- Escalated approach presents how learning evolve in the learner within the classroom which informs the development of learning progression but the landscape approach develop logical learning progression based on results of an interview or assessment.

### 2.7.4 Learning progressions and assessment

Smith *et al.* (2006:13) suggested that learning progressions base on research on children's learning can be a useful tool for elaborating, designing, improving large-scale and classroom assessments.

The work of the following researchers (Wilson *et al*., 2006; Mohan *et al.,* 2009) was the initial research used in the development of learning progressions framework and assessments. After defining the framework, they planned the progression and eventually developed the assessment instruments which are available today. Learning progression is a very useful tool that informs assessment in different ways. The construct map and progress variable are the two that form part of this study.

#### *2.7.4.1 Construct map*

A construct map is a well defined and researched idea showing different levels of performance (Wilson, 2009:718). Construct map defines what is to be assessed in terms of general interpretation of a curriculum (within and across the curricula) and a specific guide to develop other components (Wilson, 2009:718). Assessment by means of a construct map using seasons, solar system, carbon cycle, molecular theory of matter and others are recorded in literature (Wilson, 2009:719). A construct map describes the pattern of items from a more general concept to more specific concept.

#### *2.7.4.2 Progress variable*

A progress variable is an approach used to build a learning progression; this approach is used to assess the expression of a simple and ordered part of a learning progression (Wilson, 2009). Wilson and Scalise (2006: 647-648) contend that a progress variable focuses on the concept of growth. They described progress variable approach using instructional units that contribute to learner progress with a calibrated and meaningful scale to map the growth of learners' progress and understanding (Wilson & Scalise, 2006:647). Progress variable operate on formative and summative assessment level but focuses mainly on the summative level (Wilson & Scalise, 2006:643; Wilson, 2009:719-724).

The calibrated scale below (figure 2.5) makes it easy to trace learners' growth.

| | | | |
|---|---|---|---|
| **Expert** | 5. | **Production:** | Research, invention and creation |
| **LEARNERS UNDERSTANDING** | 4. | **Construction:** | Examine hyoitgesusm assumptions, relate model |
| | 3. | **Formulation:** | Relate ideas and concepts, simle models |
| | 2. | **Recognition:** | Language, difinitions, symbols, formulate |
| **Novice** | 1. | **Notions:** | Daily experience, logical reasoning, general ideas and concepts |

**Figure 2.5: A progress variable linked to curriculum. (Source: Duncan, 2009)**

### 2.7.5 Uses of learning progressions

LP are currently being developed using multiple approaches to identify developmental sequences in many grades that spans in a variety of content areas. Below are a few examples of learning progressions from different learning areas as reported in literature:

Schwartz *et al.* (2009:640) engaged in modelling practices that move along levels of the progression. In particular, students moved from illustrative to explanatory models. In the process they develop increasingly sophisticated views of the explanatory nature of models when they shift from models as correct or incorrect to models as encompassing explanations for multiple aspects of a target experience. They also developed more fine distinct reasons to revise models. Finally, they present challenges for learners in modelling practices - such as understanding how constructing a model can aid their own sense making, and seeing model building as a way to generate new knowledge rather than represent what they have already learned. Below is a rubric they used to assess the models.

**Table 2.1: A rubric for ''a learning progressions for understanding models as generative tools for predicting and explaining.''**

| Level | Performances |
|---|---|
| 4 | Learners' construct and use models spontaneously in a range of domains to help their own thinking. Learners consider how the world could behave according to various models. Learners construct and use models to generate new questions about the behaviour or existence of phenomena. |
| 3 | Learners construct and use multiple models to explain and predict more aspects of a group of related phenomena. Learners view models as tools that can support their thinking about existing and new phenomena. Learners consider alternatives in constructing models based on analyses of the different advantages and weaknesses for explaining and predicting these alternative models. |
| 2 | Learners construct and use a model to illustrate and explain how a phenomenon occurs. Learners view models as a means of communicating their understanding of a phenomenon rather than a tool to support their own thinking |
| 1 | Learners construct and use models that show literal illustrations of a single phenomenon. Learners do not view a model as tool to generate new knowledge, but do see models as a means of showing knowledge |

(Source: Schwartz *et al.,* 2009:640)

The diagrams below (figure 2.6 and 2.7) describe different general images of learning progressions. In figure 2.6 the science teacher (person in the picture) is thinking about what the learners are thinking. The layers of the clouds are the successive layers of sophistication of learners thinking.

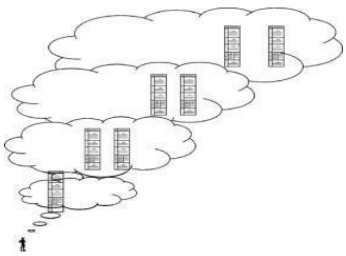


**Figure 2.6: A possible relationship between construct map structures showing different construct maps inside each level of the learning progressions. (Source: Wilson, 2009:717)**

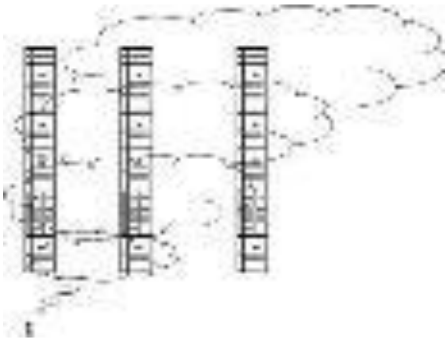


**Figure 2.7: The levels of the learning progressions are levels of several construct maps. (Source: Wilson, 2009:723)**

The diagrams above (figure 2.6 and 2.7) confirm the importance for teachers to identify how learners think about scientific concepts.

### 2.7.6 Implication of learning progressions

Stevens *et al.* (2007:9) define LP as "a strategic sequencing that promotes both branching out and forming connections between ideas related to a core scientific concept.'' In this study the scientific concept is kinematics graphs. Progressively learners should connect basic ideas from mathematics and every day experiences of speed, time, gradient, distance, and the time it takes an athlete to cover a specific distance in a race. For example, the time it takes to complete a 400m race can be connected and related to speed. That is the distance (400m) divided by the time taken.

Research shows that transfer of learning from one context to another is more efficient when the learner understands the details as well as the "big picture''. When learners are taught many pieces of disconnected facts without coordinating these facts into a functional whole or "Big ideas" the knowledge is often lost in the different forms of facts presented and learning tends to be difficult in this case. Transfer of learning is supported by deep understanding of subject matter (Bransford *et al.,* 2000: 16-17, 55-56).

Alonzo and Steedle (2008:390) assents that LP can help teachers to develop knowledge necessary for teaching a particular concept which will have an effective impact on learner's learning. Friel *et al*. (2001:143) also discusses how teachers can assist learners to progress in graph work from a lower level to an upper level.

Learning takes place as students discover new concepts, solve problems, work with others, and investigate. Learning also involves the process of conceptual change. Bruner (1969:48-49) argues that learning the unknown and relating to the known leads to understanding both. Learners can relate better for the understanding of kinematics graphs if they start from the easier known concept to more complex concept. The inference that can be made from Bruner is that since kinematics graphs are more complex than ordinary line graphs, learners must be exposed to line graphs at an earlier stage before they are introduced to kinematics graphs.

Bruner also discussed the need to grasp structure. That is the meaningful understanding of how things are related makes learning easier. For example if a learner is able to grasp the ideas and principles of line graphs in grade 9, the learner can easily identify and extrapolate the basic concepts of simple graphs into drawing, interpreting and giving acceptable conclusions in handling kinematics graphs in grade 10. It has been proved in literature that learners face difficulties understanding kinematics, drawing conclusions, and interpreting graphs (McDermott *et al*., 1987:504; Molefe *et al*., 2005:70). Therefore relating grade 9 graphs to kinematics graphs can lead to understanding of kinematics graphs.

It is easier to learn any concept when there is already background knowledge about the concept than starting completely afresh (Barkley *et al.,* 2005:12). It is therefore necessary to introduce learners to the principles and basics of graphs at an earlier grade and then kinematics graphs can follow at the same grade or higher grade. This introductory knowledge will serve as the background to build on new knowledge in grade ten. Hence reduces the difficulty of comprehension experienced by learners at grade 10 when kinematics graphs are introduced. Again if learners are exposed to well design practical activities, which challenge their prior knowledge and encourage their personal theories that are related to kinematics graphs, it will enhance their understanding.

The vocabulary, concepts and terms that are related to kinematics graph should be acquired in grade nine to make connections that enhances learning. This is confirmed by Barkley *et al.* (2005:12) 'If the schema already has a dense network of vocabulary, terms, and concepts it is easier to create connections that constitute learning.' Thus, there is the need to identify learners' conceptual resources in grade 9 and ensure they restructure their existing ideas and concepts of motion graphs in relation to the new concepts to be taught in grade 10. The use of appropriate methods of teaching and learning graphs is very crucial so that learners do not find themselves at a disadvantaged position in life.

Bao and Redish (2006: 010103-3) found that learners' inability or lack of confidence to apply what they have learnt causes them to make use of their previous knowledge too widely or too narrowly. Hence learning new concepts becomes complicated or does not even take place at all. Bao and Redish established that understanding the conditions under which to apply the existing knowledge to new knowledge is a crucial part of learning. Learning takes place when learners accumulate knowledge and concepts which serves as a foundation to build new and more complex knowledge and understanding.

One can argue from Smith *et al*. (2006:3) point of view that the difficulties learners face in kinematics graphs may be due to the inability to restructure their existing ideas*.* This can be minimized if restructuring of existing ideas of kinematics graphs is continuously planned and attempted. Without rationalizing the prior knowledge, learning kinematics graphs will be difficult. As already been stated in literature (Beichner, 1994:753), learners face difficulties in motion graphs. Line graphs are essential in mathematics and science but learners have difficulty, drawing, interpreting (Padilla, Mckenzie & Shaw, 1986) and comprehending (Friel *et al.,* 2001:140), line graphs.

The human brain starts to grow more rapidly as the children learn to use language hence early use of graphical language can enhance learning, understanding, interpretation and application of graph language to solve kinematics graph problems. Beichner found from his study that learners of high schools do not possess the graph vocabulary needed to interpret kinematics graphs (Beichner, 1994:753). Therefore early use of graph language will lead to accumulation of graph vocabulary. For the reason that learning is a continuous process, the science teacher should be responsible for teaching and learning kinematics graphs continuously from the lower grades (grade 8) through to grade 12. A suitable learning progression should be followed.

In agreement with Abbott (2002), grade 9 learners need more guidance and directives with regard to graphs and as they develop these skills and directives, assistance should progressively be reduced. It then becomes easier for them to direct their own learning later. Learners should be assisted to attain skills that can be useful in real life, this include skills to read, interpret all types of graphs including kinematics graphs and graphs from news papers and magazines correctly and with ease.

It is therefore important to build learner's experiential base in grade 8 by providing research inquiry-base experience related to kinematics graphs. In agreement with Staten (1998:27-32) learners in grade 9 should be given data and through the process of questioning and answers should be able to draw and interpret the graphs. After presenting their work the teacher should identify misconceptions and accuracies, explain and correct them. The concepts and terms related to graphs that were acquired in grade 9 should serve as learner resources in learning kinematics graphs in grade 10.

Nieuwoudt and Beckley (2004:347) suggested learners use their pre knowledge and skills from different learning areas to solve scientific problems. For instance the skills and knowledge acquired in graphs from mathematics should be tapped and applied to solve problems in kinematics especially speed or velocity versus time graphs from grade 9 to enhance effective learning and understanding. In grade 9 learners must be prepared to draw and interpret line graphs. What learners are expected to know and able to do by the end of the progression is determined by community expectations, learners' prior knowledge and skills as they enter the targeted instruction situation (Duncan & Hmelo-Silver, 2009:607-608).

LP is applicable to kinematics graphs, simple concepts such as labelling the axis, choosing suitable scales, using data from table to plot graph to complex concepts including interpreting graph, identifying relationships, and using graphs to solve problems. LP are flexible not rigid and occur in a definite broad span of time. It covers a specific and defined context within a specific topic or content domain just as kinematics graphs, which starts from grade 10 to grade 12 (which lies in the FET band) and falls under mechanics. Research can be used to develop and refine LP for instance reviewing literature on kinematics in grade 10 to find the process by which knowledge can be acquired by learners.

Graph in this study can be regarded as a binding thread in the GET phase (grade 7 to 9) and FET phase (grades 10-12). The general idea of drawing bar graphs in grade 7 and 8 develops into understanding to draw line graphs. In addition the learner should have the ability to apply knowledge and understanding of different graph concepts learnt in grade 9 to enhance the understanding of more sophisticated scientific concepts in kinematics graphs. At this stage landscape LP is created.

Duncan and Hmelo-Silver (2009:607) asserted that progressions are bounded by an upper and a lower anchor. In this study the knowledge and skills on graphs required in grade 10 form the upper anchor. The lower anchor is what learners already know about graphs before entering grade 10, i.e. their resources in terms of knowledge and skills from grade 9.

## 2.8 SUMMARY

Comprehension and interpretation of graphs becomes less difficult if learners have adequate vocabulary. The vocabulary of kinematics graph, its concepts and terms should be introduced in grade 9 to make the transition smooth and its learning easy. The concepts and terms related to graphs that were acquired in grade 9 should serve as the learner's resources in learning kinematics graphs in grade 10.The knowledge and skills obtained in graphs as learners proceed from grade 8 to grade 9 will be built upon in grade 10.

Problem solving is a very effective tool that can be used to identify concepts and knowledge learners acquired in kinematics graphs before starting the topic in class. This will assist the educator to choose the appropriate teaching and learning method, which will lead to development of effective skills that is used to comprehend kinematics graphs. A deeper understanding of graphs is a tool that can be applied to different types of kinematics graphs.

The knowledge and skills obtained in graphs as they proceed from grade 8 to 9 will be built upon in grade 10. The concepts and terms related to graphs that were acquired in grade 9 should serve as learner resources in learning kinematics graphs in grade 10. In South Africa graphs are dealt with in most learning areas in the GET phase. Learners come across varying definitions and descriptions of graphs and this may have an impact on their understanding of kinematics graph.

A conceptual change is perceived if a learner has the ability to find the relationship between velocity and speed, ability to determine acceleration from a velocity-time graph using the basic knowledge of calculating the gradient of a line graph from mathematics in grade 9. This implies that learning kinematics graphs cannot be achieved if learners have to discover meaning, interpretation and application of graphs through their own effort. For learning and mastering of concepts in graphs to take place, the learners need structured assistance and help.

Looking closely at all the diagrams in paragraph 2.7 one can conclude that learning progression is a climbing step from a lower height to a higher height within a specific time frame which consists of several concepts (construct maps) within a learning area (subject).

# CHAPTER 3

# GRAPHS AS CONCEPTUAL RESOURCES

## 3.1 INTRODUCTION

In the previous chapter a review of relevant literature related to constructivist theory, learning progressions, alternative conceptions and how they affect conceptual resources. In this study, only scientific graphs as required in the school curriculum are reviewed.

In this chapter the following will be discussed: definitions of graphs by various authors (paragraph 3.2), structure of graphs (paragraph 3.3), types of graphs (paragraph 3.4), importance of graphs (paragraph 3.5), conceptual resources and kinematics graphs (paragraph 3.6), learning progressions in graphs (paragraph 3.7), lower and upper anchor related to graphs (paragraph 3.8), understanding kinematics graphs (paragraph 3.9), implication of learning progressions on conceptual resources of kinematics graphs (paragraph 3.10) and summary of the chapter (paragraph 3.11).

## 3.2 DEFINITIONS AND DESCRIPTION OF GRAPHS

There are varied definitions and descriptions of graphs given by many different authors. For instance:

- Soobramoney and Vermaak (2010:8-9) define graph as the type of diagram that shows the relationship between two measured variables.
- The Oxford Dictionary defines graph as ‘‘planned drawing consisting of lines that confirm the relationship(s) between sets of numbers’’ (Hornby, 2006:650).
- According to Cothron, Giese, and Rezba (2006:256) a graph is a ‘pictorial set of data displayed’.
- A graph is a diagram showing the relationship between some variable quantities (Nel, Schmidt & Stols, 2006:114).

Therefore, the definitions of graphs by most authors indicate that graphs are needed to convey information and describe the relationship between variables.

## 3.3 STRUCTURE OF GRAPHS

Friel, Curcio and Bright (2001:126) described the structure of graphs using four common components of graphs which are:

*a)* ***The framework of a graph*:** The framework of graphs includes axes, scale, grids, and reference marking. This gives information about the kinds of measurement used and data measured. Friel *et al*. (2001:126) identified two frameworks which are the L and T shape framework. The L shape framework consists of the x–axis representing data measured and the y-axis that provides information about the measurement used. Picture graphs, line plots, bar graphs, line graphs, histograms are examples of L shape whereas stem plots and tales are examples of T shape graphs.

*b)* ***Specifiers:*** It is the visual dimensions that are represented by data values. For instance, lines on a line graph or bars on a bar graph are represented by data values.

*c)* ***Labels:*** Labels include the x-axis and y-axis which are associated with the L shaped framework. Robbins (2005:10) states that labels represent categorical variables; examples are gender, country, and hair colour.

*d)* ***Background of the graph:*** Graphs may be placed over colouring, grid, and pictures, which are applicable to the graphs.

Even though the four structural components, namely background, labels, specifiers and framework of the graph form part of every graph, a specific ''language'' is associated with the four components for every type of graph. The ''language'' used to explain the data plotted on each kind of graph is unique (Friel *et al*., 2001:126).

The four components of graphs described by Friel *et al*. (2001:126) above consist of some of the elements of graphs. These are discussed in paragraphs 3.3.1 to 3.3.5. The elements are; data plotted on the graph, scale, axes, title, and line-of-best-fit.

### 3.3.1 Data plotted on graphs

Data plotted on a specific graph depends on the type of data. Various authors identified different types of data. Robbins (2005:10) classified plotted information as categorical or quantitative. Whereas Cothron *et al.* (2006:90) classified the variables as qualitative or quantitative data. The words categorical (Robbins, 2005) and qualitative (Cothron *et al.,* 2006) in the context of this study give the same meaning to the variables to be plotted.

Robbins (2005:10) describes quantitative data, as data with numerical values with no emphasis on units. Examples are measureable items including height, mass, volume, and distance. Cothron *et al.* (2006:90) used both number and units to represent quantitative data. Examples are height of a wall in meters, centimetres etc, mass of a dog in kilograms, grams etc. where emphasis is placed on units and numerical values as in these examples. Unit is important in physics. Learners loose marks if they do not include the units of physical quantities calculated. Quantitative data used in drawing graphs must therefore include units as stressed by (Cothron *et al*., 2006:90).

Qualitative data on the other hand are descriptive data collected by grouping data into categories. For instance discrete categories are represented by label or measurement made with unequal intervals without using a standard scale. Examples are gender and colour. Cothron *et al.* (2006:91) further classified the categories of data according to an order of ranking which were identified as nominal and ordinal data. Nominal data is a data with series of discrete categorical variables for which there is no basis. The points between the defined categories of a discrete data do not have any meaning. Example of a graph that can be plotted with discrete data is a bar graph (Cothron *et al.,* 2006:256).

Cothron *et al.* (2006:90) identified the possibility of separating quantitative data into discrete and continuous data. Discrete quantitative data are collected using whole integers. Examples include number of babies born in a specific year and number of mango trees growing in a plantation (Cothron *et al.,* 2006:90). Nevertheless, one cannot have half baby at birth therefore; counting babies in fractions or decimals is not possible (e.g. 12.7 babies), therefore the data is discrete. Continuous quantitative data are collected using scales that are divisible into fractional units. Examples are distance in kilometres (e.g.10.5km) and volume in centimetre cube (Cothron *et al.,* 2006:255).

Qualitative data are verbal information or descriptions of male, female, cars etc collected using non-standard scales, unequal intervals without a zero point, whereas, quantitative data use standard scale with equal intervals and zero point (Cothron *et al.,* 2006:258). Qualitative data thus differ from quantitative data which use standard scales.

### 3.3.2 Scales

Scaling is an essential skill needed to understand and interprete graphs (Glazer, 2011:200). Scales are the range of data used to draw graphs from data. Scales have profound effect on the interpretation of graphs (Robbins, 2005:227; Glazer, 2011:197). ‘‘A scale is a series of marks at regular intervals used for measuring.’’ (Hornby, 2006:1301.) Cothron *et al.* (2006:258) also defines scale as a series of equal intervals and values placed on each axis of a graph. Hornby (2006) and Cothron *et al.* (2006) both stated that scale portrays equivalent intervals even thou Hornby referred to measuring instruments, whereas Cothron referred to scales on graphs.

The choice of scale to use for any specific graph is a fundamental factor for all types of graphs. Determining the right scale for numbering the axes of a graph is the most challenging part of graph construction (Cothron *et al.,* 2006:258). One of the first major problems in graphs that arises when learners move from primary to secondary school level is the use of a scale on the vertical axis (Rangecroft, 1991b:90). Choosing regular intervals as scales for graphs is often the challenge faced by many people drawing graphs with given data. Scales without sub-divisions of 1 or 10 are associated with lower success rate (Rangecroft, 1991b:90).

Robbins (2005:240) claims that there is a need to include zero in the scale with emphasis on bar graphs to see its value relative to the value of the data. In support of that, Downing and Clark (1996) suggested that if the graph shows a change in a variable with time then it should have a vertical scale that starts with zero. However, in some cases the zero origin may be misleading since it hides information the reader needs to know (Robbins, 2005:235). The scale used to draw a graph may lead to difficulties reading the graph. It is also difficult for students to choose the correct scale when given the option.

### 3.3.3 Axes

The axes of all graphs are the horizontal and vertical lines both of which intersect at a point called the point of origin. Cothron *et al.* (2006:48-53) suggest that to construct a bar or line graph one should start by drawing and labelling the x- axis (independent variable) and y- axis (dependent variable) of the graph first. *The vertical axis* is generally labelled as the y-axis. It is the line of a graph on which the depended variables data is placed. *The horizontal axis* is universally referred to as the x-axis. It is the line of a graph on which the independent variable is plotted.

Quantitative or qualitative data may be plotted on the y-axis or x-axis. Beichner (1994:755) identified difficulties learners' experience with graphs, one of which is the slope-height confusion. That is, the students assign values they read from the axes and directly assign them to slope. Apart from labelling the axes, a graph needs to be given a title.

### 3.3.4 Title

The *title* of a graph is a phrase or sentence describing the data in a given table or on a graph. According to Cothron *et al.* (2006:259) all titles containing four or more words should be in capital letters. Cothron *et al.* (2006:60) suggested that the title of a graph should be in the form 'The Effect of Changes in the Independent Variable on the Dependent Variable'.

Rezba *et al.* (2007:204) indicated that the title of a graph communicates the purpose of the graph and suggested two formats that can be used to write the title of graphs which are:

- The effect of independent variable on the dependent variable.
- How does the independent variable affect the dependent variable?

### 3.3.5 Line-of-best-fit

Line-of-best-fit is a straight line or smooth curve that shows the relationship between the dependent and independent variables (Cothron *et al.,* 2006:52). The best points that show the relationship between the variables are joined by a line. Experimental data are not accurate so the data points are not always connected directly, and this may be due to, among others, human errors (Cothron *et al.,* 2006:258). That is why line-of-best-fit is used to communicate the general data pattern. A line-of-best-fit shows the general trend of data of a graph (Rezba *et al.*, 2007:220).

A line-of-best-fit is drawn so that the same number of data points fall to either sides of the line (Cothron *et al.,* 2006: 52). Rezba *et al*. (2007:220) suggest that a line should be drawn so that about half the points are on one side of the line and the other half on the other side. Below are a few examples of line-of-best-fit illustrated on the graphs (figures 3.1, 3.2 and 3.3), Figures 3.1 and 3.2 shows incorrect lines-of-best-fit while figure 3.3 shows correct drawings.

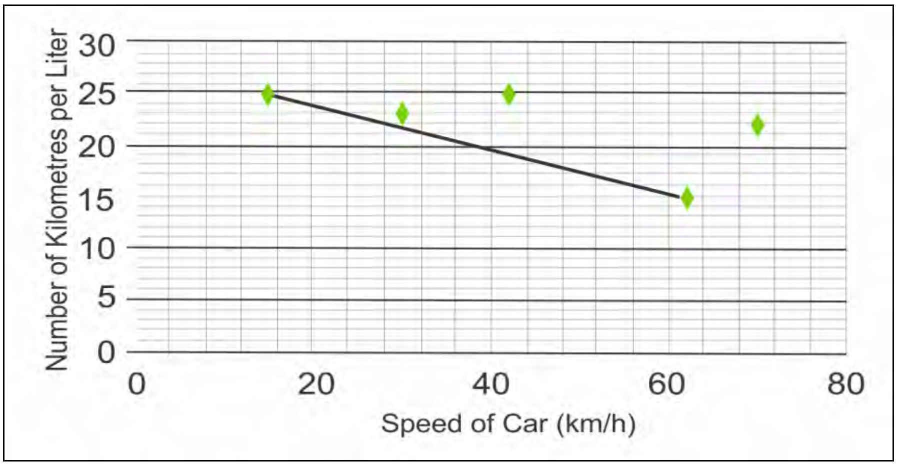



**Figure 3.1: How does the speed of a car affect gasoline consumption? (Source: Rezba *et al.*, 2007:221)**

There are too many points on one side of figure 3.1 therefore a straight line may not adequately represent the line-of-best-fit.

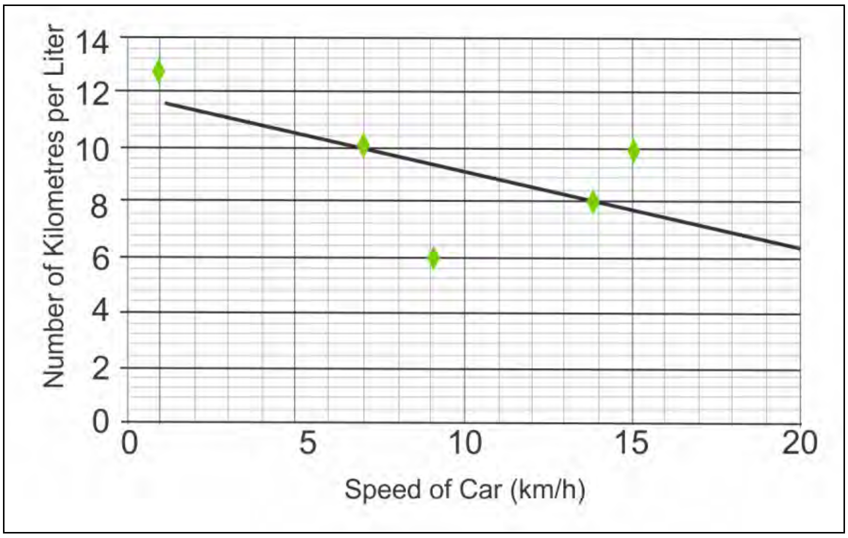



**Figure 3.2: How does the height of a flame affect boiling time? (Source: Rezba *et al.*, 2007:221).**

A curve line may be used to join the points instead of a straight line. Some of the points plotted on figure 3.2 are far from a straight line. A curved line drawn in the shape of a ''u'' would display line- of-best-fit better.

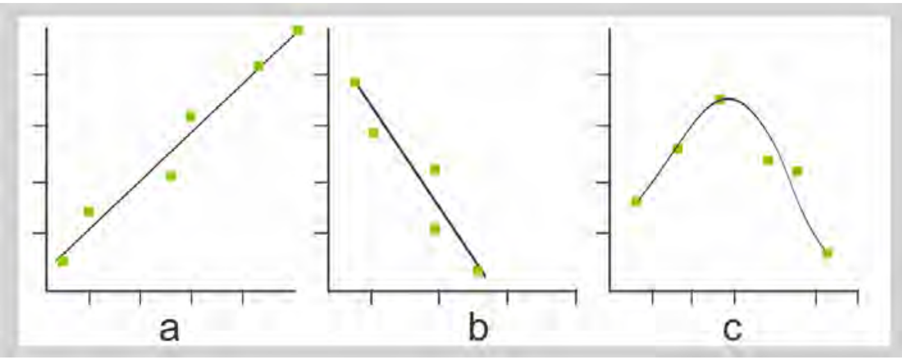



**Figure 3.3: Graphs showing better examples of line- of-best-fit (Source: Rezba *et al.,* 2007:220)**

In (a) the points tend to move upwards from left to right which shows that as the independent variables increase the dependent variable increases. In (c) the set of data increases to a peak and then starts to decrease.

## 3.4 TYPES OF GRAPHS

According to Friel *et al.* (2001:126) William Playfair was accredited for inventing statistical graphs that are used currently which are analytical tool for almost all researchers. Statistical graphs include but not limited to: picture graphs; line plots; bar graphs; pie charts; histograms; stem-and-leaf plots; box-and-whisker. A brief description of the features of some of these types of graphs is highlighted in the following sub paragraphs.

### 3.4.1 Bar graph

A bar graph (figure 3.4) uses bars of different lengths to compare data. Qualitative data is placed on the x-axis (Soobramoney & Vermaak, 2010:9). The qualitative observation and measurement variables are either discrete or continuous. Discrete data are categorical, for example, days of the week, gender, brand of battery etc. Examples of continuous data are length of time in seconds, height of plants in centimetres, etc (Cothron *et al.,* 2006:52-53). Below is a bar graph with appliances (qualitative data) on the x-axis.

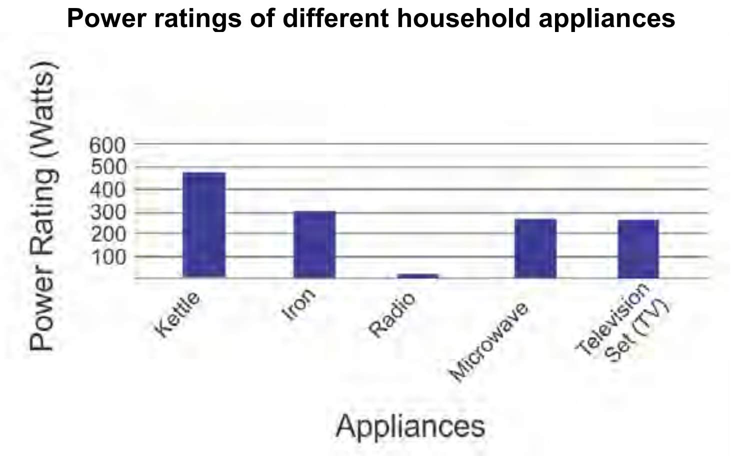



**Figure 3.4: Bar graph**

Guthrie, Weber, and Kimmerly (1993:187) indicate that bar graphs use spatial relationships to show numerical information about a topic. Bar graphs should have a common baseline. However, grouped bar charts do not show clear framework displays, and trends are difficult to read. Group bar charts are difficult to read and to follow the trends (Robbins, 2005:33). Cothron *et al.* (2006) has designed a checklist for evaluating bar graphs as shown in Table 3.1.

**Table 3.1: Checklist for evaluating bar graphs**

| Criteria | Self | Peer | Teacher |
|---|---|---|---|
| Title | | | |
| X axis correctly labelled including units | | | |
| Y axis correctly labelled including units | | | |
| X axis – scaleis correct | | | |
| Y axis- Correct scale | | | |
| Vertical bars for data pairs correctly drawn | | | |
| Data trend summarized with sentences | | | |

(Source: Cothron *et al.,* 2006:55)

Phillips (1997) mentioned that graphing in the primary level is limited to bar charts and maps. Box plots are however more efficient for comparing distributions of more than one set of data as discussed in the next sub paragraph.

### 3.4.2 Box plots

A box plot is a graphic method of displaying data based on lower extreme (minimum value), lower quartile (below 25%). The median number divides the data into half, upper quintile (below 75%), and upper extreme (maximum value). Information provided by box plots is about variation and not a logic distribution of the overall shape. Box plots can be referred to as box and whiskers (Robbins, 2005:91).

Box plots are more effective than histograms for comparing more than one distribution. John Turkey introduced box plots in the 1970s and today it is widely used in many schools (Robbins, 2005:89). Box plots are excellent for showing distribution of one data set as well as comparing distributions of multiple data sets. Figure 3.5 and figure 3.6 are examples of box plots.

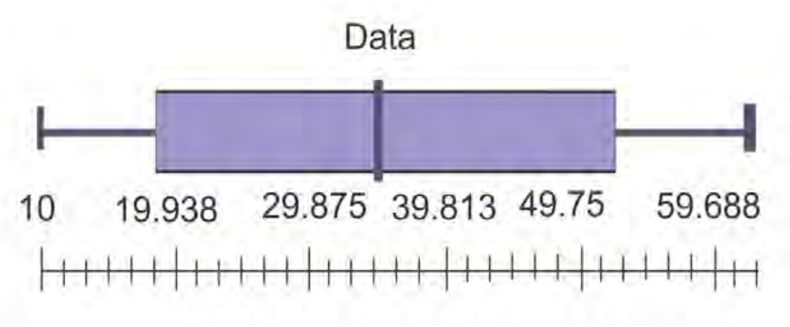



**Figure 3.5: A box plot**

Cothron *et al.* (2006:133) used the diagram below (figure 3.6) to illustrate box plots.

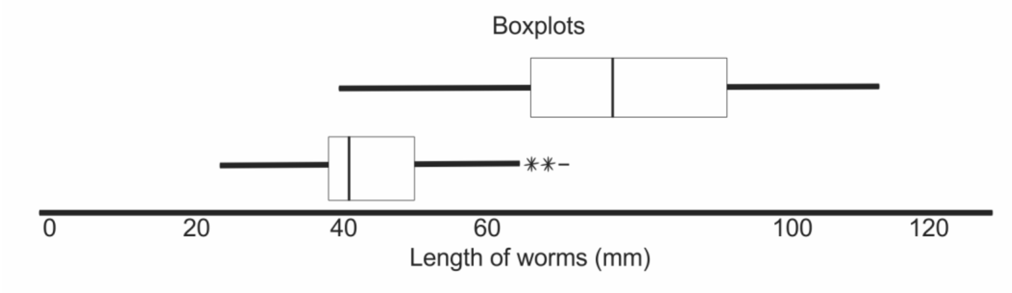



**Figure 3.6: Box plot (Source: Cothron *et al.,* 2006:133)**

### 3.4.3 Histogram

A histogram is a graph that uses bars, which touch each other (see figure 3.7). They touch because the x-axis with the independent variable is quantitative (Soobramoney & Vermaak 2010:9).

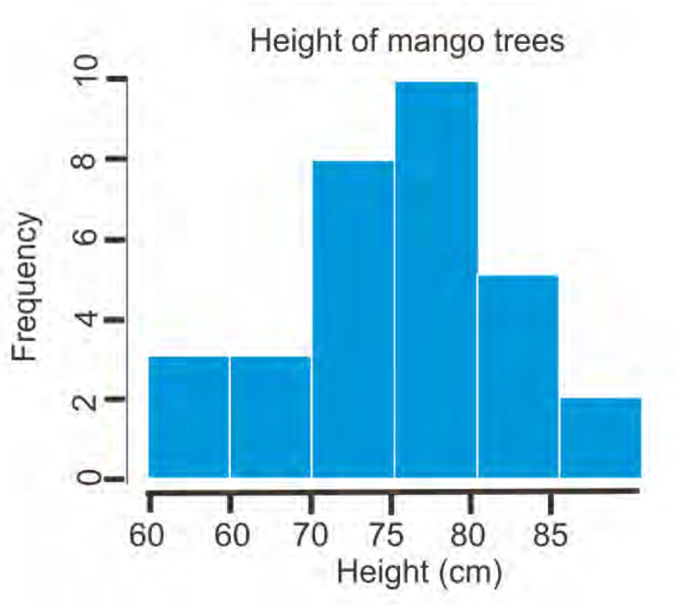



**Figure 3.7: Histogram**

A histogram shows the distribution of a set of data but do not effectively compare different distributions. Box plots and histograms both use scaled intervals to differentiate data distribution. If a proper interval for scaling is made, a histogram provides insight into the overall shape of the distribution (Robbins, 2005:77).

### 3.4.4 Dot plots

Dot plots are effective for showing categorical data. A dot plot can also be used for any situation a bar graph is used for (Robbins, 2005:69). The graph below is a dot plot showing the number of people in different rural areas in the North West Province.

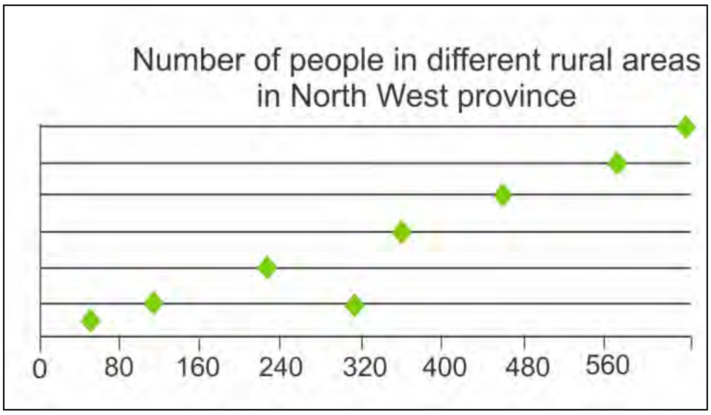



**Figure 3.8: Dot plot**

According to Robbins (2005:5), Cleveland introduced dot plots in 1984 after extensive experimentation on human perceptions. He was able to display the data using dot plots more effectively than charts (Robbins, 2005:113). Dot plots are easy to read. Trends and information are easily determined.

### 3.4.5 Line graphs

Data used to draw line graphs are quantitative. The independent variables are indicated on the x-axis and the corresponding dependent variables plotted on the y-axis (Soobramoney & Vermaak, 2010:9). Cothron *et al.* (2006:53) argues that when the values of the data are in a continuous range of measurement, a line graph is used. Continuous data is data with meaningful intervals. An example is given in the graph (figure 3.9) and Table 3.2 below.

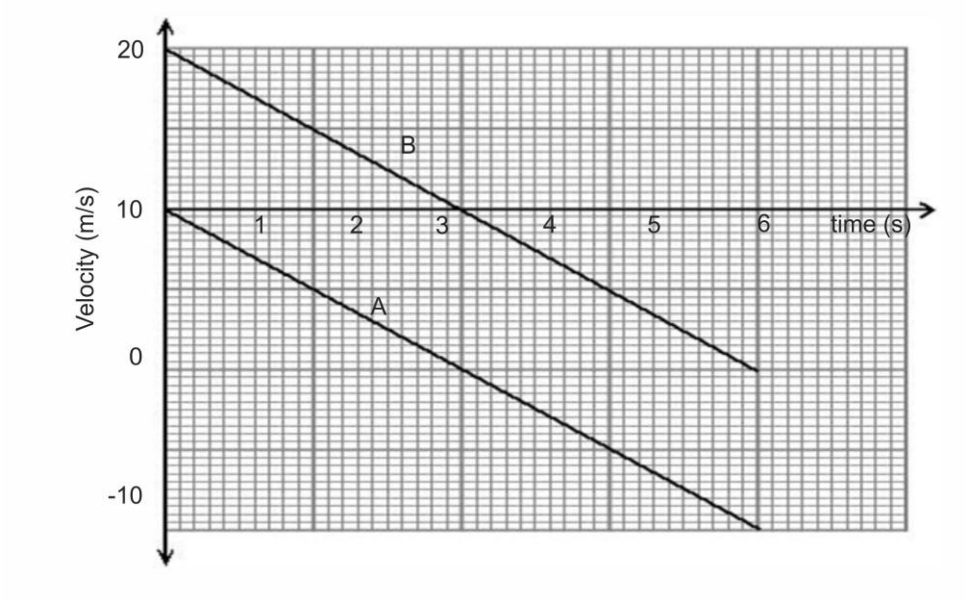



**Figure 3.9: Velocity versus time graph (Source: NCS, 2011)**

**Table 3.2: A table showing the constant increase in temperature of water**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Time (min) | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| Temperature ˚C | 10 | 20 | 30 | 40 | 50 | 60 | 70 |

Line graphs show related data and reflect functional relationships (McKenzie and Padilla 1986:571; Cross, Cross, Dlulisa & Tonkin, 2001:28). Line graphs demonstrate the relationship between continuous variables in pictographic form (Cothron *et al.,* 2006:53).

Cothron *et al.* (2006:52-53) outline a sequence for drawing line graphs.

- Draw and label the axes of the graph.
- Write data pair values for the dependent and independent variables.
- Decide on an appropriate scale for the axes.
- Plot the data pair's on the graph.
- Summarize data trend with line–of–best–fit.
- Describe in sentences by summarizing the data trend. Communicate what happens to the dependent variable as the independent variable changes.

A checklist (Table 3.3) for evaluating line graphs is as follows:

**Table 3.3: Checklist for evaluating line graphs**

| Criteria | Self | Peer | Teacher |
|---|---|---|---|
| Title | | | |
| X axis correctly labelled including units | | | |
| Y axis correctly labelled including units | | | |
| X axis correctly subdivided into scale | | | |
| Y axis- subdivided into correct scale | | | |
| Data pair correctly plotted | | | |
| Data trend summarized with line-of-best-fit | | | |
| Data trend summarized with sentences | | | |

(Source: Cothron et al., 2006:55)

### 3.4.6 Pie graphs

A pie graph is also described as pie chart or circle graph. It represents information in the form of percentages (Soobramoney & Vermaak 2010:9). Data represented in a circle graph can also be displayed in a bar graph but bar graph data cannot be displayed in a circle graph.

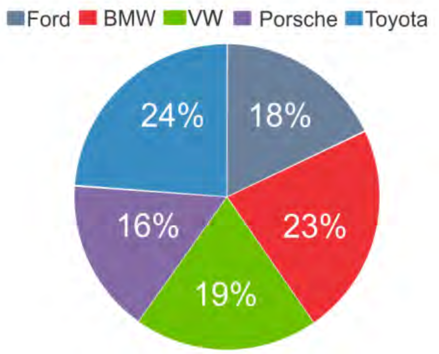



**Figure 3.10: Pie graph**

Angle judgments are made when a pie chart is read, but the angle judgments we make are biased. Acute angles are underestimated and obtuse angles are overestimated (Robbins, 2005:48).

### 3.4.7 Pictogram

In a pictogram a picture symbol illustration is used instead of data for plotting the graph. A pictorial symbol takes the place of data. Figure 3.11 is an example of a pictogram.

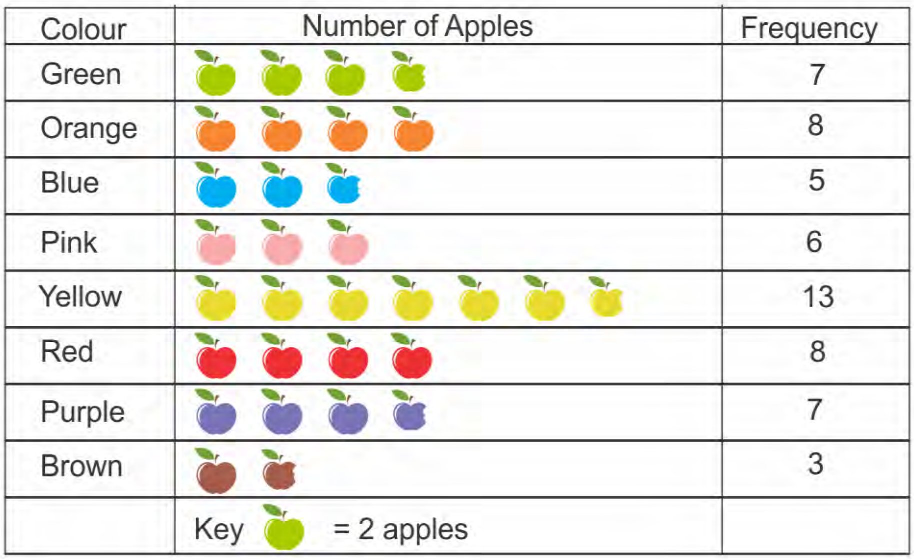



**Figure 3.11: Pictogram**

### 3.4.8 Scatter graph

It is a basic graph used for dependent and independent variables that are both quantitative. It helps identify relationships.

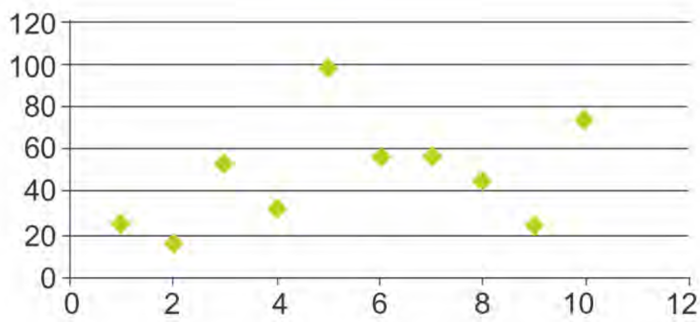



**Figure 3.12: Scatter graph**

Phillips (1997:52) noted that Pratt worked with children 8-9 years using scatter graph interpretation. Children worked on how the distance travelled by a toy car was affected by the height of the ramp on which it rolled and they found it quite interesting.

### 3.4.9 Stem-and-leaf

Stem-and-leaf is an exploratory means of plotting data based on place value and it shows the distribution of raw data (Cothron *et al.*, 2006:258). The actual numerals in the data are used to plot the graph. They are a quick way of displaying more than 25 pieces of data. Stem-and-leaf plots display data as two parts e.g. 42 is displayed as (4│2), where the 4 is the stem and the 2 (the smaller place value) is the leaf.

| | |
|---|---|
| 0 | 1,2,5,6,7 |
| 1 | 5,6,8 |
| 2 | 4,3 |
| 3 | 8,3 |
| 4 | 0,5 |
| 5 | 9,8,2, |
| 6 | 9,7,5,1,0 |
| 7 | 0,5 |
| 8 | 6,7,9 |
| 9 | 9,9,8 |

**Figure 3.13: Stem-and –leaf**

## 3.5 IMPORTANCE OF GRAPHS

Graphs are widely used in statistics, in magazines, school textbooks, and journals i.e. in most media. Therefore one needs to understand graphs to be a thinking participant in the society (Wavering, 1989:373). Graphs are used in many publications because of the ability to compress large amounts of information into a single graph. Graphs present concepts and wealth of information into a minute amount of space (Robbins, 2005:224; McKenzie & Padilla, 1986:571). For example a graph can be used to display data and it shows the relationships between variables. In addition, it promotes communication of complex concepts and ideas. A graph makes a page more attractive and inviting hence increases readership. It is a useful tool to help check data (Robbins, 2005:7, 11).

The importance of graph was discussed as far back as 1805 (Wainer, 1992). Graphs are easy to use to find information. One can make discovery from a graph without necessarily looking for it. The use of graphs can lead to discovery of concepts (e.g. scientific and kinematic graph concepts). Humans are excellent at seeing things hence graphs work well (Wainer, 1992:16) in enhancing understanding of information and promoting learning. A graph properly drawn easily answers commonly asked questions and invites deeper questions (Wainer, 1992:16).

Wainer (1992:14) describes Dr. John Snow's contribution towards graphing by describing how he plotted the incidence of deaths from cholera in central London in 1854 using dots and crosses. Snow presented his findings in graphic form and the evidence it revealed was sufficient to convince the vestry of St. James Parish for them to allow him to have the handle of the contaminated pump removed which subsequently brought an end to the cholera outbreak and deaths. This illustrates clearly the power of graphic presentation of data which, when analysed properly, gives useful information.

The skills and knowledge acquired to analyse a graph is a resource that can be used in learning kinematic graphs. Bar graphs, pie charts are the most common types of graphs learners come across in their early years of schooling as outlined in the RNCS for grades R to 9 (Department of Education, 2002b:14-31; Department of Education, 2002c:31-59). Learners come to the physical sciences classroom with some knowledge and understandings of these graphs which are their conceptual resources.

## 3.6 CONCEPTUAL RESOURCES AND KINEMATICS GRAPHS

In paragraph 2.5.3 the influence of learners' conceptual resources on learning was highlighted. Hammer (2000:56-58) emphasized the use of learners' conceptual resources to build scientific skills and develop new concepts. It is clear that the resources learners bring to the class based on their understanding of the principles of basic graph in the lower grades should be used to build their understanding of kinematics graphs.

In paragraph 2.4.1 and 2.4.2 learners' alternative conceptions and conceptual change were discussed. Learners in the classroom may possess either anchoring conceptions or alternative conceptions. Anchoring conceptions are learners' preconceptions that are consistent with the scientific concepts in the curriculum. They consequently are resources that can be used for learning new concepts. Alternative conceptions are inconsistent with the scientific concepts and interfere with learners' ability to acquire new scientific knowledge. When learners are able to reorganize or realign their preconceptions to accommodate new scientific ideas it leads to a conceptual change.

### 3.6.1 Conceptual resources related to kinematics graphs

Learners' conceptual resources can be identified in their reasoning, as they respond to questions (Hammer, 2000:58) related to graphs and kinematic graphs. However, the resources learners acquire may be naive (Redish, 1994:796). Many researchers refer to such resources as misconceptions, or alternative conceptions as discussed in paragraph 2.4.1 and 2.4.2.

DiSessa (1993:108) refers to it as intuitive physics. DiSessa (1993:109) views intuitive physics ‘‘as an expression of underlying sense of mechanism that occasionally exhibits relatively uniform results but on the whole lacks important logical hypothetical science’’. Learners’ inability to express themselves using consistent and coherent reasoning is a problem that affects their ability to use their prior knowledge effectively to understand new knowledge (or lack ability to exhibit coherent theoretical science). Learners may be capable of solving a quantitative problem such as calculating gradient but cannot analyse the same problem qualitatively (e.g to know that the gradient of a displacement–time graph gives its velocity) (DiSessa, 1993:108).

Hammer (2000:54) identified conceptual resources such as *‘’closer means stronger”* which are likely to develop in early childhood, independent of schooling. On the contrary, Hammer found out that learners do not have well-informed pre-requisite conceptions such as mass, force and velocity. Just to mention but a few. *’Closer means stronger”* (means getting closer to a source increases the intensity of its effect). This is applicable to velocity if it is reframed ’closer means slower’. ’Closer means slower’ can be a resource productively activated to understand dots made by a ticker timer on ticker tapes. For example, the part of the tape in figure 3.14, which represents the greatest velocity, is the part indicated B C.

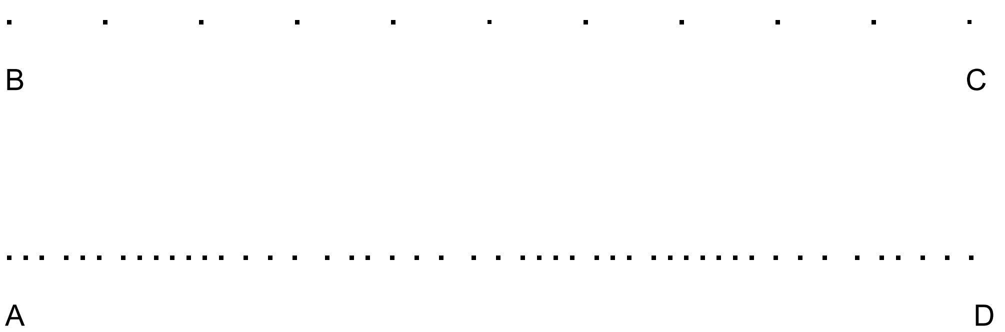



**Figure 3.14: Strips of ticker tape (Source: Appendix A)**

Whereas *’closer means faster”* is a faulty activation of resources. The resource is activated falsely because the part of the tape above that represents the greatest velocity is the part indicated by BC. The spaces between the dots are wider which indicates a greater displacement within equal time intervals.

Curcio (1987:391) revealed that the differences between grade and age have an effect on comprehension of graphs. The prior knowledge differs and that affect the level of comprehension. This implies that in any specific grade, base on learners’ age their prior knowledge in graphs will differ from others and that must be taken into consideration when introducing kinematics graphs. According to Curcio (1987), the learners in the 7th grade had better prior knowledge about graphs than learners in the preceding grades.

### 3.6.2 Everyday resources used for learning kinematics graphs

Learners learn kinematic graphs, using real world data obtained from everyday activities. For instance; an athlete running a 100m race, a car speeds up on a road, or a bus slowing down at a bus stop. Graphs are often used in magazines, journals and periodicals etc. The magazine (Easy Science) for young school going learners contains graphs. A simple activity where learners have to put 5C coins on the 1cm mark of the ruler. As number of coins increases the ruler has to be balanced by moving a finger (SAASTA, 2011: 23). Recording of the finger's position on the given chart is developing learners' ability to measure distance which is a resource useful for learning kinematics graphs.

If learners are given real world data to construct their own graphs and to verbalize the relationships and patterns observed, it will enhance their concept development that will build and expand the mathematics relationship they need to understand graphs (Curcio, 1987:391).

### 3.6.3 Integration of learners' resources

Department of Education (2002b:2-12) addresses integration and conceptual progression from one grade to the other. Learners are required to integrate the conceptual resources across the different learning areas and from grade to grade. The principles of mathematics are applied in some scientific calculations like ratios, e.g. where the ratios of elements in a chemical compound are compared.

Zietsman and Clement (1997:62-70) used the term "anchoring conceptions'' when learners conceptual resources align with scientific concepts and explained how these can serve as targets of ''bridging analogies''. Learners are able to apply their understanding in other contexts hence able to apply their mathematics skills in science, making integration of their resources a possibility.

### 3.6.4 Coherence of learners' resources

It is important to monitor learners' coherence in (understanding kinematic graphs) and address inconsistencies that may be found (Hammer, 2000:56). According to DiSessa (1993) learners' naive concepts are fragmented. Vosniadou (2008:xv) opposes this view and argues that learners' concepts are theory-like. Without participating in this debate, it is important to remember that learners must attain and apply coherence in physics concepts.

The ability to identify the conceptual areas in kinematic graphs that children find most challenging to learn is central to the development of a learning progression (Smith *et al.,* 2006).

## 3.7 LEARNING PROGRESSIONS IN GRAPHS

Educators can assist learners to progress in graph work from a lower level to an upper level by understanding their reasoning, intelligence, prior knowledge, and skills acquired (Friel *et al*., 2001:144; Duncan & Hmelo-Silver, 2009:607-608). The discussions on how lower and upper anchors are utilized to monitor progression is elaborated in paragraph 2.7 of this study. Wall and Benson (2009:84) emphasized the need to focus on the relevant main (the big) ideas that different graphs have in common i.e. the common concepts.

Friel *et al*. (2001:130) summarizes progression in graph as follows:

Level 1 focuses on extraction of data from a graph

Level 2 finding and establishing the relationship on a graph

Level 3 analyzing and extrapolating the relationships embedded in a graph.

Friel *et al*. (2001) acknowledged the relationship among logical thinking, proportional reasoning, and graphing ability. This implies that educators should match the learners' cognitive development to the concept introduced and task given at each grade. For example the progress in kinematic graphs should align with the individual cognitive ability and development using Piagetian development as a point of reference.

Rangecroft (1991a:44-46) put forward a well-thought-out and detailed treatment of what learners need to know about graphs in order to use and understand graphs in various subject areas and across stages or grade levels of schooling. This was according to England and Wales National Curriculum. It was necessary because the curriculum pointed out where learners should know at the end of each level but the steps needed (progression) to achieve these were not included. Rangecroft (1991a) suggests that graph work should begin in the early years of education, i.e. the stage at which the child is already learning about ordering and counting.

In contrast to Rangecroft, Wavering (1989:378) emphasized that graphing needs to be developed at the middle school (around 12 years of age) and high school year from simple (lower) to complex (upper) anchor through a logical progressive approach. The basics of graphing need to be developed in the early years (from grade 4 learners around 10 years old) of schooling but the content should be in line with the age. At the middle school, learners are more mature and the actual graph work can be initiated. The logical progressive presentation of graphing at the early stage should be very simple then increase difficulty to complex graphing at high school.

In chapter 2, paragraph 2.7.2.3 Salinas (2009) described an intermediate phase, which acts as a bridge between the two extreme ends of the ladder (Lower and Upper levels). The lower and upper anchors are discussed in chapter 2 paragraph 2.7. In this study lower anchor is the basic graph concepts and skills learners can develop in grade 9.

## 3.8 LOWER AND UPPER ANCHOR WITH REGARDS TO GRAPHS

Lower and upper anchor are used to describe the degree of difficulty and understanding of the correct acceptable scientific concepts. That is, from the simplest to the complex. Wainer revised (Bertin's, 1973) three levels of questions that can be answered using graphs. The three levels of questions can be summarized as follows:

- Elementary level questions- Data extraction e.g. what was carbon used for in the 20th century? The answer to this type of question can easily be drawn out from a graph (reading directly from the graph).
- Intermediate questions- Identification of trends from the data e.g. what changes can be observed between time $t_2$ and $t_3$. This type of question needs understanding and interpretation of the graph to be able to answer the question.
- Overall level questions- Understanding deeper structure of the data. Comparing trends and identifying groupings e.g. which vehicle is predicted to show the most dramatic increase in speed? The answer demands understanding of the relationship between the variables, interpretation and application (Wainer, 1992:16).

Wainer's elementary level graph questions, as discussed above, are classified as the lower anchor; while the intermediary graph questions deals with the intermediate phase and the overall level questions testing deeper understanding as the upper anchor.

### 3.8.1 Lower Anchor: Learners' conceptual resources in graph

The lower anchor is defined by Alonzo and Steedle (2008:393) as the understanding learners possess and ideas that may support development of scientific perceptions. Such scientific skills and knowledge support drawing and interpretation of kinematic graphs.

Learners cannot acquire conceptual resources in graphs by route learning. It is acquired by thoughtful and reflective learning. These resources are transferable from one situation to another. Learners acquire a rich variety of knowledge and experience in graph from mathematics, natural sciences and the interaction with the physical world. These acquired resources can serve as a foundation to build new knowledge that enhances understanding of kinematic graphs.

According to Daintith and Martin (2005:368) graph theory is the area of mathematics that deals with graphs and their properties. It has important applications in the construction of certain types of algorithms. The next paragraph (3.8.1.1) deals with mathematical knowledge and skills that can be used as resources in the learning of graphs (i.e. the lower anchor). The mathematics resources on graphs that learners, especially South African learners, should have attained before studying kinematics graphs are discussed in paragraph 3.6.1-3.6.3, 3.8.1.2 and 4.2.

#### *3.8.1.1 Graph skills and knowledge from knowledge and skills in mathematics*

Mathematical knowledge, and skills needed in physics education can be classified into four categories namely:

- Facts and simple knowledge
- Skills and procedure
- Concepts
- Understanding and relations (Molefe, 2006:46-48).

Molefe (2006:47), referred to the understanding and relations as conceptual knowledge which is illustrated in Table 3.4 below:

**Table 3.4: Mathematical conceptual knowledge and skills needed in graphs**

| Knowledge and skills | Concept /understanding |
|---|---|
| Conversion of units | Direct and indirect proportions |
| Factors of powers | Fractions to power and exponent |
| Changing the subject of simple equations | Proportion |
| Replacing symbols with numbers in an equation | Understand scientific symbols in equations and physical quantities |
| Representing and drawing points on a graph | Calculating gradient |

(Source: Molefe, 2006:47)

Molefe (2006) identified the mathematical conceptual resources related to kinematics graphs which include:

- The ability to calculate the gradient of kinematics graphs (e.g. velocity /time graph).
- The understanding of symbols in kinematics equations (e.g. $v = u + at$).
- The ability to understand relationship of variables using direct and inverse proportion to describe the relationship.
- The ability to convert fractions to powers is useful for determining scale. The ability to draw and interpret line graphs in mathematics is also a resource that is applicable to kinematics graphs.

Wavering (1989:378) suggested that teachers should be aware of the reasoning processes, typical mistakes and flaws learners bring to the classroom. They should also find ways to help the learners understand their errors in graph construction.

There has been more research on difficulties encountered by learners in kinematics graphs than on skills, knowledge, and resources needed in learning kinematics graphs. Some errors identified by Cleveland (1984:261) from graphs in science journals that were applicable to kinematics are summarized and reformulated as resources learners need to study and understand kinematic graphs:

- Labelling the parts of the graph correctly.
- Use of appropriate scale.
- Correct spacing of tick marks.(construction)
- Complete description of the graph.

Learners should possess some resources in order to explain the relationship of variables expressed in kinematics graphs. These resources include but are not limited to the following:

- The ability to label axes correctly
- Ability to use the correct units and scale

The title and labels on the axes of a graph as well as the key vocabularies are factors that require prior knowledge for comprehending mathematical relationships expressed in graphs (Curcio, 1987:383). Comparing the views of Curcio (1987:382-384) with Arons (1990:15), it is clear that scientific language and certain terminologies are essential resources needed to understand kinematic graphs. Arons affirmed his point with an illustration, where a ball is thrown into the air and stops at the top of its flight. The word stop to the learners means stand still for a while. And if the ball stands still for a while it certainly has zero acceleration, which is not wrong in terms of their reasoning, but is scientifically incorrect.

Learners begin to calculate 'rate' in mathematics in grade 9. For instance the distance travelled per second is defined as a rate that shows how many metres can be travelled in a second. This is a resource that is useful in understanding kinematic graphs (Laridon, Aird, Essack, Kitto, Pike, Sasman, Sigabi & Tebeila, 2006:183).

In grade 9 mathematics textbook, learners use graphs to interpret direct and inverse proportion (Laridon *et al.,* 2006:188) discussed in chapter 4. In kinematics, learners have to use this resource to determine and interpret the relationship between the variables.

#### *3.8.1.2 Knowledge and skills of graphs in the Revised National Curriculum Statement*

The Revised National Curriculum Statement (RNCS) grades R-9 schools mathematics (Department of Education, 2002c:61-88) in the South African context describes the learning outcomes and assessment standards for the senior phase (GET) (Grades 7-9). ''The Assessment standards for each grade show progression of knowledge, skills and values within each phase'' (Department of Education, 2002c:61). Assessment standards for the FET phase show progression of knowledge and skills from grade 10 to 12. There is therefore no direct link between grade 9 senior phase (GET) and grade 10 FET phase.

By the end of grade 9 as stated in the RNCS (Department of Education, 2002c:62-78) learners should be able to attain the under listed skills and knowledge:

- Describe patterns and relationships through the use of symbolic expressions, graphs, and Tables.
- Investigate numerical patterns to establish the relationships between variables and to analyse and describe them in the form of formulae and graphs.
- Expand the capacity to represent numbers in a variety of ways and move flexibly between representations.
- Gather, summarise, analyse, interpret, and represent both discrete and continuous data in order to identify trends and patterns.
- Solve problems that may be used to build awareness of measurement in natural sciences and technology context.
- Represent and use relationships between variables in order to determine input and /or output values in a variety of ways using verbal description, flow diagrams, tables, formulae and equations.
- Draw graphs on Cartesian plane from given equations (in two variables) and determine equations or a formula from given graphs using tables.
- Determine, analyse and interpret the similarity of different descriptions of the same relationships presented in tables, by equations, graphs on the Cartesians plane and verbally.
- Measure and compare distances and times taken by learners from home to school.
- Draw a variety of graphs by hand or technology to display and interpret data including; bar graphs, histograms with given and own intervals; pie charts; line and broken–line graphs; and scatter plots.

According to Alonzo and Steedle (2008:393) the upper anchor (top level) is the concepts learners are expected to understand. These are the kinematic concepts learners have to understand by the end of grade 10. These understanding are used to define the top level (upper anchor) of the learning progression. In the paragraph that follows (3.8.2) the upper anchor, namely knowledge and skills needed for understanding kinematics graphs is discussed.

### 3.8.2 Upper Anchor: The knowledge and skills required in grade 10 kinematics graphs

The upper anchor is the kinematic graph concepts that learners are expected to understand in grade 10. Kinematic graphs have the following features position, velocity or acceleration as ordinate and time as the abscissa (Beichner, 1994:751).

The Department of Education (2006:17-18), with regard to kinematic graphs proposed the following core knowledge and concepts for 2008-2010 in grade 10 physical sciences content in South African schools: A learner in grade 10 is required to understand the concepts listed below as upper anchor.

- Describe in words and distinguish between motion at constant velocity (uniform) and constantly accelerated motion.
- Describe the motion of an object given a position (x) versus time (t), velocity (v) versus time (t) or acceleration (a) versus time (t) graph.
- Given a description of motion in words, sketch graphs of position (x) versus time (t), velocity (v) versus time (t) and acceleration (a) versus time (t).
- Given one of the motion graphs, i.e. x versus t, v versus t, or a versus t, learners are required to sketch the other two graphs.
- Determine the velocity of an object from the gradient of the position versus time graph.
- Determine the acceleration of an object from the gradient of the velocity versus time graph.
- Determine the displacement of an object by finding the area under a velocity versus time graph.
- Use the kinematic equations to solve problems involving motion in one dimension.
- Demonstrate an understanding of motion of a vehicle and safety issues, such as the relationship between speed and stopping distance.
- Given a description of motion in words, to be able to sketch graphs of position versus time, velocity versus time and acceleration versus time.

## 3.9 UNDERSTANDING KINEMATICS GRAPHS

Friel *et al*. (2001:129) addresses the understanding of graph as reading and interpreting graphs, which many researchers have already focused on. Only a few researchers focused on constructing of graph and choice of graph. For learners to be able to interpret kinematic graphs they need to acquire graphing skills that need to be assessed (Beichner, 1994:751). They should be able to describe the graph, draw corresponding graphs, use the graph to determine given physical quantities e.g. determine the change in velocity.

Beichner (1994:752) used the physical quantities given on the table below to assess the interpretation skills of kinematics graphs. The last column gives data collected with the latest version of testing learners' interpretation of kinematics graphs.

**Table 3.5: The test of understanding kinematics graphs**

| Given | The students will... | Percent correct |
|---|---|---|
| Position-time graph | Determine velocity | 51 |
| Velocity-time graph | Determine acceleration | 40 |
| Velocity-time graph | Determine displacement | 49 |
| Acceleration-time graph | Determine change in velocity | 23 |
| A kinematics graph | Select another corresponding graph | 38 |
| A kinematics graph | Select textual description | 39 |
| Textual motion description | Select another corresponding graph | 43 |

(Source: Beichner, 1994:752)

Curcio (1987:384-386) investigated how prior knowledge of topic, mathematical content, and graphical form is related to understanding the mathematical relationships expressed in graphs with learners from grade 4 and 7. Curcio (1987:384) measured graph comprehension using twelve graphs composed of three bar graphs, three circle graphs, three line graphs and three pictographs. The results showed that prior knowledge with respect to graph comprehension is affected by age and grade differences and prior knowledge of mathematical content was the salient need for both grade 4 and 7 learners (Curcio, 1987:391).

### 3.9.1 Society expectations of learners' knowledge, understanding and skills

The ability to comprehend graphs is becoming more reliant to process information in our modern technological world (Curcio, 1987:382). Learners are expected to interpret graphs found in school and in the media. Wall and Benson (2009:84) suggest that learners should be taught the features of the categories they discovered (i.e. shading, area, or position to show either frequency or attribute) using different types of graphs. Learners will then be well prepared to read and understand both conventional and new graphs that they may come across.

### 3.9.2 Difficulties regarding kinematics graphs

Research findings show that even Honours students as well as PhD students have difficulties with kinematics (Shaffer & McDermott, 2005:921). These difficulties continue beyond high school and introductory physics. Moreover, these difficulties are not effectively addressed (Shaffer & McDermott, 2005:921).

The difficulties that kinematics present according to Shaffer and McDermott (2005:926) are among others to differentiate between velocity and acceleration of a given motion. The difficulties are mainly conceptual rather than mathematical. Their findings have led to operational definition of velocity and acceleration in terms of vectors and they help learners' apply vectors to analyze motion in one dimension.

The study conducted by Beichner (1994:754) also revealed that learners lack the vocabulary necessary to interpret kinematics graphs. Research showed that detail interpretation of kinematics graphs is a problem for learners. McDermott *et al*. (1987:506); Beichner (1994:755) discovered that the interpretation of the area under a graph is also problematic for most learners.

Guthrie *et al*. (1993:186) conducted a study on cognitive processes and deficits in understanding graphs, tables and illustrations. Their findings indicated that the level of competence in searching for trends was lower, meaning the concepts had not been learned. Nevertheless, the competence level of searching for specific information was high. It can be inferred from what is put forward by Guthrie *et al*. (1993:196-200) that, learners face difficulty in identifying trends in graphs.

### 3.9.3 Integration of mathematical concepts in kinematics graphs

Mathematics help learners understand and explain concepts and occurrences in science. Mathematics tea chers should ensure that learners can analyze data by creating graphs to help them explain concepts in science (Horak, 2006:364). Mathematical concepts are used in solving kinematic graphs problems. Arons (1995) indicated that when learners break through a mastery of mathematics reasoning with division they almost break through on control of variables, abstract concepts such as velocity and acceleration. In addition, their hypothetical deductive reasoning improves (Arons, 1995).

Nevertheless, learners who can plot and compute slopes easily without any problems in mathematic often cannot apply their knowledge and skills of graphs in mathematics to kinematics graphs in physics (McDermott *et al.,* 1987:503). Transfer of the concepts mastered in mathematics to physics to solve kinematics graphs problems can be achieved by learners if mathematics and physics is integrated and a careful development of learning progression in graphs is established.

## 3.10 IMPLICATION OF LEARNING PROGRESSION ON CONCEPTUAL UNDERSTANDING OF KINEMATICS GRAPHS IN SOUTH AFRICAN CURRICULUM

Rangecroft (1991a) pointed out that England Wales national curriculum indicated the level pupils should reach at the end of each level but the steps needed (progression) to achieve this was not clearly indicated. This is similar to South Africa curriculum, where the level learners should reach is outlined in detail but what is needed to progress from GET to FET is not clearly defined.

In South Africa extensive work is done in the use of line graphs in kinematics (grade 10) but bar graphs, circle graphs, and histograms are mainly done in grade 9. The logical inference is that mathematical skills and knowledge acquired in grade 9 can be transferable in grade 10 to solve motion problems.

To support the above argument, Hammer (2000:58) in ‘’Resources-based view of knowledge’’, suggested that students are not ready to understand a concept until they have developed resources from which to construct it. To acquire the resources, learners’ early education in science should consist largely of hands-on activities or in playful learner controlled activities than guiding learners only toward correct understanding of concepts.

The L shaped framework discussed in paragraph 3.3 is more applicable to kinematics graphs than the T shaped framework. Labelling of axes is examined internally in schools at the lower levels but externally in the National Senior Certificate (Grade 12) Physical Sciences (Appendix 1). The title of a graph is a type of label. Titles of graphs are included in the rubric or checklist for both internal and external examinations memoranda and learners loose marks if they do not include it. This is evident in grade 12 Physical sciences examination paper for February/March 2010 (paper one) question 14.2 (refer to Appendix G) and memorandum (refer to Appendix H). Paper one is the physics component of the physical sciences.

In Table 3.6 below, an illustration is given of a checklist as criteria for marking and allocating marks in graph questions. Scaling and correct plotting of points is an important skill and resource for learning kinematics graph. The marks allocations confirm the importance.

**Table 3.6: Checklist for marking kinematic graph**

| Checklist | Marks |
|---|---|
| Relevant heading | 1 |
| Axes labelled correctly with units | 2 |
| Appropriate scale | 2 |
| Plotting all the points | 2 |
| Line of best fit | 1 |

(Source: Appendix H)

## 3.11 SUMMARY

In the above chapter, various aspects of graphs have been discussed. The following were highlighted: definitions, structure, importance, and types of graphs as well as conceptual resources and difficulties related to kinematic graphs, learning progression related to kinematics graphs and factors that affect understanding of kinematics graphs.

Graphs as defined by various authors, describe relationships between variables, numbers, data, concepts etc. A typical graph is a diagram that consist of points joined together to form lines and patterns to display data pictographically and illustrate the relationship between the measured variables from which scientific deductions can be made.

Features of ordinary graphs that may influence learning and understanding of kinematic graph are scale, label, units, variables, axes and title. A velocity-time graph given the title of a position-time graph when testing learners' understanding of kinematics graphs will be misleading because the gradient gives different physical quantities. Also exchanging labels of axes, units and or scaling will give incorrect interpretation of the graph.

Hence, this study aims to identify the resources needed to learn and understand kinematics graphs in both mathematics and natural sciences and to identify logical flaws such as the absence of importance of graphs, graph related errors, and absence or errors in kinematics concepts. For this reason graphs in mathematics and natural sciences textbooks are analyzed in chapter 4.

# CHAPTER 4

# COMPARATIVE ANALYSIS OF GRAPHS IN NATURAL SCIENCES AND MATHEMATICS TEXTBOOKS OF SOUTH AFRICA

## 4.1 INTRODUCTION

Graphs are pictorial representations of data in such a manner that the facts revealed by the data can be easily seen and described. Graphs are treated in several South Africa prescribed textbooks. This chapter explores the extent to which grade 9 mathematics and natural sciences curricula contribute to the conceptual resources for learning kinematics graphs. It further discusses the uses and shortcomings of textbooks, knowledge and skills and basic requirements with regard to graphs in the curricula.

In this chapter the following will be discussed: The basic requirements of the curriculum: knowledge and skills (paragraph 4.2), the use of textbooks in teaching and learning (paragraph 4.3), dependence and disconnections of textbooks (paragraph 4.4), uses and shortcomings of textbooks (paragraph 4.5), graphs in grade natural sciences textbooks (paragraph 4.6), comparative analysis of resources needed for learning kinematics graphs in natural sciences textbooks used in South Africa (paragraph 4.7), graphs in grade 9 mathematics textbooks (paragraph 4.8), discussions: analysis of grade 9 mathematics and natural sciences textbooks (paragraph 4.9), and the summary (paragraph 4.10).

### 4.1.1 Natural sciences content and textbooks used in South African schools

#### a) Content

The learners who participated in this study followed the RNCS. It is therefore necessary that a brief description of it is made at this juncture. The South African curriculum for grade 9 natural sciences is composed of four content areas: (1) Life and Living, (2) Energy and Change, (3) Planet Earth and Beyond, (4) Matter and Materials. All these are encompassed in one single natural sciences textbook.

***Life and Living:*** Focuses on life processes and healthy living in order to understand balances, changes in environments, and the importance of biodiversity, (Department of Education, 2002b:5). This area falls under life sciences.

***Energy and Change:*** Focuses on how energy is transferred in physical and biological systems. This content area also addresses the consequences of human needs and wants on energy resources (DoE, 2002b:6). This falls under chemistry and physics.

***Planet Earth and Beyond:*** Focuses on the following: (1) structure of the planet and how the earth changes over time, (2) understanding why and how the weather changes, and the earth as a small planet in a vast universe (DoE, 2002b:6). Geography is the high school subject where the above content areas are mostly found and treated. The content falls under Astronomy and Space Science, which is not covered in high schools in South Africa as a school subject.

***Matter and Materials:*** Focus on the properties and uses of materials, as well as understanding their structural changes. This aspect is a combination of physics and chemistry (DoE, 2002b:6).

### b) Textbooks

Textbooks of natural sciences used in South African schools are subdivided according to the four content areas mentioned above. A variety of textbooks are published and submitted to the Department of Education for approval. The ones that are approved are listed and schools are allowed to make their own choice(s) from the approved list, called the National Catalogue (www.ltsm.doe.gov.za).

Textbooks from different publishers have been approved by the Department of Education (DoE) and schools in South Africa use these approved textbooks to deliver the content areas. Examples of such textbooks for natural sciences, mathematics and physical sciences include, but not limited to:

### Natural sciences grades 7 – 9:

- Science Today (Barker, Cohen, Doubell, Mgoqi, Mkhwanazi, and Mzolo, 2006).
- Science in Action (Naidoo, Bajrangi, Govender, Naidu and Pillay 2006).
- Shutters Natural Sciences (Ayerst, Dalton, Khumalo, and Smith, 2009).
- Successful Natural Sciences (Clitheroe and Dilley, 2006).
- Spot on Natural Sciences (Soobramoney and Vermaak, 2006).
- Real-life Natural Sciences (Roberts and Mokonyane, 2007).

- My Clever Natural Sciences (Fredricks, Kay, Luvhimbi, Mahooana, Middleton, and Ritchie, 2006).
- Headstart Natural Sciences (Toerien, Clitheroe, and Dilley, 2006).
- Focus on Natural Sciences (Clacherty, Barnard, Boddy-Evans, Collett, Dawson, Esterhuysen and Grayson, 2007).
- Viva Natural Sciences (Lombard, E., Lombard, O. and Geyer, 2006).

**Mathematics Grade 7- 9:**

- Maths Today (Groenewald, Minshall, Otto, Roos and van der Westhuizen, 2006).
- Study and Master Maths (Carter, Dunne, Morgan, and Smuts, 2006).
- Classroom Mathematics (Laridon, Arid, Essack, Kitto, Pike, Sasman, Sigabi and Tebelia, 2006).
- My Clever Mathematics (Nel, Schmidt and Stols, 2006).

**Physical Sciences Grades 10 – 11:**

- Study and Master Physical Sciences (Kelder and Nasiep, 2007).
- Viva Physical Sciences (Lombard, Pearson, Thomas and Lombard, 2008).

**Newer textbooks covering CAPS (Curriculum and Assessment Policy Statement):**

- Platinum Physical Sciences (Grayson, Harris, Mckenzie, Schreuder, 2011).
- SIYAVULA Physical Sciences (Hormer, Williams, Toerien, Maharaj, Masemula, Jones, Reddy, Diergaardt and Visser, 2011).

The discussion that follows in the paragraphs below cover different aspects of the content areas in the textbooks used by the schools selected to participate in this study. Textbooks are widely used by learners and educators in and out of school. Until the internet era, textbooks have remain the most valuable source of information even though they may be some possible shortcomings with respect to curriculum content coverage (Stern & Roseman, 2004:539-547; Duncan, Lubman, & Hoskins, 2011:143-149; Valverde, Bianchi, Wolfe, Schmidt, & Houang, 2002:1-3).

## 4.2 THE BASIC REQUIREMENTS OF THE CURRICULUM: KNOWLEDGE AND SKILLS

The RNCS spells out the content, knowledge and skills that must be taught per subject per phase. Process skills such as recording, investigating, and questioning, and observing, comparing, measuring, interpreting, predicting, planning, hypothesising, sorting, classifying, and communicating science information are essential in creating outcome-based tasks (DoE, 2002b:13-14). Learners are expected to acquire these skills from the grade R-9 natural sciences curriculum. According to the DoE (2002b:13), the term 'process skills' refers to the "learner's cognitive activity of creating meaning and structure from new information and experiences which are different from manipulative skills". Manipulative skills form a small aspect of process skills.

The following process skills can be associated with graphs:

***Recording information:*** This entails using a prescribed format to document information. The learner records by using Tables, labelling diagrams and listing ideas. The learner is expected to develop the skill of selecting a suitable format, knowing when and what to record and doing so without being prompted by the teacher (DoE, 2002b:13).

***Interpreting information:*** This may involve that the learner uses a variety of ways to create meaning from the acquired data and to structure the information. The learner has to change the form of information to other forms in order to reveal its meaning, look for patterns in recorded information, predict, interpolate for missing data, make an inference from given information, perceive and state a relationship between two variables, and construct statements to describe the relationship between two variables (DoE, 2002b:14).

***Communicating science information:*** This skill requires learners to know when to communicate ideas or results using the appropriate means of communication. This may involve the use of structures such as diagrams, models, Tables, concept maps, pie-charts and graphs by the learners (DoE, 2002b:14).

***Measuring:*** The learner's ability to choose appropriate instruments and to know when, how and what should be measured, as well as the accurate use of the instruments are essential skills. Learners are expected to read scales, use intermediate points between divisions on scales, and choose to do so without frequent reminder by the teacher. Measuring is an important skill and a resource for learning kinematic graphs (DoE, 2002b:13).

***Sorting and classifying:*** Involves the learner in using a given rule to sort items or data in a tabulated form, a mind map, or to list ideas or use other systems to classify. The learner decides on his/her own rules for classifying or for choosing a suitable system such as a Table, a dichotomous key, or a mind map (DoE, 2002b:13).

The knowledge and skills needed to learn kinematics graphs is accessible from the study of mathematics. Therefore, both mathematics and science influence the conceptual understanding, interpretation and drawing of graphs. "Mathematics is defined as a human activity that involves observing, representing and investigating patterns and quantitative relationships in physical and social phenomena and between mathematical objects themselves" (DoE, 2002c:13). Mathematics uses its own symbols and notations for describing numerical, geometric and graphical relationships.

Mathematics as a Learning Area includes knowledge and skills that are interrelated:

- **Knowledge:**
  - Numbers: operations and relationships
  - Patterns: functions and algebra
  - Space and shape (geometry)
  - Measurement
  - Data handling

- **Skills:**
  - Representation and interpretation,
  - Estimation and calculation,
  - Reasoning and communication,
  - Problem solving and investigation,
  - Describing and analysing (DoE, 2002c:4).

At the end of grade 9 learners are expected to have achieved the following:

Learners should be able to ***draw graphs*** on the Cartesian plane for given **equations** (in two variables), or to determine equations or formulae from given graph **using Table**s where necessary (DoE, 2002c:77).

Learners should be able to **determine, analyse and interpret** the equivalence of different descriptions of the same relationship or rule presented:

• Verbally; • in flow diagrams; • in Tables; • by equations or expressions; • by graphs on the Cartesian plane in order to select the most useful representation for a given situation. (DoE, 2002c:77).

Learners should be able to ***solve*** ratio and rate problems involving **time, distance and speed** (DoE, 2002c:85).

Learners should be able to **draw a variety of graphs** by hand and or technology to display and **interpret data** including: bar graphs and double bar graphs; histograms with given and own intervals; pie charts; line and broken-line graphs; scatter plots (DoE, 2002c:90). Learners should be able to **critically read and interpret data** with awareness of sources of error and manipulation to draw conclusions and make predictions (DoE, 2002c:91). The subsequent paragraphs offer an analysis of graphs from both grade 9 mathematics and natural sciences textbooks. One expects that the content of the textbooks align with the skills and knowledge outlined in the curriculum as discussed above.

## 4.3 THE USE OF TEXTBOOKS IN TEACHING AND LEARNING

Potgieter, Harding, and Engelbrecht (2008:198) compare the approaches of six different standard chemistry textbooks for the presentation of the influence of electrolyte concentration on cell potential. Graphical representations of any kind were absent from all the six textbooks, except from one written by Silberberg 2006 on page 918 where the author included a graph to demonstrate the mathematical relationship between the variables (Potgieter *et.al.*, 2008:198). A similar result was found in grade 9 natural sciences textbook written by Roberts and Mokonyane (2007). It shows inadequate graph related topic explanations before graph related worked examples are provided. The absence of information, concepts, and illustrations may have a negative effect on the teaching and learning of a particular topic.

Textbooks also act as surrogate teachers when the teacher is absent, hence learners should be encouraged to use the textbook as a learning resource, even though textbooks differ widely in the way they depict science and their presentation of the contents (Harrison, 2001:415). Teachers use textbooks as the principal resource to plan work programs, work schedules and the content of their science lessons. Some teachers use “students’ textbooks” as a basic reference tool, but others use it as a guide in planning what to teach (Sánchez & Valcárcel, 1999:499).

Ball and Feiman-Nemser (1988:402) mention that during their observation in a teacher education course, they noticed that the instructors promoted the idea that good teachers do not depend on textbooks and teacher guides. Instead, they should develop their own curriculum. According to Ball and Feiman-Nemser (1988:407), textbooks have to be used as resources to get ideas and not to be followed verbatim. They further argue that effective teachers can help learners learn important ideas when they develop their own units, lessons, and materials.

Ball and Cohen (1996:6) affirm that good teachers do not depend on textbooks. On the other hand, Lubben, Campbell, Kasanda, Kapenda, Gaoseb, and Kandjeo-Marenga (2003:120-123) confirm that some (20%) of the educators who participated in their study depend on textbooks as the final authority in the classroom. They gave a scenario where an educator in the classroom asked for a textbook when learners gave opposing views.

Science textbooks often do not portray learner misconceptions and thinking, but provide information on activities and content for teaching and learning (Ball & Feiman-Nemser, 1988:406). The results of Ball and Feiman-Nemser, (1988:407) study show that beginner teachers participating in the study have been trained to believe that textbooks have serious deficiencies and are inadequate for good teaching.

Selected rural Kenyan primary schools participated in the Schools Assistance Program (SAP). The results of the study demonstrate that the provision of textbooks to each learner do not guarantee achievements like passing a grade. The provision of textbooks to the rural Kenyan schools benefited the academically stronger learners more than the weaker ones (Glewwe, Kremer & Moulin, 2009:113).

## 4.4 DEPENDENCE AND DISCONNECTIONS OF TEXTBOOKS

Natural sciences and physical sciences textbooks are scientific publications used for training and they lay the foundation for a scientifically literate nation (Lemmer, Edward & Rapule, 2008:185). Learners of the current generation depend on textbooks as a source of knowledge. Educators alike depend on textbooks for the delivery of content. Gallagner and his students also noted a dependency on textbooks. Gallagner (1979) found that teachers only teach aspects of the nature of science when it is included in the introductory part of the textbooks they use.

Stern and Roseman (2004:543) examined content alignment by using a procedure that examined material alignment to specific key ideas. They found that although science textbooks aligned with the standards at the topic level, the specific ideas within the topics was not automatically included within those topics on which benchmarks and standards were set.

The claim that textbooks dictate what is taught also assumes that text books address all facets of teachers' subject content decisions.This is often not the case (Harrison, 2001:416). If educators and learners depend entirely on textbooks to dictate what to teach and learn then text books should address all the basic contents as prescribed in the curriculum.

The criteria listed below for evaluating the quality of instructional support for a topic in life sciences (Stern and Roseman, 2004:558) can be adopted to evaluate kinematics graphs in natural sciences textbooks.

**Table 4.1: Criteria for evaluating the quality of instructional support for a topic (kinematics graphs) in mathematics and natural sciences textbook**

| Category | Criteria | Check |
|---|---|---|
| Category I<br>Identify and maintain a sense of purpose | Conveying unit purpose: Does the material convey an overall sense of purpose and direction that is understandable and motivating to learners?<br>Conveying activity purpose: Does the material convey the purpose of each activity and its relationship to other graphs? | |
| | Justifying activity sequence: Does the material include a coherent sequence of activities? | |
| Category II<br>Taking account of learners ideas | Attending to prerequisite knowledge and skills: Does the material alert teachers to learners conceptual resources? | |
| | Assisting teachers in identifying learners’ ideas: Does the material include suggestions for teachers to find out what their learners think and know about familiar phenomena related to the learning outcome before scientific ideas are introduced? | |
| Category III<br>Engaging learners with relevant phenomena | Providing variety of phenomena - Does the material provide multiple and varied experience to support the benchmark?<br>Providing vivid experiences - Does the material include firsthand experiences with phenomenon? | |
| Category IV<br>Developing and using scientific ideas | Introducing terms meaningfully - Does the material introduce technical terms to facilitate thinking, use of scientific language and promote effective communication? | |
| | Demonstrating use of knowledge - Does the materials demonstrate/model or include suggestions for teachers on how to demonstrate and model drawing and interpreting graph skills or how to use learners’ knowledge? | |
| | Providing practice- Does the material provide tasks/questions for learners to practice skills or use knowledge in a variety of situations or variety of kinematics graphs? | |

| Category | Criteria | Check |
|---|---|---|
| Category V Promoting learner thinking, experiences, and knowledge | Encouraging learners to explain their ideas - Does the material normally include suggestions for having each learner express, clarify, justify, and represent his or her own ideas? | |
| | Guiding learners interpretation and reasoning - Does the material include tasks and/or questioning sequences to guide learners' interpretation and reasoning about kinematics graphs, their experiences with phenomena and readings? | |
| Category VI Assessing progress and aligning to the goals | Is there a content match between the curriculum material and assessment items?<br>Informing instruction - Are some assessments set inline with the curriculum and with advice to teachers as to how they might use the results to choose or modify activities? | |
| | Testing for understanding - Does the material assess understanding of kinematics graphs ideas and not only encouraging learners' to repeat a memorized term or phrase from the text without understanding? | |
| Category VII Enhancing the science learning environment | Providing teacher content support- Would the material help teachers improve their understanding of science, mathematics, and technology necessary for teaching the kinematics graphs? | |
| | Encouraging curiosity and questioning - Does the material help teachers to create a classroom environment that welcomes learners curiosity, rewards creativity, encourages a spirit of healthy questioning, and avoids inflexibility? | |
| | Supporting all students - Does the material help teachers to create a classroom community that encourages high expectations for all learners, that enables all learners to experience success? | |

(Source: Stern and Roseman, 2004:558-559)

However, before the listed criteria can be effectively functional, a benchmark should be established. The benchmark with reference to kinematics graphs is the concepts, learning outcomes and assessment standards in the RNCS (paragraph 4.2).

Textbooks are largely silent on how much time should be devoted to a subject matter area over the course of a school year (Freeman & Porter, 1989:404). However, some of the new textbooks used in schools in South Africa do include time frames.

Textbooks generally do not address the question of whether different students should be taught different content or whether different strategies should be used and, if so, what content they should be taught or what strategies should be used. Since textbooks treat certain topics and not others, they may influence teachers' choice of topics to teach (Freeman & Porter, 1989:404).

## 4.5 USES AND SHORTCOMINGS OF TEXTBOOKS

Science textbooks are the primary resources that are used in schools (Stoffel, 2005a:151; Hubisz, 2003). In South Africa there are schools without libraries, science laboratories and internet facilities, so their main resource is the textbook. Textbooks act as important promoters of specific subject knowledge (Valverde *et al.,* 2002:2-3). As a vision for schooling, science textbooks provide opportunities to stimulate curiosity and encourage an increased interest in science (Duncan, Lubman & Hoskins, 2011:144-148) and are used to train future scientists.

Malcolm and Alant (2004:73) argue that textbooks serve as an essential source of knowledge in science, help with curriculum planning and act as a teaching tool for teachers. In the same way Ensor, Dunne, Galant, Gumedze, Jaffer, Reeves and Tawodzera (2002:22) believe that textbooks 'set up academic pathways' for both teachers and learners.

The uses of textbooks according to Valverde *et al.* (2002:1-4) are as follows:

- Textbooks are used to provide educational opportunities and to define the school subjects as learners experience them.
- They translate a country's curriculum policies into representations and operations that are used by educators and learners in the classrooms.
- They provide opportunities to master knowledge and skills believed to be of importance to society.
- They act as mediators between the curriculum policy makers or designer and the teacher by providing guidelines in the classroom.

Textbooks provide uniformity in the subject content for all learners and educators. According to Ball and Cohen (1996:6), educators use textbooks as a way to design a relatively common curriculum within the diverse settings in the school system. If learners in a given Province or District use the same recommended textbook, then all learners and educators will have the same subject content to cover. The setting of common assessment (test and exams within the year) in such a case will be uniform and much fairer for all.

The content of textbooks is known before the textbooks existence. That is, the curriculum is determined before the textbooks are published. There is a general uniformity of content, even though the approaches used to deal with the content bring about differences between the textbooks. The approach differs from one textbook to the other (Boostrom, 2001:235).

Stoffels (2005b:532) stated that educators who participated in his study clearly mentioned that the textbook, referred to as Learner Support Material (LSM), is too simple, non-challenging and very shallow, but it is the very material that learners depend on to find all answers.

According to Hubisz (2003:51) science textbooks should be accurate and age appropriate. However, the results of his investigation identified inaccuracies and poor presentations of scientific concepts in the textbooks he reviewed. He found errors related to kinematic concepts such as speed, velocity and acceleration. Lemmer *et al.* (2008:184) state that the majority of the grade 7 educators who participated in the research assumed that textbooks do not have errors and are scientifically correct and can be used to teach learners effectively. Edwards (2007:10), however, found errors in the grade 7 textbook he analyzed.

Lemmer *et al.* (2008:180) also found that out of the 16 educators that participated in their research only four used the same textbook in grade 7. The other 9 educators used different textbooks. However, they discovered that each school used a single grade 9 natural sciences textbook. According to these findings learners will be at a disadvantage as they move from one school to another. The differences between the textbooks will make it difficult for them to find continuity in the work. Edwards (2007:97) indicates that learners who move to different schools due to transfer during a phase of their education may face the challenge of adopting and adapting to new textbooks. The content, depth, approach and presentation differ from textbook to textbook. The same experiments presented in 6 different biology textbooks examined by Duncan *et al.* differed in their presentations (Duncan *et al.,* 2011).

The study of Lumpe and Beck (1996:150) was directed at the review of biology textbooks. The analysis of Lumpe and Beck (1996:150) results reveals the following:

- Biology textbooks contain large numbers of vocabulary terms (glossary).
- Biology textbooks cover mainly the knowledge of science strand and do not cover all the strands.
- Not all textbooks integrate the four strands to display the holistic nature of science.

These results show that there is a possibility that no single textbook covers all four strands and the four content areas in the natural sciences textbooks used in South African schools.

A learner's development of interest in a subject can also be influenced by the illustrations found in textbooks. Duncan *et al.* (2011:143) state that increasing the illustrations of scientific investigations in science textbooks can facilitate an increase in early interest in science among undergraduate students.

South African educators' dependence on the traditional content-heavy textbook that was produced during the previous content-heavy curriculum dispensation (Potenza and Monyokolo, 1998) can lead to disconnections in science. Textbooks contribute to undergraduate disengagement in science because the instructors depend heavily on the content and organization of the textbooks they use (Duncan *et al.,* 2011:143).

In a study Stoffels (2005a:151) found that one educator depended on the SciGuide Learner Support Material (LSM) practical worksheets and followed it step by step, except for the biology part, which he hardly did because of limited content knowledge. This educator majored in chemistry and physics and not biology. One can deduce that the textbook (LSM) does not provide all the content the educator needs to be confident to teach or demonstrate the biology knowledge to the learners.

Research studies by Stern and Roseman (2004:556) specify that many teachers rely on textbooks and curriculum materials to provide them with some or all the content knowledge. Teachers who did not major or study a particular subject tend to rely heavily on curriculum materials and textbooks (Stern and Roseman, 2004:539; Hubisz, 2003). This situation is typical in the GET phase in South African schools, where natural sciences teachers often do not major in all three sciences (physics, chemistry and life sciences (Biology), (Stoffels, 2005b).

There is no theory for the generation of most textbooks. The content, emphasis and pedagogy is controlled by the publishers (Boostrom, 2001:230). The publishers of textbooks are concerned with the distribution and sale of the textbooks, so marketing and profit are among their priorities. Marketing strategies, cost-effectiveness and profitability are other factors that can affect the quality and differences between the textbooks.

According to the South African publishers and authors who were responsible for the grade 9 natural sciences textbook, they had 6 months to write the grade 9 natural sciences textbook that is used in most of the South African schools. They expressed the view that the short time given to develop the textbook hampered the quality of the textbooks, even though they were guided by the framework of the Revised National Curriculum Statement (RNCS) (Stoffels, 2007:8-9).

## 4.6 GRAPHS IN GRADE 9 NATURAL SCIENCES TEXTBOOKS

The selected process skills listed in section 4.2 serve as a yardstick to determine textbooks that will provide learners with the basic requirements to learn kinematics graphs in grade 9. The textbooks discussed in this section were classified as A, B, C, to J to make the analysis and discussion more understandable. The paragraphs below offer a discussion of graphs found in grade 9 textbooks used in the schools that participated in this study:

### 4.6.1 Textbook A

Clitheroe and Diley (2006:45, 84, 132) display the following graphs in their textbook:

- a pie chart of domestic energy usage in the USA;
- a pie chart illustrating the distribution of South Africa's main exports;
- a line graph showing the concentration of carbon dioxide in the atmosphere in the different periods.

Graphs are not introduced anywhere in the textbook. The importance and uses of graphs are not mentioned either. The first graph is an activity involving a pie chart. The textbook does not provide a completed example. It does not place any emphasis on the skills of drawing and interpreting graphs. Two out of the three graphs in the textbook are pie charts, and the other is a line graph. Learners who use this textbook in grade 9 will have little conceptual resources to learn kinematics graphs in grade 10. Some of the skills listed in the curriculum such as reading, scaling, the use of Tables and other types of graphs and diagrams to communicate data, results and ideas, and describing and stating relationships between variables are not reflected in the textbook.

### 4.6.2 Textbook B

Barker, Cohen, Doubell, Mgoqi, Mkhwanazi, and Mzolo (2006:33, 45, 60, 93, 109.129, 170-171, 174, 180) give different types of graphs on different pages of the book. Examples of such graphs include:

- Bar chart: A graph of the percentage daily requirement of calcium and iron obtained from 100 g of different foods.
- Line graph: A graph showing the results of Mpho's experiment - the mass of candle burnt every 10 minutes.
- Line graph: Explain how to draw and interpret a line graph.
- Line graph: Effect of light intensity on photosynthesis.
- Bar graph: The black rhino population from 1960-2004.
- Line graph: Graph of incidence of child abuse in South Africa over a recent five-year period.
- Bar graph: A graph of South Africa's share of the world's production of certain minerals in 2003.
- Circle graph/pie chart: A graph of South Africa's share of the world's production of certain minerals in 2003.

- Bar graph: Graph showing how important fossil fuel is for different purposes in South Africa.
- Bar graph: Graph illustrating the proportion of energy used by different sectors of the economies.

The textbook provides different types of graphs for practice, which can lead to the development of skills to some extent. A few line graphs related to learning kinematic graphs are included. In this textbook, the first encounter with graphs is an activity on a double bar graph which covers Learning Outcome one (LO1) Assessment Standard (AS), LO1 AS: which involves evaluating data and communicating findings; LO2 AS: involves interpretation of information. The curriculum mentions process skills that are not well represented in this textbook. These include drawing a conclusion, the use of different formats to communicate information, and the description of patterns, as well as relationships.

### 4.6.3 Textbook C

The natural science textbook for grade 9's by Toerien, Clitheroe and Diley (2006:47, 85, 133) boasts of four pie charts:

- One pie chart shows how we use electricity in our homes, asking questions like "According to the chart, which activity uses the most electricity?" The name of an activity and a percentage indicating usage is given on the pie chart. Learners read directly from the graph to gather the information for the straight forward questions.
- Another pie chart shows the oxygen, nitrogen and other gases distribution in the atmosphere. The learners are asked to draw their own pie chart of the ancient atmosphere using the information provided in the unit.
- There are two pie charts showing South Africa main exports and imports. Only three questions are related to these graphs. The questions only probed the learners to look for information. For example: "Does South Africa import more raw materials or manufactured goods?"

The numbers and types of graphs found in the textbook are very few and do not give learners adequate interaction with graphs. Learners using this textbook in grade 9 may experience some difficulty with kinematics graphs due to inadequate resources. There is not a single line graph in this natural science textbook. If the teacher solely depends on this textbook the learners may see a line graph for the first time in grade 10. They may have inadequate exposure to graphs in grade 9 and therefore have less conceptual resources to assist them in learning kinematic graphs in grade 10.

The use of different formats such as diagrams, models, Tables, concept maps, pie charts and graphs to communicate information is mentioned in the RNCS as discussed in section 4.3, but in this textbook one finds only pie charts.

### 4.6.4 Textbook D

There are four line graphs and one bar graph in a natural sciences textbook of 305 pages. The graphs illustrated include:

- A line graph showing the rate of growth of a population of bacteria and one application question on relationship (Naidoo, Bajrangi, Govender, Naidu & Pillay, 2006:52).
- A bar graph and line graph showing the number of AIDS deaths per age group and gender in South Africa (Naidoo *et al.,* 2006:58).
- Two line graphs that show the amount and percentage of carbon dioxide since 1900. Only two questions are related to the graph. For example: “How has the amount of carbon dioxide released changed since 1950?” (Naidoo, *et al.,* 2006:70).

An introduction of graphs as a topic is not included in the textbook. Instead, graphs are included in the activities without any information about the skills of drawing, interpreting graphs and the differences between the types of graphs. Other skills (mentioned in section 4.3) are not included in the textbook.

### 4.6.5 Textbook E

Soobramoney and Vermaak (2010) mostly record experimental results in the form of graphs or Tables. In the first few pages of this book, the authors explain and describe various scientific methods and the use of Tables, line graphs, bar graphs, histograms and pie graphs, variables, and how to record results. A typical example of a question related to graphs is: “Study the line graph and explain what the graph shows”. Questions and activities included in the textbook give learners practice to develop the skills needed to draw and interpret graphs.

Different graphs are illustrated in different pages by Soobramoney and Vermaak (2010:9, 12, 39 42,71,79,98, 102,131,133). For instance:

- A bar graph, histogram, line and pie graphs are illustrated on page 8 and 9.

- Two pie charts are included.
- A pie graph shows employment in the mining sector in South Africa by Province.
- A bar graph shows South African mineral sales.
- A pie chart shows the distribution of fossil fuels in Africa.
- A histogram shows the consumption of electricity in a small town at different times.
- A line graph shows the amount of hydrochloric acid secreted into the stomach over 10 hours.
- A double bar graph shows the percentage of male and female deaths above normal in a population that dies due to obesity.

Questions found in the book include plotting a line graph, drawing the different types of graphs, and interpreting Tables and graphs. The various characteristics of graphs like the length of bar graphs are used to compare data in a clearly visible way (Soobramoney & Vermaak, 2010:9). Learners are exposed to variety of exercises related to graphs such as drawing pie charts, bar graphs or histograms from a Table with information. Learners using this textbook should have a good understanding of graphs and should have the conceptual resources that will be needed to learn kinematic graphs.

### 4.6.6 Textbook F

Clacherty, Bernard, Boddy-Evans, Collett, Dawson, Esterhuysen and Grayson (2007) introduce their textbook with an explanation to the use of scientific method. The following concepts on graphs measurements, recording, observations, prediction, variables, drawing and interpreting graphs are explained on different pages as indicated below.

Independent variables with distinct categories are used in bar graphs, whereas line graphs use continuous variables. In this grade 9 textbook variables are explained, and a few (6) graphs are used as illustrations.

- A bar graph and line graph illustrates percentage composition of the earth's atmosphere and the amount of carbon dioxide in the atmosphere respectively.
- Histograms and line graphs which show records of monthly rainfall in Cape Town, Manaus, Port Nolloth, George, Durban, Victoria-West, Johannesburg and Nelspruit.

- A line graph represents the hours of day light recorded per day within a period of twelve months. Copper prices in Dollars from 2000 to 2005 are presented on a line graph.
- A bar graph shows the percentage of water usage in the world.

A good understanding of variables is a valuable resource for learning kinematics graphs. For instance, Clacherty *et al*. (2007) explain that if the independent variable has distinct categories, then a bar graph is used. On the other hand, a curve or line graph is used when both variables are continuous (Clacherty *et al.,* 2007: 7, 42, 99,138-139, 146-147,165, 227).

### 4.6.7 Textbook G

In Cherub and Govender (2006,146,160, 163,174) bar graphs and pie charts are used to illustrate energy distribution, mining income per province, percentage of oxygen on Earth and percentage of elements making up the Earth's Crust. The questions in the textbook do not highlight any relationship between variables. There are no line graphs in the textbook.

The introductory pages consist of a Table of contents; 'how to use this book'; and a science skills investigation checklist. The science skills cover hypothesis, drawing conclusion and presenting data in suitable forms.

### 4.6.8 Textbook H

This textbook was written by Fredericks, Kay, Luvhimbi, Mahooana, Middleton and Ritchie (2006) and the comments below are based on the textbook.

- The first unit is ecosystem and the first graph is a pie chart on the use of water resources in South Africa.
- The line graph for world human population growth over the last 2000 years is followed by questions like: "Explain the trend in human population growth shown in the graph".
- Another example is to give reasons for the dramatic increase in population growth. The graph and the questions will give the learners interpretation skills (Fredericks *et al.,* 2006:27).
- Other line graphs are found on page 90.
- Not a single bar graph can be found.
- Histograms are illustrated on the following pages: 29, 30, 90, and 192.

- Pie charts are found on page 170.

Horizontal and vertical axes of a graph are explained in the glossary. The importance of graphs is not mentioned in this textbook. Interesting enough, the graphs are all related to plants, animals and the climate. Compared to the other textbooks discussed in this study this textbook has the most histograms, but only two line graphs.

### 4.6.9 Textbook I

The introductory pages of the textbook written by Roberts and Mokonyane (2007) include 'what you will learn', an information web and science investigations skills. Under science investigations planning, prediction, observation, recording results, drawing conclusion and evaluating are explained. Roberts and Mokonyane (2007) mention that results should be displayed using suitable charts or graphs.

- The following graphs are found in Roberts and Mokonyane (2006), i.e. pages 51, 52, 53, 71, 75, 141, 148-151,
- Line graphs: In unit 4, Roberts and Mokonyane (2007) explain and illustrate distance-time graph, velocity-time graph, and speed-time graph.

The following resources are included in this textbook:

- Determination of the gradient of the graph
- The meaning of zero gradient
- Differentiation between a speed-time and velocity-time graph
- Calculating acceleration from a velocity–time graph
- Description of a positive and negative gradient
- Distinction between distance and displacement

However, the introduction of unit 4 only gives the overview of the unit. The importance of graphs is not explained or discussed in the textbook.

A number of questions included in unit 4 that seek to assist learners in their practice and development of skills are:

- Drawing graphs
- Interpretation of graphs e.g. velocity–time graph (Roberts and Mokonyane, 2007:151).

- Calculations related to kinematic graphs
- Differences between the kinematic graphs

Roberts and Mokonyane (2007:152) end the unit with a self-assessment sheet to be filled by the learner. This helps the learner and educator to access the progress and level of achievement, as well as the level of understanding of kinematic graphs.

The introduction of kinematic graphs in grade 9 as illustrated in Roberts and Mokonyane (2007) are accompanied by simple basic questions and problems for learners to solve. These questions and problems can be extended to gradient, drawing and interpreting the graphs, similar to what learners do in mathematics in grade 9. The learners using this textbook should have a solid foundation (prior knowledge) to learn kinematic graphs.

### 4.6.10 Textbook J

Lombard, Lombard, and Geyer (2006) wrote a grade 9 natural sciences textbook, which is subdivided into units. Each unit ends with a glossary. Unit 1 ends with explanation and definition of concepts like: interpret, investigate, plan, and follow a plan. On the introductory page Lombard and Geyer (2006:1-10) explain how to draw a line graph, label axes, plot points, draw the best line through the points, how to record results using a Table.

- A line graph shows an activity where learners have to draw a line graph of the amount of solid dissolved verses temperature (Lombard *et al.,* 2006:99).
- A bar graph shows the pulse of 2 people over a period of 10 minutes (Lombard *et al.,* 2006:185) and another bar graph can be found on page 213.

Only three graphs can be found in the entire 253 page textbook. Learners will have limited conceptual resources and poor understanding of graphs. The comparative study of the above grade 9 natural sciences textbooks are summarized and presented in Table 4.2.

**Table 4.2: Summary of grade 9 natural sciences textbooks analysis results: General information**

| TEXTBOOKS | Total number of pages | AUTHORS | COMPARATIVE VARIABLES | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Introduction Basic concepts | Number of line graphs | Number of bar graphs | Number of pie charts | Number of histograms | Introducing Skills of drawing | Discussing differences in graphs | Discussing importance and uses of graphs | Introducing skill of interpretation |
| A | 154 | Clitheroe and Dilley | No introduction | 1 | 0 | 3 | 0 | no | No | no | no |
| B | 185 | Barker *et al.* | No introduction | 3 | 3 | 5 | 0 | no | No | no | no |
| C | 156 | Toerien *et al.* | No introduction | 0 | 0 | 3 | 0 | no | No | no | no |
| D | 304 | Naidoo *et al.* | No introduction | 1 | 1 | 1 | 0 | yes | Yes | yes | yes |
| E | 188 | Soobramoney and Vermaak | There is an introduction | 4 | 7 | 3 | 2 | yes | Yes | no | Yes |
| F | 250 | Clacherty *et al.* | There is an Introduction | 13 | 9 | 1 | 6 | yes | Yes | no | Yes |
| G | 192 | Cherub and Govender | No introduction | 0 | 2 | 2 | 0 | no | No | no | No |
| H | 209 | Fredericks *et al.* | No introduction | 5 | 0 | 1 | 7 | no | No | no | No |
| I | 230 | Roberts and Mokonyane | There is an introduction | 3 | 0 | 0 | 0 | no | Yes | no | Yes |
| J | 253 | Lombard and Geyer | There is an introduction | 0 | 2 | 0 | 0 | yes | No | no | Yes |

(Source: Data collected for this study

1. The most common graph, found in eight out of the 10 (80%) natural sciences textbooks, is pie charts showing the exports and imports in South Africa.
2. (7) 70% of the textbooks have activities that are related to line graphs.
3. (2) 20% of the books have a single line graph in the whole textbook.
4. Only 10% of the textbooks illustrate more than five line graphs.
5. Only 3 (30%) of the textbooks include histograms and the same number include the skills of drawing graphs in the introduction.

6. None of the textbooks mention the importance of graphs.

7. 5 (50%) of the textbooks explain some basic skills or give examples in the introductory pages of the textbook that relates to the interpretation of graphs and development of skills.

The comparative analysis of the grade 9 natural sciences textbooks with the conceptual resources needed for learning kinematics graphs is summarized and presented in Table 4.3.

## 4.7 Comparative analysis of some resources needed for learning kinematic graphs in various natural sciences textbooks used in South African schools

A Table with the list of textbooks and the relevant information (conceptual resources) needed for learning kinematics graphs is illustrated below. The symbols √ and X are used in Table 4.3 X, means that the specific information ticked is not in that textbook, √ means that the information appears in the textbook.

**Table 4.3: Textbooks with relevant information needed for learning kinematics graphs**

| | | Relevant information needed for learning kinematic graphs identified | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Introductory pages | | | | | | Skills | | | Learning outcome | Questions related to skills needed to learn kinematics graphs | | | | | | |
| Natural sciences textbooks | Authors | Explains variables | Explains how to draw graphs | Distinguishes between graphs | Describes different graphs | Discusses the importance of graphs | Explanation of the uses of graphs | Explains how to calculate and determine gradient from a graph | Explains how to use a scale | Explains scientific skills and how to conduct investigations | List of learning outcomes and assessment standards/ assessment methods | Drawing line graph | Plotting | Scaling | Interpreting (identifying relationship) | Gradient | Identify variables | Distance-time graph |
| A | Clitheroe and Dilley | x | x | x | x | x | x | x | X | x | √ | x | x | x | √ | x | x | x |
| B | Barker *et al.* | x | x | x | x | x | x | x | X | x | √ | x | x | x | √ | x | x | x |
| C | Toerien *et al.* | x | x | x | x | x | x | x | X | x | √ | x | x | x | √ | x | x | x |
| D | Naidoo *et al.* | x | x | x | x | x | x | x | X | x | √ | √ | √ | x | √ | x | x | x |
| E | Soobramoney and Vermaak | √ | x | √ | √ | x | x | √ | X | √ | √ | √ | √ | √ | √ | x | √ | x |
| F | Clacherty *et al.* | √ | x | √ | √ | x | x | √ | X | √ | √ | √ | √ | x | √ | x | √ | x |
| G | Cherub and Govender | x | x | x | x | x | x | x | X | √ | x | √ | √ | x | √ | x | x | x |
| H | Fredericks *et al.* | x | x | x | x | x | x | x | X | x | x | x | x | x | √ | x | x | x |
| I | Roberts and Mokonyane | x | x | x | x | x | x | x | X | √ | √ | √ | √ | x | √ | √ | √ | x |
| J | Lombard and Geyer | x | √ | x | x | x | x | x | X | x | x | x | x | √ | √ | x | x | x |

(Source: Data collected for this study)

The criteria to determine the relevant information is listed in the top columns. Names of the textbooks are represented by the letters A, B, C, D, E, F, G, H, I and J.

Lombard *et al.* (2006) mention the need to choose values for the x- and y- axes of a graph, but do not mention the terms dependent and independent variables. Fredericks *et al.* (2006) define acceleration as the rate at which the speed of an object changes and displacement as a movement or distance in a specific direction, either forward or backwards. They include an explanation of linear relationship, light and force. Force is the main physics topic that is treated in detail (Fredericks *et al.,* 2006). Variables are not explained, but learners are asked to find the dependent and independent variables from a graph (Barker *et al*., 2006:129).

## 4.8 GRAPHS IN GRADE 9 MATHEMATICS TEXTBOOKS

Five out of the seven schools that participated in the study use Classroom Mathematics (Laridon, Aird, Essack, Kitto, Pike, Sasman, Sigabi & Tebeila, 2006). It is a popular book commonly used in South African Schools.

### 4.8.1 Mathematics textbook A

The Classroom Mathematics textbook for grade 9 learners contains sufficient graphs. The authors, Laridon, Aird, Essack, Kitto, Pike, Sasman, Sigabi and Tebeila (2006) discuss different types of functions and gradients. One of the functions that need mention is linear function because of its close relation to kinematics graph concepts. For instance, a linear function has a constant gradient just as a velocity-time graph with a constant acceleration.

The introductory pages of the textbook explain how to use the textbook, but chapter 10 on functions and graphs explains the coordinate system. Laridon *et al.* (2006) explain how to calculate rates, interpret and solve problems using direct and inverse proportion. “Rate” is described as the quantity of one variable item per unit of another variable item (Laridon *et al.,* 2006:122).

In Chapter 10 of the textbook (Laridon *et al.,* 2006:202-205), learners are requested to practice analysis and interpretation of information graphically to solve abstract and real-life problems. For example, a graph of the distance (in kilometres) versus the time (in minutes) that a taxi driver travels from a point A to point B to take a passenger to the airport. If learners master these types of graphs well in grade 9 mathematics class it can serve as conceptual resources that can be used in kinematics graphs in grade 10. The question of how many learners will be able to transfer this knowledge from mathematics to physics remains to be answered.

The organization, representation and interpretation, as well as analysis of data through a variety of graphs are illustrated as follows in Mathematics textbook A.

- Pie chart: Shows the number of people living with HIV/AIDS.
- Stem-and-leaf plot: Learners use given data to draw and determine the range, mean number and make conclusions.

- Scatter plot: Draw scatter plot using given data. Learners have to identify relationships and criticize the data.
- Histogram: Shows foreign tourist arrival between 2000 and 2004.
- Bar graph: Shows the favourite colour of a number of learners.
- Pictogram represents number of cars per month.
- Broken-line-graph: The rise in temperature in a week
- Line graphs: Draw a straight line graph using given data from a Table showing the distance travelled by a car over a period of 10 seconds.

These are just few examples from (Laridon *et al.,* 2006:198-256).

Laridon *et al.* (2006) explain a variety of graphs in more detail than Groenewald *et al*. (2006) and Nel *et al.* (2006). The exposure of learners to many different graphs forms a foundation for learning and understanding kinematics graphs. This resource, if well applied, can enhance learners' understanding and performance in kinematics graphs, which will indirectly contribute positively to the understanding of physics in general. Laridon *et al.* (2006) give learners enough opportunity to work with a variety of graphs. These learners become well equipped in grade 9 with the skills of drawing and interpreting graphs related to kinematics graphs. Learning and understanding kinematics graph in grade 10 then becomes much easier. Kinematics graphs must progressively be built into the grade 9 concepts, which could serve as prior knowledge.

### 4.8.2 Mathematics textbook B

Nel, Schmidt and Stols (2006) start with modules, units and activity as part of the contents. It starts with module 1 unit 1 the number system. The introductory pages describe a few words related to graphs in the glossary such as notation, fraction, binary, prehistoric etc., followed by an article about the history of mathematics. Each unit starts with a glossary; explanation of words or terms to be used in the unit. Without any pre-explanation and examples, a direct and indirect proportion pair activity is given. Other examples are:

- Abdul walks 5km in 35 minutes. How far does he walk in 21 minutes? (Nel *et al.,* 2006:31).
- Explain the concept indirect proportion. (Nel *et al.,* 2006:32).
- Draw a graph using the information from the given Table (Nel, *et al.,* 2006:32).

Learners have to use a given graph to complete a Table (Nel *et al.,* 2006:32). Examples of questions asked are: “As the number of bricklayers increases, what happens to the number of hours?”

Nel *et al.* (2006:114-138), model 2 unit 4 deals with the use of graphs to model mathematics. This unit commences with the outcomes of the unit, followed by a glossary (meaning of words) including terms such as axes, dependent and independent variables, graph, gradient, positive and negative gradient, intercept, y=m x + c, and origin. These terms and words were included in the questionnaire used for the empirical study reported in this dissertation. Therefore, learners using Nel *et al.'*s textbook could have an upper hand in understanding and applying positive and negative gradient.

The introductory pages of Nel *et al.* include an explanation of graph, origin, and number line, ordered pair, and Cartesian plane with examples and how to use each in solving problems. Learners have to solve problems (activities) without any worked out example to assist them to figure out how to solve a specific graph related problems. The questions include drawing graphs, drawing up Tables, using graphs to describe relationship, etc.

Direct and indirect proportionality activities equip learners with skills that will assist them to interpret graphs. Learners should know that when the ratios are equivalent they are in direct proportion. This resource can be useful when reading and interpreting kinematic graphs.

The following graphs are illustrated in the textbook of Nel *et al*. (2006):

- Line graphs; pages 32,121, 123,124,129,135,136
- Pie chart; pages 40, 217, 251
- Histogram ; pages 236, 249,260
- Bar graph; pages 247,248,254

Even though this textbook covers the resources needed for learning kinematic graphs, are there sufficient worked out examples to equip the learners with problem solving skills?

### 4.8.3 Mathematics textbook C

Mathematics textbook C was written by Groenewald, Minshall, Otto, Roos, Van der Westhuizen (2006). The first chapter deals with real numbers and covers LO1. The concept ratio is defined, followed by a problem and solution. An example with possible solution related to rate is given.

Direct and indirect proportions are defined and differentiated. Groenewald *et al.* (2006:10) define direct proportion as two quantities that increase or decrease in the same proportion, while indirect proportion is defined as 'one quantity increases while the other decreases such that their product is always the same' (Groenewald *et al.,* 2006:11). Two different methods to solve each of direct and indirect proportions problems are given.

Chapter 3 is entitled 'Graphs'. It covers learning outcomes (LOs) 2 and 3, as well as assessment standards (AS) 3, 5, 6, and 7. The introduction of the chapter includes LOs and ASs and a list of materials needed for activities. It explains formulae, Tables and graphs as methods to represent data in mathematics. Definitions of variables, independent and dependent variables are also given. Baseline assessments (find your position from a street map) also form part of the introduction of this chapter. This activity checks learners' basic conception and understanding of coordinates. The chapter elaborates on the relationship between two variables represented in the form of Tables, formulae and graphs.

The questionnaire used in the study tested relationships between two variables represented in the form of Tables, formula and graphs. This implies that the school using this particular textbook should have good background knowledge to answer the questions related to kinematics graphs. The learners should be equipped with the basic resources needed to learn kinematics graphs.

Exercises on graphs related to kinematics graphs in Groenewald *et al.* (2006) are listed below:

- Exercises that ask learners to explain how to draw graphs by plotting points. Questions such as "plot the points in your Table on the graph paper", "what is the independent variable" (Groenewald *et al.*, 2006:39) are good resource questions.
- A table shows the time it takes for a tennis ball dropped from the top of a building to reach the ground (Groenewald *et al.*, 2006:44).
- A table that shows an athlete's distance from his starting point at certain times (Groenewald *et al.*, 2006:45).
- The data in the table is used to draw line graphs, identify relationship, calculate speed, and determine how far the athlete was from his starting point 9 seconds after he started running, and whether the athlete ran at a constant speed?

These types of questions and activities should enhance learners' skills to interpret and draw kinematics graphs.

If learners can determine the speed in m/s at which the athlete runs, from a Table of distance and time in mathematics, then introducing kinematics graphs in grade 9 natural sciences is possible.

The types of graphs found in Groenewald *et al.* (2006): pages 45, 47, 49, 50, 53, 54, 56, 271, 272, 274, 275, 276, 277, 278, 28, 282, 283) are:

- Line graphs
- Bar graphs
- Histogram
- Pie charts

### 4.8.4 Speed-time graphs in the mathematics textbook

All three mathematics textbooks used in the schools participating in the study deal with speed, speed/time graphs and gradients that relate to kinematics graphs.

Laridon *et al*. (2006:127-128) explain that linear functions have a constant gradient and the textbook includes worked out examples on calculating gradient. Examples of problems found in the textbook are average speed, distance and comparing average speeds (Laridon *et al*., 2006:190-191). Drawing a graph using data from a Table is followed by questions that require reading values from the graphs and interpreting changes on the graphs. There are other questions such as:

- Using graphs to determine distance travelled at a specific time.
- For a given scale learners are asked to draw a graph to show the distance travelled by a car travelling at a constant speed of 80km/h over a period of time: (Laridon *et al*., 2006:198-199).
- A speed-time graph is given followed by questions that require finding the stages at which an increase or decrease in speed or distance occurs.

Nel *et al*. (2006:221) define speed as the total distance travelled divided by the total time, and explain how to convert unites e.g. from m/s to km/h. The questions in the textbook consist of interpretation, calculation of gradient and average speed and reading from the graph (Phosa's journey from his home to town). Examples of the questions are:

- Calculating the slope of a line
- Calculating Phosa's average speed

- Using the graph to find the distance travelled
- Calculating the speed of a moving taxi

Explanation of how to calculate speed is followed by questions involving time and distance. This includes examples of questions and solved problems (Groenewald *et al.,* 2006:243-244). Activities given provide learners with sufficient practice of graphing skills. Conversion of the units for speed m/s to km /h and vice versa is an essential skill.

The information in Table 4.4 is a checklist used for analysing the various mathematics textbook with respect to graphs and was designed for the purpose of this study.

**Table 4.4: Relevant information found in the mathematics textbooks essential for learning kinematics graphs**

| Criteria | Textbook 1 Nel et al | Textbook 2 Laridon *et al.* | Textbook 3 Groenewald *et al*. |
|---|---|---|---|
| Introductory -- Glossary of basic concepts | √ | x | x |
| Activities related to: | | | |
| Drawing line graphs | √ | √ | √ |
| Gradient | √ | √ | √ |
| Identify variables | √ | √ | √ |
| Interpret graphs | √ | √ | √ |
| Scaling | X | x | x |
| Speed/time graph(s) | X | x | x |
| Distance/time graph(s) | √ | √ | √ |

(Source: Data collected for this study)

### 4.8.5 Comparing the introductory pages of grade 10 physical sciences textbooks

Schools order their textbooks from the list of different grade 10 textbooks approved by the DoE. They receive an invitation during the course of the year to publishers display and marketing of textbooks. The checklist designed above can guide educators to select textbooks that can enhance the teaching and learning of kinematics graphs.
The following can be found in the introductory pages of grade 10 Study and Master Physical Sciences textbook (Kelder, 2008).

- Learning outcomes and assessment standards
- Units and derived units
- Converting units
- Direct proportionality
- Distinguish between dependent and independent variables
- Explain the need to use a sharp pencil and a ruler to draw a sketch graph
- Drawing accurate graphs: the largest possible scale should be chosen, draw a best-fit straight line using a ruler, label the axes, and plotting points (Kelder, 2008).

The introduction to the KAGISO senior secondary physical sciences textbook of Grayson, Mckenzie, Dilraj, Harris, Burger and Schreuder (2008) includes learning outcomes, assessment standards, and the outline of an exam paper. Basic scientific skills and concepts are not included in the introductory pages.

The textbook of Lombard, E., Pearson, Thomas, Lombard, O. (2008) has no introductory pages. It starts with a Table of contents and then goes straight to the chapter content. The chapter (module) of mechanics starts the content with distance, speed, acceleration, motion graphs etc. Comparing the three grade 10 physical sciences textbooks, only one out of the three textbooks depicts the basic concepts and skills needed to learn, understand and solve kinematics graphs and physics problems in general.

The physical sciences textbook called Platinum by Grayson, Harris, Mckenzie, and Schreuder (2011) is used in one of the schools participating in this research. The authors introduce the textbook with the Table of contents, followed by revision of matter and material. Materials that objects are made of are explained on the first page of the first chapter. Mechanics (motion and motion graphs) are among the last five topics in the textbook. The chapters on motion do not include an explanation of scientific skills, basic concepts, dependent and independent variables or other resources necessary for understanding kinematics graphs.

## 4.9 DISCUSSION: ANALYSIS OF GRADE 9 TEXTBOOKS

Textbooks are used by educators as a resource for planning lessons and teaching.
Ball and Cohan (1996:412) affirm that textbooks are used by educators to design instructions used for learning and teaching. An analysis of the information found when evaluating grade 9

mathematics and natural science textbooks reveals that many forms of representations are used but not explicitly taught in secondary schools (grade 9). The presentation in the form of constructing and interpreting tables and graphs are taught as a tool for communication and reasoning. This tool is found within relevant subjects for example physics and mathematics, but is not depicted as a tool for solving problems (Dwain, 2008).

Based on the examples of the graphs included in the various grade 9 natural sciences and mathematics textbooks used in some schools in Potchefstroom, it can be concluded that the majority of the examples have no relation to kinematics. The majority of the graphs were bar graphs. Out of the 13 textbooks analyzed only four explained the basics of drawing, interpreting and constructing graphs.

Glazer (2011:183-187) emphasises the learning of scientific inquiry skills, the ability to interpret data, as well as competence in interpreting graphs. These skills are becoming not only important, but essential for scientific literacy and understanding in today's world. Hence, they should be included in grade 9 natural sciences textbooks and intensely taught to equip the grade 9 learners who may not continue with their education at the end of this grade. This is essential because in South Africa grade 9 is the first exit year.

Textbooks can be very useful, some are comprehensive and they give guidelines to educators and learners, but looking at the analysis of grade 9 textbooks it appears that one single textbook does not provide the entire basic content needed in grade 9 to study and understand kinematics in grade 10. Out of 10 of the grade 9 natural sciences textbooks, 9 (90%) do not give any guidelines on the basics of drawing graphs, variables and scale. Therefore, the teacher and learner cannot solely depend on the textbook to provide the conceptual resources for learning kinematics graphs.

As already stated, graphs are important in science, so a good grasp of graphs is a great stepping stone to achievement in science (physics). Textbooks should therefore treat graphs more in-depth with challenging activities that contribute to the learning of content, scientific skills and processes (Lemmer *et al.,* 2008:185). The activities should not be included because they have to be there, but should be carefully selected to contribute towards conceptual change.

Lemmer *et al*. (2008) recommend that textbooks should cover the core knowledge where the unit components form a coherent unit. Furthermore, educators should be trained to select the relevant textbooks for the learners. The educators need to be equipped to review manuscripts, textbooks and other LTSM (Lemmer *et al.,* 2008). Since textbooks have a tremendous impact, educators need assistance in the selection of the appropriate textbook(s) out of the many approved textbooks for a single subject or learning area.

It can then be concluded from the above analysis that graphs in grade 9 mathematics and natural sciences textbooks should be treated in detail to give learners the foundation to read and interpret graphs. Real life situations and real life graphs should be incorporated so that the learners at the exit level in grade 9 can gain sufficient knowledge to apply in the real world. This is crucial because the end of grade 9 is the first gateway to the real world.

'In principle, textbooks are one of the major important sources of influence on understanding the processes of science' (Duncan *et al.*, 2011:149). A lack of emphasis on processes of scientific investigation is an impediment to learners' understanding of science (Duncan *et al.*, 2011:148). This comment is based on the figures found in the biology textbooks examined. The lack of adequate graphs in grade 9 natural sciences textbooks can also be an impediment to learners' understanding of kinematic graphs.

Irrespective of the fact that grade 9 natural sciences textbooks might be scientifically accurate, age appropriate, and motivating, if they do not contribute significantly to learning relevant graphing ideas and skills, they become inadequate. In this study the adequate textbook is the one considered to have ideas and skills to learn kinematics graphs easily.

Learners need to have a firm conceptual understanding of what is represented on the graph and how it is done. The textbooks should concentrate on developing the conceptual understanding of graphical concepts and laying a foundation on which grade 10 physical sciences can be built.

## 4.10 SUMMARY

There are more similarities and fewer differences amongst the grade 9 mathematics textbooks than the natural sciences textbooks. The natural sciences textbooks vary a great deal with respect to the content coverage of the curriculum. The need to streamline cannot be over-emphasised. The improvement of the natural sciences textbooks used in South African schools should be on the agenda of science reformers and curriculum developers. Two or three natural sciences textbooks should be recommended and used in all the schools to ensure uniformity.

The content of the textbook can then be a guide to determine the resources learners have, as well as their prior knowledge. Most physical sciences educators do not teach natural sciences and/or mathematics.

Only one natural sciences educator out of the seven schools that participated in this research study teaches both mathematics and physical sciences. The physical sciences educator may not be aware of the resources and pre-knowledge the learners possess to learn kinematics graphs. If an educator does not teach grade 9 natural sciences or mathematics, studies such as these may be helpful to identify learner conceptual resources for learning kinematics graphs.

Learners develop conceptual resources as they interact with problems and activities related to graphing skills and knowledge in textbooks. Exercises to develop the skills of reading from pie graphs, line graphs (distance against time) and bar graphs are clearly described by Cross *et al*. (2001:28-29, 74). The authors encourage learners to come up with their own data from a given scenario related to the real world to plot a line graph. The relationship between speed in km/h and time in hours is an indirect proportion, emphasized by (Cross *et al.,* 2001:79-80). This is a conceptual resource for learning grade 10 kinematics graphs.

One cannot depend on a single textbook to cover all the grade 9 natural sciences topics, including kinematics graphs, equally. Educators should use a combination of textbooks and educator's guides as resources and to develop their own materials according to the learners' needs to help them learn important ideas. Some important concepts one will expect learners to learn related to graphs include amongst others: scaling, calculating gradient, drawing line graphs, interpreting, identify relationships, and identifying variables. These concepts are also needed for learning kinematics graphs.

The next chapter explains the research methods used in this study. This study made use of a mixed method comprising of quantitative and qualitative research designs.

# CHAPTER 5

# RESEARCH METHODOLOGY

## 5.1 INTRODUCTION

The previous chapters (Chapter 2–4) reviewed the relevant literature related to the grade 10 learners' conceptual resources needed to learn and understand kinematics graphs. In this chapter, the research method used to identify the conceptual resources obtained in grade 9 to study kinematics graphs in grade 10 is outlined.

The following objectives are stipulated for the study:

- Identify the conceptual resources related to graphs that grade 10 physical sciences learners have obtained in their studies of natural sciences and mathematics in the GET Band.
- Statistically analyze the coherence and integration of the learners' resources.
- Propose methods to include with the learning process of grade 9 for smooth learning progression of graphs from natural sciences in the GET Band to physical sciences in the FET Band.

This chapter begins with (paragraph 5.1) the introduction, followed by (paragraph 5.2) that addresses the research design. (Paragraph 5.3) describes the methods used in the study. (Paragraph 5.4) deals with collection and analysis of data, it also provides the profile of the samples and data that were collected for this study. In (paragraph 5.5) additional remarks related to the pilot study are given while (paragraph 5.6) provides a summary of the chapter.

## 5.2 RESEARCH DESIGN

Research is a systematic process that involves a methodical collection of data in order to answer a question, resolve a problem, create knowledge or generate understanding of a phenomenon (Leedy, 1997:5).

As in Leedy and Ormrod (2010:3-6) the following seven characteristics of research are applied in this study:

- Research begins with a question in mind. The question that the researcher had in mind was concerned with what the conceptual resources were that grade 9 learners would have with regard to graphs? The researcher formulated a question with the hope of finding answers and solutions.

- Research demands the identification of a problem stated in clear, unequivocal expressions or a clear goal. The problem statement was written clearly and unambiguously in chapter 1 of this dissertation.
- Research requires a plan. A systematic plan was developed to address, integrate and combine several research techniques. The research techniques and their implementation in this study are described in this chapter.
- Research deals with the main problem divided into appropriate sub-problems. The sub-problems addressed in this study are given as objectives (Paragraph 1.3.2 and paragraph 5.1).
- Research is guided by specific research question or hypothesis and tries to find directions through appropriate hypotheses. The researcher formulated a hypothesis for the study (Paragraph 1.5).
- Research deals with facts and their meanings and accepts certain critical assumptions. The researcher collected relevant facts through a literature review (Chapters 2 and 3). Taylor and Watson (2010:46) state that ‘review of literature is the power source of the conceptual framework in conducting qualitative and quantitative research’.
- Research requires collection and interpretation of data in an attempt to resolve the research problem. According to the researcher data is collected and interpreted objectively in this study based on the factual data rather than the researcher’s beliefs and ideology (Chapters 5 and 6).
- Research is recurring. All research processes are inculcated into each other in a circular manner. The researcher did not follow a linear path. Mestre (2000:151) used an analogy for describing research as a cumulative endeavour. He compared research with ‘bricks’ of empirical evidence used for ‘building’ knowledge.

Mestre (2000:168) argued that a single technique would not provide all the necessary information for solving a research problem. In this study different techniques were used in an endeavour to gather sufficient information for addressing the problem.

There have been debates among education researchers on whether the techniques that yield qualitative data are better than the techniques that yield quantitative data. According to Mestre (2000) the type of data depends on the type of research question under investigation.

A mixed method approach can be used to collect both qualitative and quantitative data, with the two types complementing each other.

### 5.2.1 Mixed method research

Mixed method research is described by Teddlie and Tashakkori (2009:23-27) as a method that is used to answer the research question by making use of qualitative and quantitative data collection and analysis. Any technique of collecting and analysing data has weaknesses and strengths. By combining different methods, the weakness of one method may be counteracted by the strength of the other. The mixed method design has the advantage that it enables the researcher to provide both verification and generation of theory in the same study using confirmatory and investigative questions (Teddie & Tashakkori, 2009:33). The approach depends on a quantitative method to produce precise and measurable data, which can easily be drawn into tables and graphs.

The qualitative method enhances the understanding of the data produced by the quantitative method (Tashakkori & Teddlie, 2010; Dahlberg & McCaig, 2010). A mixed method approach provides better deductions and wider divergent views (Teddlie & Tashakkori, 2009:33). The combined approach gives an additional dimension to the research design and would "offer far richer findings at the reporting stage" (McCaig, 2010:38) of the study.

The quantitative method is expressed in numbers and more objective while the qualitative method, expressed in words, is more subjective (Dahlberg and McCaig, 2010:22-23; Taylor, Trumbull & Watson, 2010:164). Quantitative research reaffirms the objectivity and reliability of a study (Denzine & Lincoln, 2008; Teddlie & Tashakkori, 2009:209).

The qualitative research is influenced by the ability to generate theory (Creswell, 2012:64). In order to generate rich, detailed and valid data that contribute to in-depth understanding of the context, a qualitative method needs to be part of this study (Creswell, 2012:238). Based on the above reasons, the mixed method consisting of qualitative and quantitative designs was selected for this study.

According to Teddlie and Tashakkori (2009:26) the data are collected simultaneously or sequentially in a mixed method study. Table 5.1 below adopted from Morse (1991) illustrates this concept. The QUAL or qual is an abbreviation for qualitative and quan or QUAN stands for quantitative. The lower case letters imply that less emphasis is placed on it. On the other hand upper cases mean more weight is placed on that specific method (Morse & Niehaus, 2009).

**Table 5.1:** **Types of designs**

| Approach | Type of data collected |
|---|---|
| QUAN + qual | Simultaneous |
| QUAL + quan | Simultaneous |
| QUAL→ Quan | Sequential |
| QUAN→ Qual | Sequential |

(Source: Morse 1991)

The focus in this study is: QUAN → qual, i.e. this study was mainly quantitative followed by the qualitative approach. This approach is preferred because it builds on the strength of both qualitative and quantitative data. The quantitative and qualitative methods for collecting, analysing and linking data are of importance because they provide insight that a single method canot provide, thus strengthen the study (Tashakkori & Teddlie, 2010).

Figure 5.1 represents a visual presentation of the sequential method of collecting and analysing data, the QUAN-qual mixed method.


**Figure 5.1:** **Visual presentation of the QUAN-qual mixed method (Source: Creswell, 2008:557)**

The quantitative results were collected and discussed first, followed by the qualitative results. After this had been done the next step was a comparison between the quantitative statistical results and the qualitative findings. The qualitative method was discussed after the quantitative method (survey) to give an in depth analysis and answers to the 'how' and 'why' questions (Smith & Bowers-Brown, 2010:117).

In this study the quantitative research design was of high priority followed by qualitative that was used to help explain the quantitative findings. This is illustrated in the visual presentation procedure in Figure 5.1 adopted from Creswell is applied in this study.

Figure 5.2: shows a mind map adapted from Creswell (2012) that illustrates the research design and method applied in this study.

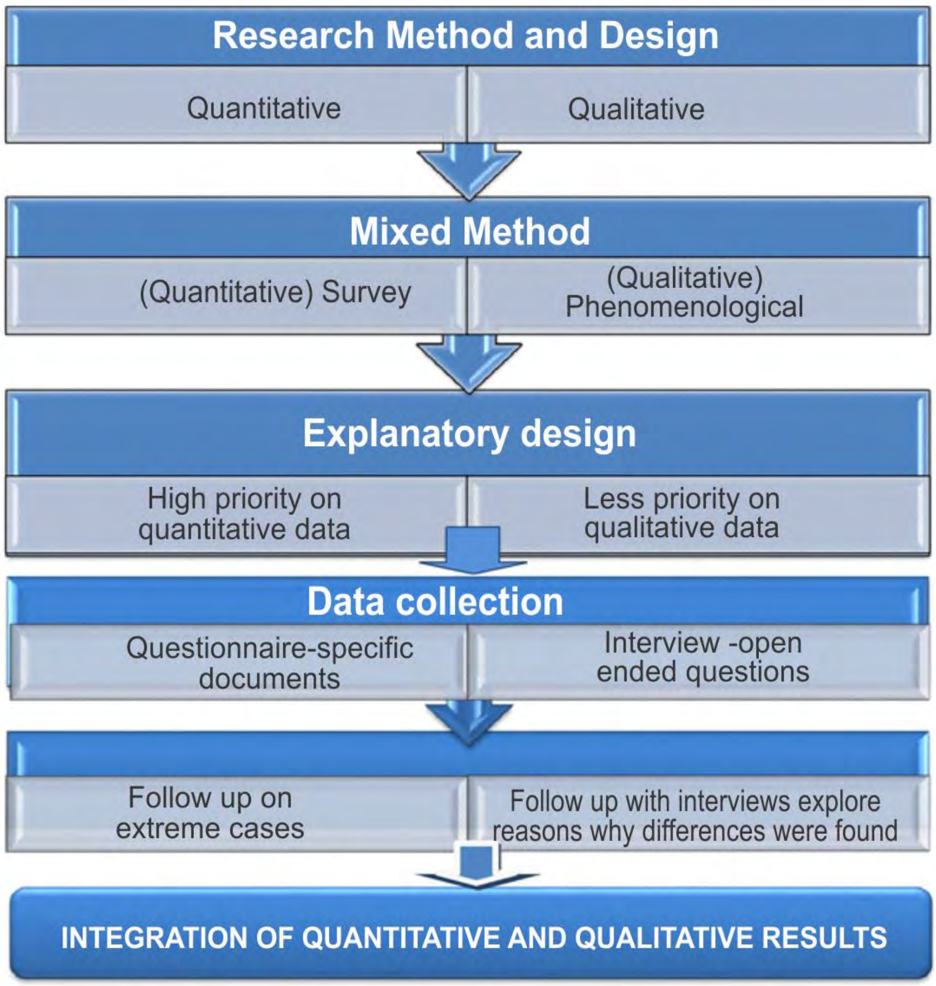



**Figure 5.2: Mind map-illustrating techniques for collecting quantitative and qualitative data for the study. (Source: Creswell, 2012:551-557)**

### 5.2.2 Quantitative research design

Quantitative research design involves describing ‘reality’ through numbers. This provides a tremendously powerful set of tools for producing and analysing data in scientific terms (Tolmie, Muijs & McAteer, 2011:4). The purpose of using quantitative research design in the study was to gather specific, narrow, measurable and observable data (Creswell, 2008:54-55) and to apply statistical processing methods (Leedy and Ormrod, 2010:182) to determine the coherence and integration of learners’ understanding of graphs.

The quantitative research design for this study can be characterised as a descriptive survey. Descriptive research is a type of quantitative research design that involves identifying the characteristics of a survey and possible correlations (Leedy and Ormrod, 2010:182).

The purpose for using a descriptive research design in this study was to determine the grade 10 learners' conceptual resources, the coherence in their answers and their ability to integrate the various resources they obtained in grade 9 mathematics and natural sciences.

**A survey** is a popular method in marketing, social attitude studies and educational research. Surveys are popular because they are cost effective, efficient and can yield much information within a reasonable time (Vogt, 2007: 90). For these reasons a survey is used to avoid producing unrepresentative results. Surveys do not easily influence or alter the nature of the data collected (Tolmie *et al.*, 2011:33).

### 5.2.3 Qualitative research design

Qualitative research was used in this study because it helped to identify and describe the existing learning resources and problems of the grade ten learners (Leedy & Ormrod, 2010:136). It also produced data that informed us about the quality of learners' knowledge in the natural sciences classroom, their situation with reference to kinematics graphs and answers to the 'how' and 'why' and that assisted in exploring the ideas and experiences of the learners (Smith & Bowers-Brown, 2010:112).

Creswell (2008:53) argued that in qualitative research, literature review played a minor role in justification of the research problem. Instead, it explored more information and understanding from the participants than from literature. For this reason a small group from the participants were interviewed to provide a broader perception of their conceptions about graphs learned previously in mathematics and natural sciences. In addition, reasons for the responses they provided in the questionnaires were obtained.

**A phenomenological** study is used to describe and understand an experience from the participants' point of view that is meaningful (Leedy & Ormrod, 2010:141). It also searches for meaning through human experience that will lead to obtaining knowledge. The data sources include the use of tape recording and interviews. In phenomenological research the researcher did not include his/her own personal experiences but the participants were asked to describe their experiences (Trumbull & Watson, 2010:67). Different authors have expressed their views of the phases and how to conduct phenomenological research. Trumbull and Watson (2010:68) reviewed the different views and summarised them into 8 steps according to which the researcher would act:

1. Separate himself / herself from the phenomenon.
2. Reduce prejudice.
3. Identify data in pure form.

4. Examine group(s).
5. Eliminate irrelevant or overlapping data and repetitions.
6. Identify themes.
7. Describe the themes.
8. Fuse and organise the data for deeper meaning.

These steps outlined by Trumbull and Watson influenced the data collection and analysis of the interviews used in this study. Phenomenological study was preferred in this study because the unstructured interviewing that was applied aimed at gathering information from the participants that described their previous experience in natural sciences and mathematics with particular reference to graphs.

## 5.3 RESEARCH METHODOLOGY

According to Tolmie *et al.* (2011:32) the methods and procedures used to collect data from the samples determine the type of deductions that can be made about the relationships between the variables. The mind map illustrated in figure 5.1 of the study consisted of a survey that did not take place in a laboratory. The survey was to identify how the groups (e.g. from different schools) compare on a variable.

Rubin and Rubin (2005:36) describe responsive interviewing as interviewing that brings out the interviewee's experience and understanding. It is flexible and adaptive. For these reasons, responsive interviewing was employed in this study. The interviewees (participants) were asked open-ended questions and the questions were modified to explore what was heard and what their responses to the kinematics and graph questions were.

The study started with a pilot study to determine whether the items of the questionnaire were on the appropriate level and to ensure the validity of the questionnaire for the survey. This was followed by an empirical study that utilised a questionnaire (quantitative method) and interviews (qualitative method).

### 5.3.1 Pilot study

In the pilot study, a group consisting of 20 grade 9 learners and ten grade 10 learners from a High School in Potchefstroom (School G) participated in the pilot study. There are more learners doing grade 9 natural sciences than grade 10 physical sciences hence the ratio 2:1 was used. They were selected randomly. They represented mixed abilities.

The pilot study took place in November. The learners answered the questionnaire during the fourth term. Around November most schools were found revising and preparing the learners for the end of year promotion examination. It was assumed that by then the syllabus for the year had been completed or nearly completed and therefore relevant data could be collected. The questionnaire was administered to both grade 9 and 10 learners to determine which group would be appropriate to use for the study.

The questionnaire consisted of three sections. Section A of the questionnaire consisted of seven demographic questions. Section B was mainly general graphs-related questions that assessed learners' perceptions regarding the role and importance of graphs in natural sciences as well as their graphing skills. Section C was made up of six questions and several sub-questions that included questions on drawing, interpretation, gradient determination of graphs, and the identification of mathematics and kinematics graphs.

The pilot study indicated that, the questionnaire was too difficult for grade nines and too lengthy. The grade 9 learners made comments such as: "It is difficult, boring and long". Over 60% of the grade 9 respondents did not attempt items of question six on kinematics graph, implying that it was difficult for them to solve. 40% of the respondents could not complete the questionnaire within a total of the four hours allocated time. Not a single learner completed within two hours. The 55.6% that completed the questionnaire used the full four hours. These learners indicated that it was difficult and that they would need more time while they were attempting to answer the questionnaire. 60% asked for explanations and 40% did not attempt some of the questions.

The above observations led to shortening the questions and administering the questionnaire to only grade 10 learners in the empirical study at the beginning of the year before they started with kinematics lessons. Another reason for using grade 10 learners for the empirical study was that the grade 10s had decided to select physical sciences as a subject of choice for the rest of high school education. Some or all of the grade 9 learners may choose subjects other than physical sciences and they might not show much interest and willingness in participating.

The problems encountered in the pilot study that led to the changes in the questionnaire were the level of difficulty of the questions, the length and response choices. The grade 9 learners struggled to complete the questionnaire. The changes that were made included:

- The grade tens instead of the grade nines were used for the empirical study.
- The length and number of questions was reduced from 13 pages to nine pages.

The participants were the researcher's own learners. Some of them were more concerned with impressing their teacher than with focusing on participating in a research study.

Two learners from grade 9 refused to hand in their questionnaires because they felt they had performed badly. Hence the researcher school was not part of the empirical study.

### 5.3.2 Empirical study

The empirical study aimed at finding possible responses to the research questions. The research questions included the following:
What conceptual resources have been obtained in the GET band that can be productively used for the learning of kinematics graphs in Grade 10?
The two secondary research questions were:

a) Are these conceptual resources sufficiently linked and integrated for effective learning of kinematics graphs?

b) How can the learning progression for graphs be enhanced from the GET to the FET band?

A combination of quantitative and qualitative methods was used to investigate the first research question. Information gained from the results of the first research question was expected to lead to recommendations regarding learning progression from GET to FET (i.e. answering the two secondary research questions). The research took place at the beginning of the 2011 school year when the grade tens had only just started their year.

The study was conducted by collecting information on a number of topics related to concepts in kinematics and graphs. This was done around the same time for each group of grade 10 learners in the six different schools. The objective was to describe the patterns of responses and relationships between the variables, which could lead to identifying their conceptual resources. According to Tolmie *et al*. (2011:33) what was done can be described as correlational design.

The area in which the study took place is discussed in the next paragraph. The careful selection of the study area influences the achievement of the objectives of the research.

#### *5.3.2.1 The study area*

Knowledge of certain aspects of the community within which the research was carried out contributed to the achievement of the aim of the study. For this reason the geographical position, language and other demographic factors formed part of paragraph 5.3.2.1.

### i) Geographical Location

The research was carried out in Potchefstroom, which is part of the Tlokwe Municipal area. Potchefstroom is in the North West Province of the Republic of South Africa. The province shares an international border with the Republic of Botswana by the Molopo River. Below is the map of North West Province (figure 5.3).


**Figure 5.3: Map of NorthWest (Source:Stayinsahttp://www.stayinsa.co.za/southafrica/northwest)**

### ii) Language

In the North West Province about 63.4% inhabitants are Setswana speaking (South Africa, 2012). The communities around Potchefstroom communicate mainly in Afrikaans, English and Setswana. The learners that participated in the research consisted of significant percentages of English, Afrikaans and Setswana speakers.

### iii) The schools

The schools that participated in the study were labelled as follows:

School A

School B

School C

School D

School E

School F

School G participated only in the pilot study.

The labels were used to hide the identity of the schools. The first school visited was labelled A the second B and the last school F.

**iv) Mode of data collection**

There are different modes of collecting data, namely electronic questionnaires and paper-based questionnaires. There are three types of electronic questionnaires. These are e-mail questionnaires, email invitations linked to URL and questionnaires on a web page (Thomas, 2004:14).

Paper-based questionnaires were used in this study because they can be mailed or distributed in person or sent home with students. The researcher personally delivered the questionnaires to the schools to maximise the response rate and to be sure of receiving response within a shorter time. Individual and group interviewing is another mode of collecting data but individual face-to-face interviewing was preferred in the study.

#### *5.3.2.2 Population and sampling*

Mixed method sample size is determined by combining two different types of sample sizes. The larger quantitative sample was based on a well-defined population and cautiously selected smaller qualitative samples based on informal sampling structures. The mind map below illustrates the steps involved in sampling. It was adapted from (Teddlie & Tashakkori, 2009:191).

| | |
|---|---|
| TLOKWE AREA OFFI CES | • sampling school Area offices |
| POTCHEFSTROOM | • sampling of schools within the area |
| GRADE 10 PHYSICAL SCIENCES | • sampling learners within the school |

**Figure 5.4: Mind map of sampling sequence (Source: Teddlie & Tashakkori, 2009:191)**

### Population of learners

The sampled unit for the research was selected from a population of high schools in the Potchefstroom area. Fifteen schools were identified in the Potchefstroom area. Each of the schools consists of varying numbers of learners with different numbers of grade 10 physical science learners.

## The sampling method

A non-probability sampling method, called purposive sampling, was used in the study. According to Leedy (1997:204-205), non-probability sampling does not guarantee presentation of each element of the population in the study. According to Babbie (2010:193), purposive sampling is the selection of participants based on the knowledge of a population. The researcher has knowledge of physical sciences learners. In total 201 grade 10 physical sciences learners from six schools participated in the empirical study.

## Selecting the schools

Seven high schools out of 16 high schools in the Potchefstroom area were randomly selected and used as the sampled units. All the grade 10 physical sciences learners from the schools selected completed the questionnaire, thus representing the full population. The population distribution was as follows:

All the grade 10 physical sciences learners in school A: 35 learners

All the grade 10 physical sciences learners in school B: 38 learners

All the grade 10 physical sciences learners in school C: 32 learners

All the grade 10 physical sciences learners in school D: 33 learners

All the grade 10 physical sciences learners in school E: 36 learners

All the grade 10 physical sciences learners in school F: 27 learners

## Selecting the learners

A convenient sample was used in the research and all the grade 10 physical sciences learners from six different schools in Potchefstroom participated in the empirical study. This gave a total number of 201 learners. The learners were from different socio-economic backgrounds. The questionnaire was in English, which is the second language of the majority of learners.

After the results of the questionnaires had been analysed, three learners out of the 201 participant were selected for interviews in which the reasoning behind their responses to the questionnaire was probed. The purpose was to get insight into the conceptual resources of learners with different capabilities. A learner with high marks in the questionnaire, one with low marks and one among the average range were selected for interviews. The varying abilities of the learners gave a wider range of coverage of grade 10 learners' conceptual resources, understanding and reasoning.

## 5.4 DATA COLLECTION AND ANALYSIS

The data collected consisted of responses to pre-set questions in a questionnaire and semi-structured interview results. Numeric data were gathered from a large number (201) of individuals. General emerging questions were used to generate responses from the 201 participants. Data information was collected from (3) a smaller number of individuals by using oral interviews.

### 5.4.1 Data collection

The following research instruments were used to collect the data:

- Questionnaires
- Unstructured interviews

#### *5.4.1.1 Questionnaire*

**A questionnaire** was used to collect data because there was no existing information to answer the research question (Thomas, 2004:2). Paper based questionnaires were used instead of electronic questionnaire because the majority of the participants do not have acess to internet facilities.

### a) Questionnaire construction

The structural questionnaire used in this study consisted mainly of questions from existing research questionnaires, exam papers and textbooks, namely the Test of Understanding Graphs in kinematics (TUG-K) of Beichner (1994), the Mechanics Baseline Test (Hestenes and Wells, 1993; Redish, 2003), previous grade 9 CTA's, physical sciences grade 12 NSC exam papers (DoE, 2008-2011), grade 9 mathematics and natural sciences textbooks and grade 10 physical sciences textbooks. Learners' understanding of concepts and their ability to apply skills in the following areas were investigated, namely the scaling of axes, the determination of gradient and interpretation of gradients and intercepts. The questions included the drawing and interpretation of graphs in mathematics and physical sciences contexts, such as functions and kinematics graphs.

The following procedure was followed to ensure content validity and reliability: Three academics in the field of research, as well as Statistical Consultation Services at the North- West University (NWU) of South Africa were asked to review the questionnaire. Statistically calculated Cronbach's Alpha coefficient values of which more than 0.70 indicated reliability. A pilot study was used to ensure that the questions from the questionnaire were clear and the length viable. In the pilot study, twenty learners from Grade 9 and ten grade 10 learners completed the questionnaire. The results of the pilot study were used to authenticate the questionnaire.

The final questionnaire (Appendix A) was subsequently developed for grade 10 physical sciences learners. It was divided into three sections, i.e. A, B, and C. The questionnaire consisted of: short questions, multiple choice items, and questions to explain, draw and interpret graphs, questions on units, and definitions of kinematics concepts. These were among the types of questions used in paragraph C. A Likert-type rating scale was applied in paragraph B to test learners' perceptions. Likert-type rating scale is a 'summed rating scale consisting of several related items designed to measure the same idea or same construct' (Thomas, 2004:32).

### Section A: Demographic information (Parameters)

Paragraph A mainly required demographic information as well as learners' achievements in mathematics and the natural sciences [NS1-physical sciences component and NS2 the life sciences component]. This paragraph was made up of 7 items covering the (1) Gender; (2) Age; (3) Marks in NS1; (4) Marks in Mathematics; (5) Marks in NS2; (6) Duration in grade 10 and (7) Home Language. This information was used as parameters in the study. The effect that these factors had on the results of the questionnaires was determined.

### Section B: Perceptions of competency

Paragraph B assessed learners' perceptions of their graph skills, the role and importance of graphs in science and other ideas regarding graphs. A total of 15 questions were asked. A five-point scale was used, ranging from (1) "I totally disagree"... to (5) "I totally agree.
A scale anchor was used and the definition (anchor) for each scale point for the responses was defined. A scale anchor is the definition of a point on a response scale (Thomas, 2004:56). A five-point scale anchor was used in the questionnaire.
Few questions that demanded explanations were included in paragraph B.

### Section C: Conceptual understanding and problem solving

This paragraph comprises of a variety of questions such as multiple choice items, short and long questions to probe learners' knowledge of basic concepts (variables and units), graphs in mathematics and kinematics.
There were six questions with sub-questions, testing kinematics concepts as well as mathematics concepts related to kinematics graphs.

### b) Administering the questionnaire

The questionnaires were sent to the six schools and both the school teachers and the researcher supervised learners when they responded to the items. This took place in the convenience of their classrooms. The questionnaire was administered in a more relaxed atmosphere than under strict examination conditions. Nevertheless, discussions were not allowed.

Thomas (2004:127-128) suggested the following guidelines for a successful and high response rate.

- *Pre-notification*: Send a postcard or letter, or call the respondents to make them aware of your intention.
- *Follow ups*: Follow ups increase respond rates
- *Incentives*: Tokens or promised incentives are very effective but offering study results as incentives is not effective at all. Nevertheless, enclosed incentives produce higher response rates than promised incentives.

Following the reasons above the researcher visited each school first and alerted the awareness of the potential respondents about participating in the research. This was done through the principals of the schools. Permission was granted and the date and time that were stated in the pre-notification letter was approved. Incentive was used to motivate the potential participants and to maximise the response rate. According to Thomas (2004:123) a good response rate is important because it is likely to get respondents that match the demographic characteristics of the target group.

#### *5.4.1.2 Interviews*

Structural interviews seemed unrealistic in this study since the learners gave varying answers to the questionnaire. Therefore, a set of ordered predetermined questions could not be administered. Since structural interviews were not viable, unstructured open-ended interviews were considered appropriate. Open-ended questions were used as a follow-up for deeper understanding of learners' responses to the items and for greater understanding of their reasoning (Fontana & Frey, 2008:129). The interviews were conducted within a month after analysing the responses to the questionnaires.

### 5.4.2 Data analysis

The responses to the questionnaires and interviews were the raw data that needed to be changed into understandable and usable information by analysis of the data.

#### a) Preparing the data for analysis

A coding plan was first determined and coding documentation was prepared. Below (Table 5.2) is an abstract from the coding documentation used in the study. The scale of measurement used was nominal. The numbers were used to identify the groups without being an indication of any order or ranking. The numbers and alphabets used for coding had no intrinsic meanings (Thomas, 2004:141). Table 5.2 is an example that shows how numbers are used in the coding.

**Table 5.2: Coding documentation**

| Section | Question | | Response | Coding |
|---|---|---|---|---|
| A | 1 | What is your gender | Male | 1 |
| | | | Female | 2 |
| A | 2 | What is your age? | 11 years | 1 |
| | | | 12 years | 2 |
| | | | 13 years | 3 |

(Source: the study questionnaire)

#### b) Data editing and quality control checks

The data were edited and checked to eliminate numbers that are out of range as well as data entry errors. Missing data and patterns of responses were identified and rectified where necessary. A short data set from the responses to the questionnaire was designed and an identification (ID) number was assigned to each of the respondents. The ID number was written on the paper questionnaire providing a way to link the paper questionnaire to the data. According to Thomas (2004:134), assigning ID numbers to respondents ensures quality control and easy verification to determine whether there had been an error. Table 5.3 shows a sample of a short data set from the responses to the questionnaire used in the study. L1, L2 etc. represent the ID numbers used in the study.

**Table 5.3: A short data set from the responses to the questionnaire on section A and B**

| Question number | Aspect tested | L1 | L2 | L3 | L4 | L5 | L6 | L7 | L8 | L9 | L10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SECTION A | | | | | | | | | | | |
| 1 | Gender | 2 | 2 | 1 | 2 | 2 | 1 | 1 | 2 | 2 | 2 |
| 2 | Age | 5 | 5 | 2 | 4 | 5 | 5 | 3 | 5 | 6 | 5 |
| 3 | Highest mark in Natural Sciences NS 1 | 6 | 4 | 5 | 5 | 5 | 5 | 4 | 5 | 3 | 3 |
| SECTION B | | | | | | | | | | | |
| 1 | Graph important in science | 4 | 4 | 4 | 4 | 5 | 5 | 4 | 4 | 3 | 3 |

(Source: data from the study)

The Statistical Consultation Services at the North-West University used descriptive statistics to summarise and analyse the questionnaire results of the group in a statistical analysis. They disaggregated the results for sub-groups based on the demographic data. Variables and scale of measurement were the two important concepts considered when summarising data (Thomas, 2004: 141).

Scales of measurement are the categorisation of data from the questionnaires in terms of the type of information communicated by the numbers. It is important to know and understand the scale of measurement. This helped to determine the appropriate statistical technique used. The appropriate statistical analyses used in the study were nominal, interval and ordinal. Below is a table (Table 5.4) indicating the scales of measurements and some analyses that are appropriate for each kind of data according to Thomas (2004:142) applied to.

**Table 5.4: Scales of measurement and statistical tests**

| Scale of measurement | Appropriate statistical analyses |
|---|---|
| Nominal | Percentages, charts and graphs, chi-square test (for difference and relationships) |
| Ordinal | Nonparametric tests |
| Interval | t-test, correlations, analysis of variance etc |
| Ratio | Same as interval-level data |

(Source: Thomas, 2004)

Matching data displayed to categories of data are as listed below:

- Nominal - the relative heights of the bars of a bar graph has mathematical significance.
- Ordinal (bar graphs) - order and heights of bars of bar graphs have mathematical significance for discrete data.

- Ordinal (histogram) - order and heights of bars of histogram have mathematical significance and adjacent bars must be contiguous using a continuous data.
- Interval – Heights, order, width and spacing of bars have mathematical significance for discrete data. Histograms are used for continuous data.

Reliability evidence appropriate for the questionnaire was test-retest and internal consistency. Internal consistency was appropriate for the Likert type ratings scale (Thomas, 2004:114) and it was also determined for other questions. ''Test-retest reliability is based on the assumptions that a test is reliable if the results of its repeated administration differentiate the members of a group in a consistent manner'' (Teddlie & Tashakkori, 2009:211).

The data grouped as shown in the Table below were submitted for statistical analysis.

**Table 5 5: Grouping of questionnaire items**

| **Constructs** | **Criteria** | **Items** |
|---|---|---|
| Perception of competency | Section B | B1,B2,B3,B4,B5,B6,B7,B8,B9,B10, B11,B12,B13,B14 and B15 |
| Basic Concepts | Section C | 1.1A; 1.1B; 1.1C; 1.3.1; 1.3.2; 1.4.1; 1.4.2; 1.4.3; |
| Drawing and interpretation of graphs_mathematics | Section C | 2.1; 2.2; 2.3.1; 4.2.2A, 4.2.2B; 3.1; 3.2; 4.2.2C; 4.2.2D; 4.2.2E; 4.3.1; 4.3.2; 4.4.1; 4.4.2 ; |
| Drawing and interpretation of graphs_physics | Section C | 5.1.1; 5.1.2; 5.1.3; 5.1.4; 5.1.5; 5.2.1; 5.2.2; 6.1.3 6.4.1; 6.4.2; 6.4.3; 6.5.1; 6.5.2; 6.5.3; |
| Gradient_ mathematics | Section C | 4.1, 4.2.1_A, 4.2.1_B , 4.2.1_C, 4.2.1_D, 4.2.1_E |
| Gradient_physics | Section C | 5_1_1, 5_1_2, 5_1_3, 5_1_4, 6.1.1; 6_1_2AB, 6_1_2BC, 6_1_2CD, 6_1_2DE, 6_1_2EF, 6_1_2FG |

(Source: the study questionnaire)

Alternative groupings that were also analysed statistically included questions on:

- line graphs
- bar graphs
- relationship and
- graphs (drawing and interpretation of the graphs in general).

#### *5.4.2.1 Quantitative data analysis: Survey*

All the responses were coded and the data were submitted to the Statistical Consultation Services at the North-West University. Appropriate tables were used to present the results of the statistical analysis (Table 6.9-6.18).

The descriptive statistics that were used to describe the data were the frequency distribution, mean and standard deviation of the data. The data were further analysed by using a t-test, an analysis of variance, and a chi-square test to compare subgroups and examine the relationship and association between the variables (Table 6.19 - 6.27).

#### *5.4.2.2 Qualitative data analysis: Interview*

The qualitative data analysis began after the first interview had been completed. The content of the interview was examined to determine whether it provided enough information. It also indicated whether the project made sense (Rubin &Rubin, 2005:202). According to Rubin and Rubin (2005) qualitative interviewing analysis involves systematic coding, extraction of information from transcripts, breaking down documents into data units, combining data units on the same topic and relating different themes.

Individual in-depth interviews with three selected participants based on typical response and maximal variation principle (Creswell, 2010:58) were implemented in the study. Conversational or dialogic style of interviewing was used to encourage the respondents to participate more actively. Open-ended questions and probes were used to yield in-depth responses about the participants' experience, their perception, opinion and knowledge. The data consisted of verbatim quotations with sufficient context to be interpreted. Narrative was used to communicate the results of the interviews because doing so provided a way of making sense of learners' lives in the natural sciences class (Willis, 2007: 296).

The researcher took note of the following when analysing the interview:

a) The researcher separated himself/herself from the phenomenon
b) The researcher reduced prejudice
c) Identified data in pure form
d) Examined individuals and groups
e) Eliminated irrelevant or overlapping data and repetitions
f) Identified themes
g) Described the themes
h) Looked beneath data for deeper meaning

A detailed discussion of the analysis of the interview results is delineated in paragraph 6.4. The ethical issues that guided the study are discussed below.

## 5.5 Ethical issues

**Ethical requirements:** Learners participated voluntarily. The researcher received permission from the Department of Education, the Principal and the learners. The learners had the option of writing their names or not. The procedure was explained to the learners and they were given the choice to participate by signing a consent note or reject it and leave. The learners that volunteered to participate were allowed to respond to the items in the questionnaire. The questionnaires were followed by interviews with selected learners who also participated voluntarily.

The ethics policy of the North-West University and the Educational Research Organization were adhered to as part of conforming to the conditions set by the University. The following aspects were taken into consideration:

*Privacy:* Privacy of the participants was respected. They received fair and equitable treatment from the researcher. Names of learners and schools were not mentioned in the study. Identification numbers were used to identify learners and schools. The participants were informed that they would remain anonymous. The completed questionnaires were stored in a secure location where only the project team had access to these surveys. Videos and other personalised records would be destroyed once the data needed had been extracted.

*Consent:* Consent from the District Education office was received. A letter was sent to the district executive manager. A clear idea of what the research would involve was explained to the potential participants. This included all aspects of the research that could influence their willingness to participate such as the results of their response. The learners signed a written declaration.

*Protection of research participants:* The researcher took the responsibility to ensure the safety of all participants at all times. The research did not create any form of risk for any learner. It should rather develop them. Participation was voluntary.

*Length of time:* The participants were informed of the timescale of their participation. The questionnaire was one hour and the interview 30 minutes to an hour.

*The use of the results:* The participants were told the results would be used for academic purposes and a copy sent to the Department of Education.

Smith (2010:48) differentiated between anonymity and confidentiality. He described anonymity as hiding the identity of the participants but disclosing the information.

Confidentiality on the other hand means the information cannot be made public while at the same time revealing the origin of such information. The findings disseminated to the Department of Education will not reveal any information that will lead to identification of the schools and learners.

## 5.6 ADDITIONAL REMARKS

The learners that participated in the pilot study were very grateful because the mathematics aspect of the questionnaire acted as revision and boosted up their confidence and performance in the November promotional examination. The pilot study was used to ensure that the scale anchor would be balanced and the questionnaire would be suitable and clear for easy understanding.

## 5.7 SUMMARY

This study used a non-experimental, descriptive quantitative design to obtain numerical data about learners' conceptual resources obtained in grade 9 that can be used productively to learn kinematics graphs in grade 10. The study also used a qualitative design through interviews to get rich insight in order to describe a learning progression of kinematic graphs from the GET to the FET phase.

A total number of 231 learners from the seven schools identified as schools A, B, C, D, E, F and G participated in the study. These numbers (231 learners and seven schools) include the numbers that participated in the pilot study and the empirical study. Moreover, only 201 learners participated in the actual study (empirical study). The wide variety of schools and learners that participated provided a wider range of conceptual resources on drawing, interpretation and understanding of graphs and kinematics graphs. This should in turn contribute towards the achievement of the study objectives.

In the next chapter, the results of the empirical study are discussed. This includes interpretation and explanation of the results. The results are presented in percentages, averages, and in the form of Tables and graphs. Thomas (2004:140) suggested that descriptive statistics such as percentages, averages, and measures of variability, charts and graphs should be used to depict the results.

# CHAPTER 6

# RESULTS OF THE EMPIRICAL STUDY AND DISCUSSIONS

## 6.1 INTRODUCTION

The results of the empirical study are reported in this chapter. The study entailed quantitative and qualitative studies as discussed in chapter 5. Chapter 6 has seven paragraphs. It begins with the introduction (paragraph 6.1), followed by (paragraph 6.2), the overview. In (paragraph 6.3) the results of the demographic information are outlined and an analysis of the quantitative results is given in (paragraph 6.4). The quantitative results are then discussed in (paragraph 6.5). The analysis and discussion of the qualitative data and results is given in (paragraph 6.6). The final paragraph 6.7 gives a summary of the chapter. The words learner(s) and participant(s) are used interchangeably in the chapter.

## 6.2 OVERVIEW

As described in paragraph 5.3.1 the empirical study commenced with a pilot study to determine whether the length and level of the questionnaire was appropriate. In addition it was to ensure the validity and reliability of the questions. Each answer to the questionnaire selected by the learners was coded by using numbers and letters of the alphabet. These were simply labels and had no intrinsic meaning. A frequency distribution was used to organise the raw material and to show the number of times each code appeared (Thomas, 2004:141).

The results of the empirical study were obtained from the analysis of 201 grade 10 learners' responses. The grade 10 learners attempted the questions on kinematics graphs even though they had not done it in class as at the time of administering the questionnaire. The detailed results of the empirical study are presented in the next paragraphs. Paragraph 6.3 gives and discusses the results of Section A of the questionnaire (Appendix A), namely the demographic variables of the learners. The results of the quantitative questions in Sections B and C of the questionnaire are summarised in tables and figures under paragraph 6.4. The quantitative analysis is discussed in paragraph 6.5. Patterns and trends in the data were identified from the interviews and the results expressed in paragraph 6.6. The interviews were conducted to support the quantitative findings with reference to the research questions.

## 6.3 RESULTS OF DEMOGRAPHIC INFORMATION

The results of the demographic informtion are illustrated in sections 6.3.1, 6.3.2 and 6.3.3 in the form of tables and a pie chart.

### 6.3.1 Frequency distribution

According to Gravetter and Wallnau (2008:34) frequency distribution ''is an organized tabulation of the number of individuals located in each category on the scale of measurement''. Frequency distribution Tables were used to allow the researcher to see at a glimpse the entire scores and to compare individual scores relative to all the other scores (Gravetter & Wallnau, 2008).

The frequency distribution of the demographic variables is a list of all the values that the variable has in the sample and the number of cases that each value has. Codes were used for statistical processing, e.g. female was coded (2) and male (1). The number of cases of males and females is indicated on the frequency Table under the column frequency. Coding helps to identify information easily, for example the number of girls that participated in the empirical study can be seen at a glance. The frequency distribution show mistakes made during the coding. Spot errors, e.g. numbers that do not fit in the range of possible values can be detected easily (Tolmie *et al*., 2011:7), e.g. (3) under gender is an error. Coding values for gender can only be one (1) or two (2).

In the following paragraphs frequency Tables (6.1- 6.8) of the demographic information of the participants are summarized and a discussion is provided. The demographic information was gathered from Section A of the questionnaire. The demographic variables obtained in the study were gender, age, performance in natural sciences and mathematics, life sciences in grade 9, number of years in grade10, home language, and school. Tables 6.1 to 6.8 show the frequency distributions. A short discussion follows each of the Tables. The results are then discussed more comprehensively in Section 6.3.2 and summarized in Section 6.3.3.

**Table 6.1: What is your gender?**

| Gender | Male | Female | Total |
|---|---|---|---|
| Frequency | 89 | 112 | 201 |
| Percentage | 44.3 | 55.7 | 100 |

(Source: Data collected for this study)

The number of boys and girls that participated in the study was 89 (44.3%) and 112 (55.7%) respectively.

**Table 6.2: What is your age?**

| Age | 13 | 14 | 15 | 16 | 17 | 18 | Total |
|---|---|---|---|---|---|---|---|
| Frequency | 0 | 5 | 63 | 86 | 25 | 22 | 201 |
| Percentage | 0 | 2.5 | 31.3 | 42.8 | 12.4 | 10.9 | 100 |

(Source: Data collected for this study)

All the learners were above the age of 13 years. There were 22(10.9%) that were 18 years old above the expected average age in grade 10.

**Table 6.3: What is your highest mark in last year (grade 9) natural sciences (physical sciences component - NS 1) ?**

| Percentage of marks obtained | Below 40 | 40-59 | 60-69 | 70-79 | 80-89 | 91-100 | Total |
|---|---|---|---|---|---|---|---|
| Frequency | 13 | 53 | 54 | 56 | 22 | 3 | 201 |
| Percentage | 6.5 | 26.4 | 26.9 | 27.9 | 10.9 | 1.5 | 100 |

(Source: Data collected for this study)

There were 13(6.5%) learners that obtained below 40% in natural sciences at the end of grade nine but they are all doing physical sciences in grade 10. Only three (1.5%) learners obtained above 90%.

**Table 6.4: What is your highest mark in last year (grade 9) mathematics?**

| Percentage of marks obtained | Below 40 | 40-59 | 60-69 | 70-79 | 80-90 | 91-100 | Not answered | Total |
|---|---|---|---|---|---|---|---|---|
| Frequency | 19 | 50 | 61 | 45 | 23 | 2 | 1 | 201 |
| Percentage | 9.5 | 24.9 | 30.3 | 22.4 | 11.4 | 1.0 | 0.5 | 100 |

(Source: Data collected for this study)

Fifty learners (24.9%) obtained between 40-59 % and 61(30.3%) between 60 and 69 % while the rest of the learners obtained above 70% as their highest mathematics marks in grade 9. Out of the 201 learners two (1%) obtained above 90%. one (0.5%) learner did not attempt to answer this question.

**Table 6.5 What is your highest mark in last year (grade 9) natural sciences(Life sciences-NS 2)?**

| Percentage of marks obtained | Below 40 | 40-59 | 60-69 | 70-79 | 80-90 | 91-100 | Not answered | Total |
|---|---|---|---|---|---|---|---|---|
| Frequency | 17 | 53 | 53 | 50 | 23 | 4 | 1 | 201 |
| Percentage | 8.5 | 26.4 | 26.4 | 24.9 | 11.4 | 2.0 | 0.5 | 100 |

(Source: Data collected for this study)

The trend is similar to both mathematics and NS1. Fifty-three (26.4%) learners obtained between 40% and 59%. Four learners (2%) obtained more than 90% and 17(8.5%) below 40%. One (0.5%) learner did not indicate the mark obtained in grade 9.

**Table 6.6: For how long have you been doing grade 10?**

| Number of times doing grade ten | Once | Twice | More than twice | Total |
|---|---|---|---|---|
| Frequency | 186 | 11 | 4 | 201 |
| Percentage | 92.5 | 5.5 | 2.0 | 100 |

(Source: Data collected for this study)

Not all the participants had done grade 10 once. Four (2%) out of 201 had been doing grade 10 more than two consecutive years due to academic results. 186(92.5%) learners did grade 10 once and 11(5.5%) twice.

**Table 6.7: Home language**

| Language | Asian | English | Afrikaans | Setswana | Sesotho | Other | Total |
|---|---|---|---|---|---|---|---|
| Frequency | 0 | 15 | 28 | 102 | 25 | 31 | 201 |
| Percentage | 0.0 | 7.5 | 13.9 | 50.7 | 12.4 | 15.4 | 100 |

(Source: Data collected for this study)

English was home language to 15(7.5%) of the participants and it is also the only language of instruction in four out of the six schools participating in the study. The other 186(92.5%) have English as their second or even third language. Afrikaans as home language is spoken by 28(13.9%) learners but only two schools that took part in the study used Afrikaans as the language of instruction.

**Table 6.8: Number of learners per school**

| School | A | B | C | D | E | F | Total |
|---|---|---|---|---|---|---|---|
| Number of learners | 35 | 38 | 32 | 33 | 36 | 27 | **201** |
| Percentage | 17.4 | 18.9 | 15.9 | 16.4 | 17.9 | 13.4 | **100.0** |

(Source: Analysis of survey data collected for this study)

The percentage of learners per participating school is summarised in the pie graph below. The pie graph is colour coded and the percentage ranges between 14 % and 19 %.

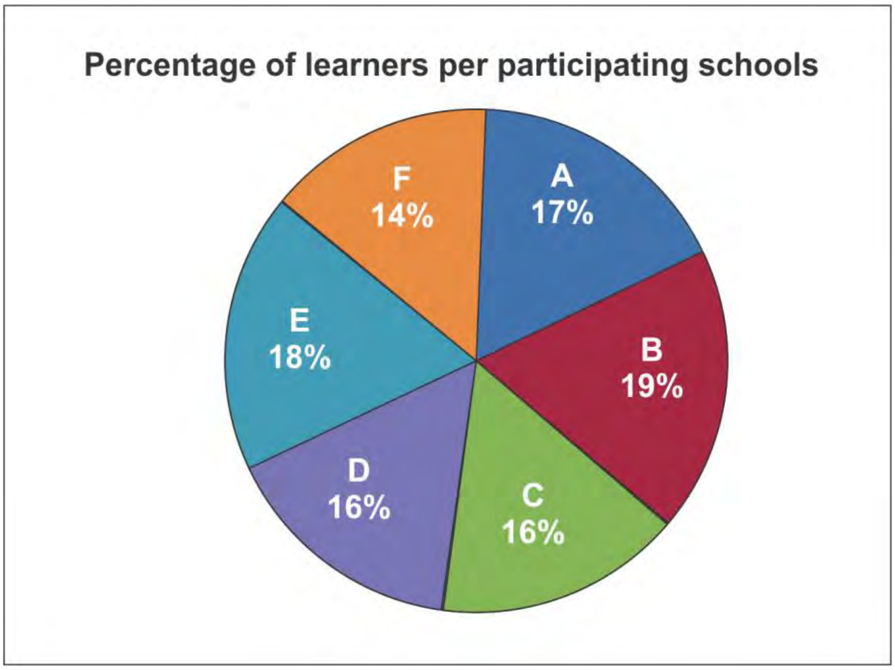



**Figure 6.1: Percentage of learners per participating school (Source: Analysis of survey data collected for this study)**

### 6.3.2 Discussion of demographic variables

The frequency distribution of the demographic variables (section A of the questionnaire) is summarised in Tables 6.1 to 6.8. The Tables include the description of the variable, frequency and percentage of the demographic variables.

***Gender:*** The difference between the number of boys and girls who participated was only 11.4%. The number of boys that participated was less than the girls even thou all the schools that participated were co-ed schools.

***Age:*** Out of the total learners who participated 47(23.3%) were older than 16 years. Five (2.5%) were younger than the rest in the grade, about two years younger than the grade age.

In South Africa a learner in grade 10 is expected to be 16years. South African children are expected to start grade one at the age of 6 years and have to turn 7 years in the year they enter grade one, so the expected age in grade 10 is between 15 and 16 years.

***Performance in natural sciences (physical sciences component)***: The majority of the learners obtained between 40% and 79%. All the participants, including the 13 learners that obtained below 40% in grade 9, are currently doing physical science as a major subject in grade

10. There were 25 (12.4%) learners who obtained 80% and above, these learners are likely to have a better understanding of graphs than the 13(6.5%) who obtained below 40%.

The poor foundation and performance may have a negative effect on understanding and excelling in physical sciences in grade 10.

***Performance in mathematics:*** 19(6.5%) obtained less than 40% in mathematics and 16(3.5%) in natural sciences (physical sciences component). This implies that, few learners (3%) obtained less than 40% in mathematics than in natural sciences (physical science component). The same percentage of learners 12.4% (25) obtained above 80% in both natural sciences and mathematics. This shows a possible relationship between the performance in natural sciences and mathematics. The 19(6.5%) learners that obtained below 40% at the end of grade 9 are offering both mathematics and physical sciences in grade 10. Some learners saw the mathematics questions as revision and were grateful for the opportunity. One (0.5%) learner did not indicate the marks obtained this might be due to the very low marks obtained.

***Performance in natural sciences (life sciences component)*****:** The life sciences component of natural sciences was not included in the results and discussion of the empirical study because it has no direct influence on kinematics graphs.

***Number of times doing grade 10*****:** A higher percentage 186(92.5%) spent only a year in grade 10. We had learners 15 (7.5%) learners who had been doing grade 10 more than once. These learners repeating the grade may be struggling with the content due to lack of conceptual resources.

***Home language:*** Setswana was the predominant language among the participants of this study. This must be due to the geographical location where the study took place. The home language of (102) 50.7% of the participants was Setswana. Only (15)7.5% of them were English. The minority of the participants used English as their home language although English is the language of tuition and assessing in four out of the six participating schools. This may have affected their understanding of what they have been taught in school. The other two schools have both Afrikaans and English as parallel medium of instruction.

***Schools:*** In the empirical study a total of 201 questionnaires were distributed to six different schools. The schools were represented by the alphabets A, B, C, D, E and F. The numbers of participants are more or less the same for all six schools. The number ranges between 27 and 35 per school.

### 6.3.3 Summary of results of demographic variables

- 201 learners completed the questionnaire
- There were learners that were older and others that were younger than the expected age in grade 10 in South Africa which is between 15 and 16 years.
- Thirteen and nineteen learners' obtained below 40% in physical sciences and mathematics respectively in grade nine.
- Fifteen learners had repeated grade 9 at least once.
- English the medium of instruction is the second and third language for more than 86.1% of the learners. 13.9% of the learners attend Afrikaans medium schools where their first language Afrikaans is used as the medium of instruction.
- The number of participants from each one of the six schools was about equal.

## 6.4 QUANTITATIVE RESULTS: ANALYSIS AND DISCUSSIONS

Paragraph 6.4 consists of subparagraphs which provide statistical analyses and graphical displays of the learners' responses to Sections B and C of the questionnaire (see appendix A). Appropriate Tables are used to present the results of the statistical analysis, which is divided into five subsections.

The five subsections are:

6.4.1 Frequency distribution

6.4.2 Reliability of questionnaire

6.4.3 Descriptive statistics

6.4.4 Test for correlation between constructs-Non parametric correlations

6.4.5 Effect of parameters on constructs

**Subsection 6.4.1** Shows the grouping of the questions and the frequency distribution of the learners' responses to the questionnaire. These are illustrated in Table 6.9 to 6.14 and Table 6.15 shows the difficulties.

**Subsection 6.4.2** Cronbach's Alpha Coefficients were determined statistically to test for consistency in responses in the individual groupings. The reliability of the questionnaire as a whole was determined by grouping the questions into four groups namely perception and competency (section B), basic concepts (section C question 1), maths (section C questions 2, 3, 4), physics (section C questions 5, 6). The researcher also grouped the questions in different ways to determine the reliability and consistency of learners' responses, as illustrated in Tables 6.15 to 6.19. Inter-item correlations were determined for the various groups of items. An inter-item correlation was used to judge the reliability of the instrument this was determined by how well the items yield similar results (Trochim, 2006).

**Subsection 6.4.3** After the Cronbach's Alpha coefficient had been calculated and necessary items removed to obtain reliable groupings, the descriptive statistics for each construct were calculated as indicated in Table 6.20.

**Subsection 6.4.4** Correlation between constructs was determined by using the Spearman's rho coefficients. The correlations (non-parametric correlations) between the constructs are shown in the Table 6.21. The *p-values* were interpreted as follows: $p < 0.05$ implies correlations between questions are statistically significant. Correlation is significant at the 0.01 level (2-tailed) and the values of effect of size are 0.3 and 0.5.

**Subsection 6.4.5** Test for differences in responses due to the parameters was done by using ANOVA. Analysis of variance is an inferential tool abbreviated as ANOVA. According to Tolmie *et al.* (2011:285), ANOVA is "a form of analysis of statistical significance aimed at examining how far individual scores on the dependent variable within different experimental conditions can be accounted for by differences between the group means."

The test for differences was done in this study to determine whether there were any differences in responses according to gender, age, language, school, performance in mathematics and natural sciences in grade 9, number of times in the same grade (grade10) and the effect these parameters have on the conceptual resources needed to learn kinematics graphs (Tables 6.22 to 6.28).

### 6.4.1 Learners' responses to groups of items of the questionnaire.

Frequency Tables (Table 6.9-6.14) shows the number and percentage of learners who responded to section B and C questions of the questionnaire. The questions were grouped into six different sets as indicated in column one of the tables for the purpose of comparison between the number of learners who answered the questions correctly. Descriptions of the items are given in the second column, the frequency and the percentage of learners that provided acceptable answers is given in column three and four respectively. The description in column two starts with the section on the questionnaire followed by the question number then content of the question. e.g. B1 means section B question one (1). Section B tested learners' perception or competency of a graph skill (B) and section C tested their applications of the skills (C). The relationship between the competency or perception indicated by the learner in Section B and the skill demonstrated in Section C is explained in this paragraph.

There are six different sets of Tables (i.e. Table 6.9–6.14) showing the groupings (Group 1 to 6) of the items and the learners' responses to the items of the questionnaire.

Each grouping includes both competency and perception **(B)** and skill **(C).** Group 5 and 6 (i.e. Tables 6.13 and 6.14) were further grouped under the criteria mathematics **(M)** or physics **(P)** respectively.

**Table 6.9: Learners' response to Group 1 items**

| Grouping-Criteria | Description | Frequency (N=201) | Percentage% |
|---|---|---|---|
| **BASIC CONCEPTS:** Competency and perception | **B1** Graph importance in science: | 77 | 38.3 |
| | **B1** Explain the importance of graph in science | 33 | 16.4 |
| Explanation: Skill | C1.1 Variable | 8 | 4 |
| | Distance | 48 | 23.9 |
| | Speed | 22 | 10.9 |
| | C1.3.1 Unit for speed | 46 | 22.9 |
| | C1.3.2 Unit for distance | 90 | 44.8 |
| Application: Skill © | C1.4.1 to 1.4.3 Independent variable | 60 | 29.9 |
| | Dependent variable | 57 | 28.4 |
| | Constant | 23 | 11.4 |

(Source: Analysis of survey data collected for this study)

*Group 1* (Table 6.9): Out of 201 learners 77(38.3%) said that graphs were important but only 33(16.4%) participants were able to mention the importance of graphs. Only eight (4%) of the participants could explain the term *variable* in the scientific context. A much higher percentage could apply their knowledge of variables.

For instance, 23(11.4%) could identify the constant variable, 57(28.4%) the dependent variable and 60(29.9%) the independent variable in the given problem situation. This result can probably be attributed to the degree of application of these terms in grade 9 mathematics and natural sciences. The concepts of *distance* and *speed* were poorly explained. Only 48(23.9 %) and 22(10.9%) of the learners were able to explain distance and speed respectively.

The questions on units were answered much better than the definitions. The unit for speed was given correctly by 46(22.9%) of the learners while 90(44.8%) learners could provide the unit of distance.

Definitions such as “how far things are away from each other’’ for distance and ‘’how fast or slow an object moves’’ for speed was provided as response. Application of variables was well answered.

The basic concepts needed to learn kinematics graphs seems to be lacking among the learners who participated in the study for a total average percentage of 23.9% responded positively by providing the expected answers to the questions.

**Table 6.10: Learners’ response to Group 2 items**

| Grouping-Criteria | Description | Frequency (N=201) | Percentage % |
|---|---|---|---|
| BAR GRAPHS | **B6** Interpreting | 44 | 21.9 |
| Competency | **B7** Drawing | 134 | 66.7 |
| Skill | **C3.1** Draw using correct Label & scale. | 53 | 26.4 |
| | **C3.2** Interpret | 46 | 22.9 |

(Source: Analysis of survey data collected for this study)

*Group 2* (Table 6.10): A high number of learners 134(66.7%) agreed that they could draw bar graphs, only 53(26.4%) learners were able to draw the graph using correct scale, indicating heading and labelling the axis. The indicated competency of 134(66.7%) learners who can draw bar graphs in section B contradict with the number 53(26.4%) who demonstrated acceptable skill of drawing bar graphs. Thus 39.6% more had the competency than those who demonstrated the skill. Only 44(21.9%) said they had the competency of interpreting graphs. A corresponding number 46(22.9%) correctly interpreted the given graph.
Interpretation and drawing of bar graphs is a challenge for the learners with a total average percentage of 34.5%.

**Table 6.11: Learners’ response to Group 3 items**

| Grouping-Criteria | Description | Frequency (N=201) | Percentage % |
|---|---|---|---|
| LINE GRAPHS | **B12** Draw Table from graph | 95 | 47.3 |
| Competency | **B13** Draw graph from data | 76 | 37.8 |
| Skills | **C2.1** Draw x-axis from data | 44 | 21.9 |
| | **C2.1** Use of scale | 39 | 19.4 |
| | **C2.2** Draw graph from data-Scale& label | 44 | 21.9 |
| | **C2.3.1** Draw Table from graph | 52 | 25.9 |
| | **C.5.2.2** Kinematics; draw distance/time graph | 32 | 15.9 |

(Source: Analysis of survey data collected for this study)

*Group 3 (*Table 6.11): The number of learners that indicated they agreed that they could draw Tables from graphs was 95(47.3%). Their perception of competency to draw a Table from a graph and the actual skill were not closely related. Of the 95(47.3%) learners who said they had the ability to draw a Table from a graph, only 52(25.9%) could draw a Table from a graph correctly. A smaller number of learners, 76(37.8%) indicated strongly that they could draw a graph from data, but only 44(21.9%) were able to draw the graph (the x-axis of a graph) from the data given. Total of 32(15.9%) learners demonstrated the skill of drawing a distance/ time graph from the given data.

The use of scale was poorly answered: Only 19.4% of learners from all the schools that participated in the study were able to draw the axis to scale. However only 44(21.9%) demonstrated all the skills of drawing line graphs, labelling axis, plotting points and using scale correctly. Drawing of line graphs as indicated in Table 6.11 group 3 is a challenge for the learners with a total average percentage of 27.2% having and demonstrating the ability correctly.

Other studies have found that line graphs seem to be more difficult to understand, draw and interpret than other graphs (paragraph 2.7.6 and 3.9.2) that appears to be the case here also.

**Table 6.12: Learners' response to Group 4 items**

| Grouping-Criteria | Description | Frequency (N=201) | Percentage % |
|---|---|---|---|
| Relationship | | | |
| Competency | **B5** Variables from graph | 48 | 23.9 |
| Skills | **C3.2** Variables from graph | 46 | 22.9 |

(Source: Analysis of survey data collected for this study)

*Group 4* (Table 12): With regards to the identification of the relationship between variables of a line graph 48(23.9%) claimed that they had the competency to identify the relationship between variables of a line graph. But 46(22.9%) were able to demonstrate that. The problem dealt with in the questionnaire included the relationship between concepts that learners experience daily (i.e. moisture and heat). This may be the reason for almost the same number of learners answering the question correctly and the same number declaring having the competency. The total average percentage of learners having both competency and skills to identify and describe the relationship between variables from a line graph was 23.4%.

*Groups 5 and 6* (Table 6.13 and 6.14) were divided into subgroups called **M1, M2 to M8 and P1, P2 to P9**. The divisions refer to subtopics applied in both mathematics **(M)** and physics **(P)**. The subtopics were included to assess the learners' ability to transfer and integrate concepts in mathematics **(M)** and physics **(P).** The numbers 1 and 2 as part of the labels have been used to differentiate between different concepts, e.g. the first mathematics concept tested was the ability to differentiate between positive, negative and zero gradients and it was labelled as **M1**. The corresponding physics concept was denoted by **P1**.

*Group 5* (Table 13): On an average 62.3% of the learners were able to distinguish between positive, negatives and zero gradients in the mathematics section.

***M1*** Over 70% of the learners were able to interpret the given mathematics graphs correctly. The possible reason that can be put forth for the low performance for C4.2.1, namely 85(42.3%), is a lack of knowledge (conceptual resources) or it is not in the grade 9 or 10 curriculum. It is perhaps the lack of exposure to such questions in their grade 9 textbooks (refer to paragraph 4.6 to 4.8) that contributed to fewer learners' ability to identify zero gradient 99(49.3%) for E.

The learners distinguished between the graphs with negative and positive gradient but identifying zero gradients was more of a challenge.

***M2*** Interpreting graphs intersecting each other was poorly answered with 18(9%) for C4.4.1 and 42(20.9%) for C4.4.2. Learners said during the interviews that they were taught that in order to find where lines intersect you have to equate the lines so many 71(35.3%) selected option B.

***M3*** From the Table 57(28.4%) learners gave the correct formula used to calculate the gradient of a straight line. The formula is found in the mathematics textbooks used in the schools that participated in the study (refer to paragraph 4.8).

***M4*** The results are the same as ***M1***. It is included for comparison purpose, to be used to compare the results of ***P4****.*

***M5*** 52(25.9%) learners completed the Table in C2.3.1 with the correct answers. A number of the learners 75(37.3%) completed the Table with errors which can possibly be attributed to inability to identify patterns and trends. A handful 47(23.4%) did not attempt to complete the Table. The possible reason is they did not do series and sequences in grade 9 or could not apply it to solve the problem.

***M6*** Drawing a line graph, using the correct scale, plotting and joining points, labelling both axes correcty and using a graph heading were done by 44(21.9%) learners.

***M7*** A Table was given and 33(16.4%) learners correctly used the given data to draw the time values on the given time axis.

***M8*** Over 50% of the learners that participated in the study recognized the y-intercept for C4.2.2 C and D. If we compare C and D with A 68(33.8%), B 57(28.4%) and E 96(47.8%), the reason for the high performance in C 112(55.7%) and D 113(56.2%) is possibly that the graph runs through the origin which the learners at this level are familiar with.

***M9*** It is rather surprising that learners responded very poorly in naming the feature ***c*** 55(27.4%) and ***m*** 90(44.8%) in straight–line graph equations for it is in their grade 9 mathematics textbooks (refer to chapter 4, paragraph 4.8).

Questions pertaining to mathematics covered in grade 9 curriculum (paragraph 4.2) were disturbingly poorly answered. A total average percentage of 40.3% of the participants managed to provide the expected response (correct answers).

**Table 6.13: Learners' response to Group 5 items**

| Grouping- Criteria | Description | Frequency (N=201) | Percentage% |
|---|---|---|---|
| Mathematics | **M1** C4.2.1 | | |
| | A | 157 | 78.1 |
| | B | 142 | 70.6 |
| | C | 85 | 42.3 |
| | D | 143 | 71.1 |
| | E | 99 | 49.3 |
| | Distinguish between negative, positive, zero gradient | | |
| | **M2 C4.4** Intersection C4.4.1 | 18 | 9.0 |
| | **M2 C4.4** Intersection C4.4.2 | 42 | 20.9 |
| | **M3** Gradient C4.1 | 57 | 28.4 |
| | **M4** Distinguish between negative, positive, zero gradient C4.2.1 A | 157 | 78.1 |
| | B | 142 | 70.6 |
| | C | 85 | 42.3 |
| | D | 143 | 71.1 |
| | E | 99 | 49.3 |
| | **M5 C2.31** C2.3.1 | | |
| | Table completely correct | 52 | 25.9 |
| | Table completed with some errors | 75 | 37.3 |
| | **M6** Drawing graph from Table C2.2 | 44 | 21.9 |
| | **M7C2.1** Drawing the time values from given data on time axis (x-axis) C2.1 | 33 | 16.4 |
| | **M8 C4.2.2** A-E y-intercept A | 68 | 33.8 |
| | B | 57 | 28.4 |
| | C | 112 | 55.7 |
| | D | 113 | 56.2 |
| | E | 96 | 47.8 |
| | **M9** C4.3 Line graph C4.3.1 | 55 | 27.4 |
| | C4.3.2 | 90 | 44.8 |

(Source: Analysis of survey data collected for this study)

**Table 6.14: Learners' response to Group 6 items**

| Grouping- Criteria | Description | Frequency (N=201) | Percentage % |
|---|---|---|---|
| Group 6 | **P1** C5.1.1 to C5.1.5 | | |
| Physic | 5.1.1 | 147 | 73.1 |
| Application | Displacement-time graph 5.1.2 | 110 | 54.7 |
| | 5.1.3 | 93 | 46.3 |
| | 5.1.3 | 53 | 26.4 |
| | 5.1.4 | 41 | 20.4 |
| | **P2** C6.5.3 Point on a velocity-time where two lines cross (intersection) | | |
| | 6.5.3 | | |
| | A | 46 | 22.9 |
| | B | 31 | 15.4 |
| | C | 42 | 20.9 |
| | D | 21 | 10.4 |
| | E | 43 | 21.4 |
| | G | 17 | 8.5 |
| | **P3** 6.1.1 Gradient: calculates velocity from graph 6.1.1 | 1 | 0.5 |
| | **P4** C6.1.2 Position- time graph (Distinguish between positive, negative, zero gradien) | | |
| | AB | 152 | 75.6 |
| | BC | 94 | 46.8 |
| | CD | 105 | 52.2 |
| | DE | 105 | 52.2 |
| | EF | 106 | 52.7 |
| | FG | 75 | 37.3 |
| | C 6.1.3 Direction(position/time) | 20 | 10.0 |
| | C 6.4.3 Direction(velocity-time) | 79 | 39.3 |
| | **P5** C5.2.1 Completing Table | | |
| | Table completed completely correct | 42 | 20.9 |
| | Table completed with errors | 113 | 56.2 |
| Group 6 Physics application | **P6** C5.2.2 Drawing graph | 13 | 6.5 |
| | **P7** C6.4.1 & 6.4.2 Reading values from x-axis (time) | | |
| | 6.4.1 | 33 | 16.4 |
| | 6.4.2 | 28 | 13.9 |
| | **P8** C6.5.1 Reading values from y-axis (velocity from a velocity-time graph) | 91 | 45.3 |
| | 6.5.2 Calculate distance to determine which vehicle is ahead | 70 | 34.8 |

| Grouping- Criteria | Description | | Frequency (N=201) | Percentage % |
|---|---|---|---|---|
| | **P9** C6.2.1 Speed of blocks | 6.2.1 | 13 | 6.5 |
| | C6.2.2 Position of blocks | 6.2.2 | 51 | 25.4 |
| | **P10** Ticker timer | 6.3.1 | 110 | 54.7 |
| | C6.3.1 to C6.3.3 | 6.3.3 | 121 | 60.2 |
| | C6.3.2 and C6.3.4 Explanation | 6.3.2 | 4 | 2.0 |
| | | 6.3.4 | 7 | 3.5 |

(Source: Analysis of survey data collected for this study)

*Group 6* (Table 14): P1 147(73.1%) and 110(54.7%) of the 201 participants could indicate whether the gradient between times 0 and 1 second is zero, positive, or negative and whether it increases, decreases or stay the same respectively.

The number of learners who selected the correct answer for question 5.1.3 and 5.1.4 are 93(46.3%) and 53(26.4%) respectively. The learners had the ability to determine if the gradient of the given displacement–time graph decrease, increase or stay the same but a lot more 101(50.2%) selected B for 5.1.4 indicating the gradient of the graph decreases. The reason for selecting B may be due to the shape of the graph. Question 5.1.5 involved using a displacement-time graph to determine the time at which the graph shows zero gradients. The inability to read off values correctly from a graph attributed to the poor performance 41(20.4%) in selecting the time at which the gradient was zero.

**P2** 32(15.9%) learners were competent to use the correct scale, plotted points correctly and drew a straight line graph through the origin, and labelled axes correctly. 7(8.5) made no attempt to draw the graph.

**P3** Just one (0.5%) learner could calculate correctly the velocity from a position–time graph.

**P4** For the given intervals learners were asked to state whether the gradient is positive, negative, or zero and over 45% were capable to provide the accepted answer for each interval.

**P5** The Table was completed with no errors by 42(20.9%) learners. A lot more 113(56.2%) completed the Table with some errors.

**P6** There were only 13(6.5%) learners able to draw the graph using the correct scale, correct label, plotted the points correctly and joined the points to form a straight line graph (the line of best fit) through the origin.

**P7** A look at P7 on Table 6.14 group 6 shows similarities in the number of learners correctly interpreting a velocity-time graph.

There were only 33(16.4%) who could determine the time the velocity was 2m/s and 28(13.9%) the time there was no movement. Only 79(39.3%) learners identified the direction of the velocity correctly.

**P8** The ability to read off values correctly from a velocity-time graph was poorly answered with only 91(45.3%) having the ability. Calculating the area under the given velocity–time graph was correctly done by 70(34.8%) learners. Another question that involve the interpretation of a graph was poorly answered, 42(20.9%) were capable of explaining what happened at the point of intersection when two lines crossed on a velocity-time graph.

**P9** The positions of two blocks at successive constant time intervals were represented by numbered squares and the learners were asked to find the instant the blocks have the same speed or were at the same position. These questions were badly answered with 13(6.5%) finding the instant the two blocks had the same speed and 51(25.4%) the instant the blocks were at the same position. The poor performance may be due to position and speed confusion (Trowbridge & McDermott, 1980:1027).

**P10** Analyzing the results of items 6.3.1 to 6.3.4 from Table 6.14 (group 6), the majority 110(54.7%) of the learners were able to select the ticker tape that represented the larger speed and 121(60.2%) the greater acceleration. A rather low result was obtained for the corresponding explanation and reasons for question 6.3.2. Only 4(2%) learners and 7(3.5%) learners gave the correct scientific explanation for question 6.3.4. Learners struggle to give scientific reasoning. This may be due to lack of the correct vocabulary as discussed in the literature paragraphs 2.7.6 and 3.7 The results are in accordance with Beichner's finding, which is learners lack the vocabulary needed to interpret kinematic graphs (Beichner, 1994:753).

The results show that learners struggle with the skill of interpreting kinematics graphs (line graphs), reading data from a given graph, scaling of axes which confirms McKenzie and Padilla (1986) findings (paragraph 2.7.6). As already been stated in literature (McDermott *et al*., 1987; Molefe *et al*., 2005), learners face difficulties in motion graphs. Line graphs are essential in mathematics and science but learners have difficulty in drawing, interpreting (Padilla, *et al*., 1986: 20) and comprehending (Friel *et al*., 2001:140) line graphs.

**Comparing M and P with reference to Tables 6.13 and 6.14:**

Learners' responses to pairs of mathematics (M) and physics (P) questions are now compared: **M1**: was well answered compared to **P1**: Learners could distinguish between positive, negative, and zero gradient in all the mathematics questions but did not do the same for the similar physics displacement-time and position-time graph questions.

**M2 and P2:** The number of participants that could answer questions related to intersection of line graphs in mathematics differed from that of physics. More learners applied the concept correctly in mathematics. Fewer learners could apply that concept correctly in physics. Interpretation of the point of intersection of line graphs (in maths and physics) was badly answered. For both below 30% of the learners provided the correct answer.

**M3 and P3**: Forty learners did not attempt **P3** (calculating gradient) and only one wrote the right answer. **M3** was better answered than **P3.** A lot more learners gave the correct formula for calculating gradient **M3** but could not apply this mathematics knowledge in kinematics graph **P3.**

**M4 and P4**: Learners could identify negative, positive and zero gradient in both the mathematics and physics questions. An average of over 52.8% of the learners were able to distinguish between positive, negative and zero gradients from a position-time graph **P4**, compared to an average of over 51.9% in mathematics **M4**. They showed correspondence in their response in mathematics and physics.

**M5 and P5**: From the results and discussions above more learners completed the Table correctly from a graph in mathematics **M**5 than the Table showing the distance covered by Mpho at certain times in **P5**. But a greater number 113(56.2%) out of 201 completed the Table with some errors in **P5**.

**M6 and P6:** The percentage of learners who could draw kinematics graph from a given Table **P6** was less than the percentage of learners who could draw a line graph from a given Table **M6**. Questions on the drawing of graphs were poorly answered in both cases.

**M7 and P7**: Less than 17% of the total learners that participated in the empirical study could either read values correctly from the time axis (x-axis) or select a scale to draw the time values on the x-axis for both **M7** and **P7**. The rest (more than 70%) did not show these skills.

**M8 and P8:** Learners were able to solve problems related to y-intercept in mathematics **M8.** Application of graph skills to kinematics graphs **P8** was also poorly answered (i.e. reading values from the y-axis).

**M9 and P9** could not be compared for they measure different variables. **P10** could not be compared with **M10** because there were no other items to be grouped under **M10**. **M** ends at **M9.**

## Summary

- Most of the learners could not calculate or determine velocity from a position-time graph.
- Finding the instance two blocks have the same speed or are at the same position was badly answered.
- Identification of object with greater speed as well as acceleration was well answered by the majority of the learners.
- The learners showed the ability to solve problems related to y-intercept but could not apply the concept to solve kinematics graphs questions related to reading a value from the y-axis.
- The learners could calculate gradient.
- Most of the learners were able to distinguish between positive and negative gradient.

## Results showing learners' difficulties

The results illustrate the difficulty learners have in applying different principles and skills to solve a problem even if they can use them separately. These results are in line with Bao and Redish (2006) findings (paragraph 2.7.6). Table 6.15 shows questions that are not answered or wrongly answered due to the difficulties.

**Table 6.15: Questions that were not answered or wrongly answered**

| Question Number | Frequency (N=201) | Percentage |
|---|---|---|
| C1_1_A,B, C | 193 | 96.0 |
| C1_4_A,B,C | 178 | 88.6 |
| C2_3_2 | 189 | 94.0 |
| C4_1 | 173 | 86.1 |
| C4_4_1 | 183 | 91.0 |
| C5_1_5 | 159 | 79,1 ≈ 80 |
| C5_2_2 | 168 | 83.6 |
| C6_1_1 | 200 | 99.5 |
| C6_1_3 | 181 | 90.0 |
| C6_2_1 | 188 | 93.5 |
| C6_3_4 | 194 | 96.5 |
| C6_4_1 | 168 | 83.6 |
| C6_4_2 | 173 | 86.1 |
| C6_5_3 | 159 | 79.1≈ 80 |

(Source: Analysis of survey data collected for this study)

Table 6.15 above shows questions (items) that 80-100% of the learners could not provide the expected response. Analysis of the results in table 6.15 revealed the items learners struggle with as listed below.

*The items with which the learners struggled most include:*

- Understanding and identifying variables.
- Determining equations of line graphs in mathematics.
- Identification of zero gradients.
- Interpretation of the point of intersection of line graphs (in mathematics and physics).
- Differentiation between position and speed.
- Linear representation of acceleration.
- Interpretation of kinematics graphs.

### 6.4.2 Reliability of questionnaire - Cronbach's Alpha coefficient

The researcher used different groupings of questions to determine the reliability, as illustrated in Tables 6.16 to 6.19. Cronbach's Alpha coefficients were statistically determined for reliability due to consistency of learners' responses to a group of questions. If the Cronbach's Alpha coefficient is > 0.7, it indicates reliability. Tables 6.16 to 6.19 show the different groupings and sets of questions (groupings), Cronbach's Alpha coefficients and the consistency (internal consistency) at which the learners responded to the questions.

Different groupings of questions were used as constructs to determine the reliability of groups of questions and to determine which questions the learners answered in a consistent way. Firstly, the consistencies of all questions related to mathematics and those related to physics from sections B and C were grouped together under two sets. The Cronbach's Alpha coefficients and the consistencies of responses within each set are summarised in Table 6.16 and 6.17.

**Table 6.16: Consistency in all the mathematics and the physics questions**

| Sets of questions | Cronbach's alpha | Consistency |
|---|---|---|
| Mathematics | 0.811≈0.8 | Very good |
| Physics | 0.753 ≈0.8 | Very good |

(Source: Analysis of survey data collected for this study)

The learners answered both mathematics and physics related questions consistently correctly or incorrectly. This is indicated by the high Cronbach's Alpha coefficient of approximately 0.8. These values confirm that the questionnaire can be regarded as reliable.

Reliability of the questionnaire was further established by grouping the questions into four namely: perception of competency (section B), basic concepts (section C question 1), mathematics applications (section C questions 2, 3, 4) and physics applications. (Section C questions 5 and 6). The Cronbach's Alpha coefficients indicated good to very good internal consistencies, as shown in Table 6.17.

**Table 6.17: Table showing four groupings of section B and C items of the questionnaire**

| Groupings | Items | Cronbach's alpha | Internal consistency |
|---|---|---|---|
| Perception of competencies | Section B | 0.812 | Very good |
| Basic concepts | Section C: C_1_1 to C_1_4 | 0.714 | Good |
| Mathematics application | Section C: C2_1 to C4_4 | 0.811 | Very good |
| Physics application | Section C: C5.1-C6 | 0.713 | Good |

(Source: Analysis of survey data collected for this study)

The Cronbach's Alpha coefficient is 0.812 for all competency questions, which is very high. The group of mathematics applications also tested very high. The other sets of questions, namely the understanding of basic concepts related to graphs in both physics and mathematics as well as the physics applications were lower, but still above 0.7.

The questions were regrouped again (6.18), this time according to the questionnaire groupings that were used in the frequency distribution. The Cronbach's Alpha coefficients were calculated to determine the internal consistency of the various groups of questions.

**Table 6.18: Cronbach's Alpha coefficient of groupings used in the frequency distribution**

| Grouping-criteria | | Cronbach's alpha coefficient |
|---|---|---|
| Group 1 | Basic concepts and perceptions | 0.461 |
| Group 2 | Bar graphs | 0.810 |
| Group 3 | Line graphs | 0.804 |
| Group 4 | Relationship | 0.794 |
| Group 5 | Mathematics | 0.811 |
| Group 6 | Physics | 0.713 |
| Group 7 | Perception of competency | 0.812 |

(Source: Analysis of survey data collected for this study)

The value of the Cronbach's Alpha coefficient is 0.461 for the set of items (C_1_1A, B, C, B5, C_1_4) on basic concepts and perceptions. In this set, B5 was the only question on perception of competency. When this question was deleted and only items on basic concepts were used (as in Table 6.19) the Cronbach's Alpha coefficient increased to 0.714. Excluding problematic items could lead to a meaningful increase in the Cronbach's Alpha value (Tolmie *et al.*, 2011:156). B5 is a question that requires of learners to indicate whether they can identify the relationship between variables from a line graph, while the other questions of this set were related to definitions and units of speed and distance, and the definitions and applications of variables. Understanding the relationship of variables used in a line graph may be difficult to learners. Due to the high correlation among the questions C1_1A to C_1_1 C, C1_2, C1_3_1 to C1_3_2, C1_4_A to C_1_4_C, the decision was made to keep them as a group (called basic concepts).

Due to differences in learners' perceptions of their competencies (section B) and their actual competencies shown in section C, the questions were regrouped as illustrated in Table 6.19. The differences between Tables 6.18 and 6.19 are: There is an overlap of questions from sections B and C in Table 6.18 but there is no overlap of questions from sections B and C in Table 6.19.

The physics as well as mathematics groupings in Table 6.18 was further divided into questions on gradient and questions on interpretation of graphs in Table 6.19. The groupings which are our constructs are the set of crucial questions that will lead to answering the research questions and to achieve the aim and objectives of the study. Reliability of each set of crucial questions in Table 6.19 was calculated statistically using Cronbach's method for assessing internal consistency.

**Table 6.19: Cronbach's Alpha coefficients of the questionnaire constructs**

| Questionnaire groupings | | Cronbach's alpha coefficient | Mean–inter-item correlation |
|---|---|---|---|
| Group 1 | Perception of competency | 0.812≈0.80 | 0.203 |
| Group 2 | Basic concepts | 0.714≈0.71 | 0.197 |
| Group 3 | Bar graphs | 0.810≈0.80 | |
| Group 4 | Line graphs(drawing, scale, labelling) | 0.804≈0.80 | |
| Group 5 | Graph interpretation mathematics | 0.745≈0.75 | 0.165 |
| Group 6 | Kinematics graph interpretation physics | 0.753 ≈0.80 | |
| Group 7 | Gradient physics | 0.699≈0.70 | 0.164 |
| Group 8 | Gradient mathematics | 0.745≈0.75 | 0.165 |

(Source: Analysis of survey data collected for this study)

The final groupings (groups 1 to 8) portray high Cronbach's Alpha coefficients ranging between 0.7 and 0.8. From Table 6.19 it is clear that reliable groupings with high internal consistency have been used. The mean–inter-item correlation should lie between 0.15 and 0.55 (Clark & Watson, 1995; Trochim, 2006). None of the mean-inter-item correlations for the constructs in Table 6.19 is lower than 0.15 or higher than 0.55 and this confirms that all the sets of questions in Table 6.19 have been answered consistently. The groups of Table 6.19 were consequently used as constructs for further statistical processing of which the results are given in the following subsections.

### 6.4.3 Descriptive statistics

After the Cronbach's alpha coefficient had been calculated and items removed to obtain reliable groupings, the descriptive statistics for each section were calculated as in Table 6.20 below. In Tables 6.19 and 6.20 groupings look similar but the mean and standard deviation were determined and included in Table 6.20.

**Table 6.20: Descriptive statistics**

| Groupings | | Number of participants | Mean | Standard deviation |
|---|---|---|---|---|
| Group 1 | Perception of competency | 201 | 0.37228 | 0.55220 |
| Group 2 | Basic concepts | 201 | 0.2460 | 0.22605 |
| Group 3 | Bar graph | 201 | 0.3685 | 0.19928 |
| Group 4 | Line graph | 201 | 0.3492 | 0.14722 |
| Group 5 | Graph interpretation–Mathematics | 201 | 0.39893 | 0.67416 |
| Group 6 | Kinematics graph interpretation-Physics | 201 | 0.3492 | 0.14722 |
| Group 7 | Gradient – Physics | 201 | 0.5177 | 0.24127 |
| Group 8 | Gradient – Mathematics | 201 | 0.4286 | 0.22621 |

(Source: Analysis of survey data collected for this study)

The larger the standard deviation, the bigger the amount of variability (Elmore & Woehlke, 1997) therefore gradient-physics has more variability than gradient mathematics. The standard deviation of 0.67416 for mathematics graph interpretation indicated greater variability than the standard deviation for kinematics graph interpretation (physics).

The learners performed better in gradient mathematics and gradient physics with a mean score of 0.4286 (i.e. 42.86%) and 0.5177 (51.7%) respectively than in mathematics graph interpretation with a mean score of 0.39893 (39.89%). The answers of mathematics-graph interpretation show the largest variability of all the groupings. For most of the groups the standard deviation (SD) values are low which means the data are consistent (Babbie, 2010:432). These values indicate coherence and consistency in the way the questions were answered. A mean value of 39.89%, SD=0.67416 for mathematics graph interpretation, shows that there was a wide variety of responses to the interpretation of the graphs-related questions.

### 6.4.4 Test for correlation: Non–parametric correlations

Correlation is a technical term for the association between two or more variables. ''The numerical indicator of the strength and direction of the correlation or linear relationship between the two variables is referred to as correlation coefficient." (Tolmie *et al.,* 2011:288.) The correlation coefficient used in the study is the Non-parametric Spearman's correlation coefficient or Spearman's rho (r). Spearman's rho is among the most popular and generally used for statistical correlations. The values of effect size are 0.1, 0.3 and 0.5. A correlation coefficient of 0.1 indicates a small non-practically significant correlation, a correlation of 0.3 a medium practical visible correlation and 0.5 a large practically important correlation (Steyn, 2009).

Non-parametric correlation was used to test the relationship between the variables and to test the hypothesis (Taylor & Williams, 2010:182). Non-parametric correlation shows good general influence. The correlations between questionnaire constructs are shown in Table 6.21.

**Table 6.21: Non- parametric correlation (Spearman's rho coefficients)**

| **Groupings** | **Perception of competency** | **Basic concepts** | **Drawing and interpretation of graphs_ mathematics** | **Drawing and interpretation of graphs_physics** | **Gradient_ mathematics** | **Gradient_ physics** |
|---|---|---|---|---|---|---|
| Perception of competency | 1.000 | ** 0.328 | ** 0.292 | * 0.180 | ** 0.218 | ** 0.187 |
| Basic concepts | ** 0.328 | 1.000 | ** 0.586 | ** 0.309 | ** 0.511 | ** 0.356 |
| Drawing and interpretation of graphs_mathematics | ** 0.292 | ** 0.586 | 1.000 | ** 0.424 | ** 0.932 | ** 0.498 |
| Drawing and interpretation of graphs_physics | * 0.180 | ** 0.309 | ** 0.424 | 1.000 | ** 0.385 | ** 0.872 |
| Gradient_mathematics | ** 0.218 | ** 0.511 | ** 0.932 | ** 0.385 | 1.000 | ** 0.464 |
| Gradient_physics | ** 0.187 | ** 0.356 | ** 0.498 | ** 0.872 | ** 0.464 | 1.000 |

(Source: Analysis of survey data collected for this study)

Correlations were determined and it was revealed that there were correlations between the constructs as indicated in Table 6.21. Two stars ** means a large practically important correlation and one star * implies visible significant correlation. The correlation between basic concepts and drawing, interpretation of graph_mathematics as well as gradient_mathematics has a large practically important correlation. The values are 0.586 and 0.511 respectively. Drawing and interpretation of graph_mathematics and gradient related response in mathematics is important in practice with a value of 0.932. The correlation between drawing and interpretation of graph_physics and gradient related responses in physics is also important in practice with a value of 0.872. There is a large practically important correlation between the constructs discussed in this paragraph because they have large correlation coefficient values, i.e. greater than 0.5.

Correlation between drawings and interpretation of graphs_mathematics and gradient_physics is 0.498 while the gradient_ physics and gradient mathematics is 0.464, i.e. approximately 0.5 which is a practically important correlation. Drawing and interpretation of graph_mathematics and drawing and interpretation of graphs_physics revealed a correlation coefficient of 0.424. This is less than 0.5 and more than 0.3 therefore it is practically visible significant correlation. Table 6.21 above indicates that the correlation between perception of competency and basic concepts is 0.328. The correlation coefficient for basic concepts and gradient_physics is 0.356. The correlation between basic concepts and drawing and interpretation of graph_physics yielded a correlation coefficient value of 0.309. Correlation between drawing and interpretation of graph_physics and gradient_physics is 0.385. These values are medium and represent practical visible significant correlations.

Correlation between learners' perceptions of their competencies and their applications thereof was low. There was a small correlation of 0.187 between perception of competency (the learners who said they could calculate the gradient of kinematic graphs) and gradient_physics (i.e. those who could actually do it). The following correlations between perception of competency and;

- drawing and interpretation of graph_mathematics is 0.292
- drawing and interpretation of graph_physics is 0.180
- gradient_mathematics is 0.218.

These are small values (less than 0.3) and therefore they are non-practically significant correlations. The correlation between competency in drawing graphs and the application in drawing the graphs is very low as well as the explanation and application of basic concepts related to kinematics graph (x<0.3). This inconsistency can be attributed to varying responses to scaling, labelling, plotting points and headings of graphs. The result is confirmed by the high standard deviation for perception of competency (group 1) and graph interpretation (group 5) in Table 6.9 and 6.13 respectively.

There was a relation in how the constructs were responded to. For example, if a learner indicated in section B not competent in drawing a line graph, similar results were noted in either drawing and interpretation of graph_mathematics or drawing and interpretation of graph_physics. The correlation between section B and the rest of the constructs is $x < 0.5$ therefore the correlation is not important but visible in practice. The similar questions in mathematics, such as gradient, were answered consistently in both mathematics and physics sections, whether they were answered well or not.

### 6.4.5 Effect of the parameters on constructs

An **ANOVA** (Analysis of variance) test is conducted to test for the demographical variables. In this study the ANOVA test was performed to test for differences between the different schools, age groups, languages, number of times in grade ten and how that affected the response to the group of questions from the questionnaire. *The meaning of the p-values is*: $p< 0.05$ implies correlation between questions were statistically significant. The t-test is a special case of analysis of variance (ANOVA) which was conducted to test for differences in response between two groups (Tolmie e*t al*., 2011:119), e.g. the gender of the learners being either male or female.

The effects of the parameters used in this study on the responses are discussed in the following paragraphs. Statistical significance was determined to find the level of consistency. Table 6.22, 6.23 and 6.24 show the parameters gender, age, performance in natural sciences, performance in mathematics, number of times doing grade 10, home languages and schools.

**Table 6.22: Effect of gender differences in response to the items**

| Groupings (constructs) | Gender | N | Mean | Sig. (2-tailed)p-value | Std. Deviation |
|---|---|---|---|---|---|
| Perception of competency | BOYS | 89 | 3.7785 | **.203** | .55221 |
| | GIRLS | 112 | 3.6785 | **.203** | .55063 |
| Basic concepts | BOYS | 89 | .2772 | **.081** | .24568 |
| | GIRLS | 112 | .2212 | **.088** | .20693 |
| Drawing and interpretation of graph mathematics | BOYS | 89 | .3933 | **.116** | .22225 |
| | GIRLS | 112 | .3488 | **.126** | .17750 |
| Drawing and Interpretation of graphs physics | BOYS | 89 | .3678 | **.111** | .16417 |
| | GIRLS | 112 | .3344 | **.121** | .13111 |
| Gradient_mathematics | BOYS | 89 | .4569 | **.114** | .25726 |
| | GIRLS | 112 | .4061 | **.125** | .19641 |
| Gradient_physics | BOYS | 89 | .5298 | **.526** | .26577 |
| | GIRLS | 112 | .5080 | **.535** | .22062 |

(Source: Analysis of survey data collected for this study)

**Gender:** A t-test was used to compare between boys' and girls' responses to all the constructs. The p-value was more than 0.05, which implies both boys and girls who participated in this study, answered the questions statistically similar. The t-test thus shows there was no significant difference between the responses of the boys and girls (p>0.05).

**Table 6.23: Effect of age differences in response to the items**

| Groupings (constructs) | Sig (2-tailed) value |
|---|---|
| Perception of competency | 0.854 |
| Basic concepts | 0.000 |
| Drawing and interpretation of graphs mathematics | 0.000 |
| Drawing and interpretation of graphs physics | 0.040 |
| Gradient_mathematics | 0.289 |
| Gradient _physics | 0.021 |

(Source: Analysis of survey data collected for this study)

**Age:** Table 6.23 indicates that the p-values are smaller than 0.05 which means there is statistically significant difference between how the different age groups answered the questions in the different groupings (constructs). Except their perception of competence and how they responded to the gradient questions from their mathematics textbooks.The prior knowledge of learners of different ages and grades differ and that seems to affect the level of comprehension (paragraph 2.61).

**Table 6.24: Effect of Performance in natural sciences NS1 in response to the items**

| Groupings (constructs) | Sig (2-tailed) value |
|---|---|
| Perception of competency | 0.001 |
| Basic concepts | 0.001 |
| Drawing and interpretation of graphs mathematics | 0.063 |
| Drawing and interpretation of graphs physics | 0.091 |
| Gradient_mathematics | 0.000 |
| Gradient_physics | 0.018 |

(Source: Analysis of survey data collected for this study)

**Performance in natural sciences:** There was no statistically significant difference between the results based on marks learners obtained in natural sciences NS1 (physical sciences component) with regard to interpretation of graphs (p=0.063) as well as the physics questions (kinematics graphs) (p=0.09). The p-value for the other constructs is less than 0.05 that denotes a statistically significant difference.

**Table 6.25: Effect of performance of mathematics in response to the items**

| Groupings (constructs) | Sig (2-tailed) value |
|---|---|
| Perception of competency | 0.000 |
| Basic concepts | 0.000 |
| Drawing and interpretation of graphs mathematics | 0.136 |
| Drawing and interpretation of graphs physics | 0.000 |
| Gradient_mathemtics | 0.000 |
| Gradient_physics | 0.000 |

(Source: Analysis of survey data collected for this study)

**Performance in mathematics:** Learners with higher marks in mathematics (> 80 %) compared with learners with lower marks in mathematics (illustrated in table 6.25) answered the questions practical significantly different. The p-value was obtained for all the constructs except interpretation of graphs related to their mathematics curriculum having p= 0.136. p<0.05 means there is a statistically significant difference between how learners with higher and lower marks answered section B, gradient, physics and mathematics questions.

**Table 6.26: Effect of number of times doing grade 10 in response to the items**

| Groupings (constructs) | | Sum of Squares | Df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| Perception of competency | Between Groups | 1.338 | 2 | .669 | 2.220 | .111 |
| | Within Groups | 59.647 | 198 | .301 | | |
| | Total | 60.985 | 200 | | | |
| Basic concepts | Between Groups | .299 | 2 | .150 | 2.985 | .053 |
| | Within Groups | 9.921 | 198 | .050 | | |
| | Total | 10.220 | 200 | | | |
| Drawing and interpretation of graphs _mathematics | Between Groups | .446 | 2 | .223 | 5.894 | .003 |
| | Within Groups | 7.496 | 198 | .038 | | |
| | Total | 7.942 | 200 | | | |
| Drawing and interpretation of graphs _physics | Between Groups | .078 | 2 | .039 | 1.806 | .167 |
| | Within Groups | 4.257 | 198 | .022 | | |
| | Total | 4.335 | 200 | | | |
| Gradient_mathematics . | Between Groups | .399 | 2 | .199 | 4.014 | .020 |
| | Within Groups | 9.836 | 198 | .050 | | |
| | Total | 10.234 | 200 | | | |
| Gradient_physics | Between Groups | .293 | 2 | .146 | 2.554 | .080 |
| | Within Groups | 11.349 | 198 | .057 | | |
| | Total | 11.642 | 200 | | | |
| Graph_mathematics | Between Groups | .509 | 2 | .254 | .557 | .574 |
| | Within Groups | 90.391 | 198 | .457 | | |
| | Total | 90.900 | 200 | | | |

(Source: Analysis of survey data collected for this study)

**Number of times doing grade 10:** Referring to Table 6.26 none of the p-values was less than 0.05. It can be concluded that there was no statistically significant difference in how the learners who repeated and those who did grade 10 for the first time responded to sections B and C questions. Responses from the repeaters, whether once or twice in the same grade, revealed no statistical difference in their conceptual resources.

According to Georghiades (2000:120) we expect that the learners doing grade 10 more than once should construct understanding based on their previous experiences. Being exposed to kinematics graphs more than once, it is expected they have acquired richer experience and should do better (paragraph 2.2 and 3.9). However the results reflect no effect, therefore these same learners are still struggling with mathematics and physical sciences in the same grade according to the results of this study.

**Table 6.27: The effect of different home languages**

| **Constructs** | | **Sum of Squares** | **DF** | **Mean Square** | **F** | **Sig. p-value** |
|---|---|---|---|---|---|---|
| Perception of Competency Section B | Between Groups | 1.908 | 4 | .477 | 1.583 | .180 |
| | Within Groups | 59.077 | 196 | .301 | | |
| | Total | 60.985 | 200 | | | |
| Basic concepts | Between Groups | 1.572 | 4 | .393 | 8.907 | .000 |
| | Within Groups | 8.648 | 196 | .044 | | |
| | Total | 10.220 | 200 | | | |
| Drawing and interpretation of graphs C_mathematics | Between Groups | 2.388 | 4 | .597 | 21.062 | .000 |
| | Within Groups | 5.555 | 196 | .028 | | |
| | Total | 7.942 | 200 | | | |
| Drawing and interpretation of graphs C_physics | Between Groups | .374 | 4 | .093 | 4.622 | .001 |
| | Within Groups | 3.961 | 196 | .020 | | |
| | Total | 4.335 | 200 | | | |
| Gradient_mathematics | Between Groups | 2.705 | 4 | .676 | 17.604 | .000 |
| | Within Groups | 7.529 | 196 | .038 | | |
| | Total | 10.234 | 200 | | | |
| Gradient_physics | Between Groups | .629 | 4 | .157 | 2.796 | .027 |
| | Within Groups | 11.014 | 196 | .056 | | |
| | Total | 11.642 | 200 | | | |
| | Total | 90.900 | 200 | | | |

(Source: Analysis of survey data collected for this study)

**Home language:** The differences between and within the different home languages (Table 6.27) are statistically significant with $p<0.05$, except for perception of competency (Section B). The p-value for perception of competency is greater than 0.05 ($p>0.05$). The differences between responses from the different home languages were observed as statistically significant. The home language affected the understanding of the concepts.

**Table 6.28: Comparing the responses of the schools**

| ANOVA- COMPARING LEARNERS' PERFORMANCE :THE SCHOOLS' RESPONSES | | | | | | |
|---|---|---|---|---|---|---|
| **Constructs** | | **Sum of Square** | **D** | **Mean Square** | **F** | **Sig. p-value** |
| Perception of competency | Between Groups | 7.233 | 5 | 1.447 | 5.248 | .000 |
| | Within Groups | 53.751 | 195 | .276 | | |
| | Total | 60.985 | 200 | | | |
| Basic concepts | Between Groups | 3.575 | 5 | .715 | 20.984 | .000 |
| | Within Groups | 6.645 | 195 | .034 | | |
| | Total | 10.220 | 200 | | | |
| Drawing interpretation and of graphs _Mathematics | Between Groups | 4.987 | 5 | .997 | 65.815 | .000 |
| | Within Groups | 2.955 | 195 | .015 | | |
| | Total | 7.942 | 200 | | | |
| Drawing interpretation and of graphs_Physics | Between Groups | .708 | 5 | .142 | 7.613 | .000 |
| | Within Groups | 3.627 | 195 | .019 | | |
| | Total | 4.335 | 200 | | | |
| Gradient_Maths | Between Groups | 5.271 | 5 | 1.054 | 41.423 | .000 |
| | Within Groups | 4.963 | 195 | .025 | | |
| | Total | 10.234 | 200 | | | |
| Gradient_Physics | Between Groups | 2.219 | 5 | .444 | 9.185 | .000 |
| | Within Groups | 9.423 | 195 | .048 | | |
| | Total | 11.642 | 200 | | | |

(Source: Analysis of survey data collected for this study)

**Schools:** ANOVA was used to compare the responses of learners from the six schools to the questions. The results are summarized in Table 6.28. It shows that there is a significant difference between the six groups ($p<0.05$). Responses from the different schools thus revealed significant differences.

The differences can be attributed to the type of school, qualification and experience of educators teaching in the school and extent to which topics in the natural sciences, mathematics and physical sciences are dealt with.

## 6.5 DISCUSSION OF QUANTITATIVE RESULTS

The quantitative results is discussed in detail under the following sub paragraphs 6.5.1 Perception of competency and skills; 6.5.2 Coherence and integration; 6.5.3 Conceptual resources.

### 6.5.1 Perception of competency and skills

The results have proved that learners' perception of competency do not always corresponds with the actual demonstration of the skill or knowledge. In some cases as discussed in paragraph 6.4 a higher number of learners will indicate they have the competency but fewer applied the skill or knowledge correctly and vice versa.

### 6.5.2 Coherence and integration

The high Cronbach's Alpha coefficient values obtained for different constructs in the questionnaire indicated that there was an internal consistency within the answering pattern of the questions. This confirms that there was coherence in the response pattern. The questionnaire can therefore be considered reliable.

The correlation between gradient _physics and interpretation of_ physics graphs is 0.872 which is very high. This implies that the learners' responses in the physics context were consistent. The good performers performed well in most of the questions, while the weak performers do not have a good overall understanding. Similarly, the students performed consistently in the mathematics constructs with a high correlation value of 0.932.

Only medium correlations (< 0.5) were obtained between mathematics and physics constructs. This result implies that the learners sometimes transferred their mathematics knowledge to physics and sometimes not. For example, the learners had not been taught kinematics graphs but they were able to solve basic gradient-related questions which they had understood in grade 9 mathematics lessons. This is confirmed by Bransford *et al.* (2000:16-19) as discussed in paragraph 1.2 and 2.7.6. Transfer of learning occurs when prior-learned knowledge and skills affect the way in which new knowledge and skills are learned and performed. The learners, however, did not transfer their knowledge of gradients to solve problems on kinematics graphs. A reason may be conceptual difficulties with the science concepts such as speed.

The age and maturity of grade 10's contributed to their ability to attempt the kinematics questions. An average of 44.4% of the grade 9's did not attempt the kinematics graphs questions (pilot study) but the grade 10's attempted the kinematic graphs even thou both groups had not done kinematics graphs as a topic in the science classroom.

Comparing specific questions, 73% of the grade 10's interpreted the displacement /time graph correctly compared to 68% of the grade 9's. Question 5.1.4 was a challenge for both groups 26.4% of grade 10's provided the acceptable answers as against 16% of the grade 9's. Age and grade differences have an effect on graph comprehension (Curcio, 1987).

### 6.5.3 Conceptual resources

The empirical findings revealed that the learners had difficulties with the basic kinematics concepts for instance only 6.5% of the participants could draw the graph (distance/time) from given data. Learners could not distinguish between speed and distance. On an average, only 33.2% could distinguish between speed and distance. This supports literature findings of (Halloun & Hestenes, 1985). Difficulties to differentiate between related concepts such as distance and speed remains a challenge. Halloun and Hestenes (1985) stated that one of the most common and a critical problem in physics education is the failure to discriminate among the various kinematical quantities. This is true for this study. For example, less than 50% could write the correct unit for speed (26.4%) and distance (22.9%) respectively. They used everyday life descriptions for speed and distance instead of giving the scientific definitions.

**Basic concepts:** The challenges the grade 10 learners faced were: The ability to draw graphs using the correct scale; define speed scientifically; draw a graph from a given equation, and questions related to the interpretation of the given position-time graph.

**Drawing and interpretation of graph:** Only 6.1% of the learners of school D drew the graph to scale. This result is in favour of Robbins (2005) as discussed in literature paragraph 3.3.2. Robbins (2005:277) found that most of the graphs in his study were not drawn to scale. Very few (19.4%) participants could draw the x and y axis to scale. This can be attributed to inadequate practice in grade 9. Paragraph 4.6 to 4.8 show limited scale drawing in both grade 9 mathematics and natural sciences textbooks analysed.

Interpretation of graphs can be a resource for learning kinematic graphs if the skills are properly mastered in grade 9 and learners can apply them correctly. The educator should also ensure that the learners transfer their resources to new contexts such as kinematics graphs. If learners can interpret graphs and calculate the gradients then they have resources to interpret and solve kinematics graphs problems.

The quantitative results from chapter 6 and the interview indicate a lower percentage of learners' ability to interpret the kinematics graphs and this supports Beichner's results (Table 3.5), 39% of the participants were able to describe given kinematics graphs (Beichner, 1994:752).

**Gradient:** The conceptual resource, gradient of graphs, was done in grade 9. Calculating gradient, determination of gradient from a graph, interpretation of a bar graph, and drawing a graph are resources related to kinematics graphs that learners should have acquired in grade 9. These concepts are expertly been included in grade 9 mathematics textbooks used by the participants of this study (paragraph 4.8).

The learners did not use the same concept in solving similar problems on gradients. Learners explained positive gradients as increase in gradient but did not apply their concept scientifically to solve the gradient in problems.

Table 6.29 is a summary of the results indicating the conceptual resources acquired by the participants for understanding kinematics graphs. These are resources obtained in mathematics and natural sciences that could help them learn and understand kinematics graphs in grade 10. The Table shows the average number of learners that answered all the sub-questions correctly under each grouping.

**Table 6.29: Conceptual resources acquired by the learners for understanding kinematics graphs**

| GROUP- Criteria | Range (the number of learners that answered consistently correct | Resource |
|---|---|---|
| 1. Basic concepts | 7>x< 92 | Low to medium |
| 2. Bar graph<br>Draw, label, scale, and interpret. | 45>x<53 | Low |
| 3. Line graph<br>Draw, label, scale, and interpret. | 33>x<45 | Low |
| 4. Variables-relationship | 24>x< 61 | Low |
| 5. Gradient | (76>x<158) | High |

(Source: Analysis of survey data collected for this study)

The researcher decided to accept a concept as resource (high) if the number of learners within the range was more than 100 out of the 201 participants. Each grouping (concept) is made up of more than one question. If an average of more than 100 learners answered the questions within the group consistently correct then it is accepted as a resource.

From the result of Tables 6.9 to 6.29 as well as the discussions from chapter 6, the following conceptual resources were identified:

- ➢ Calculating gradient
- ➢ Distinguishing between positive and negative gradient
- ➢ Identifying increasing and decreasing gradient
- ➢ Determine gradient from line graphs.

The results and discussions revealed that the learners demonstrated the acquisition of these conceptual resources listed above.

From the analysis and summary of the results it was clear that the grade 10s did not apply some of their mathematics knowledge and skills to solve the corresponding kinematics graph questions such as calculating gradient of a velocity/time graph. This is in agreement with the findings of McDermott *et al.* (1987: 503) who states that students who do not have problems drawing graphs and calculating gradient cannot apply what they have learnt in mathematics in physics.

## 6.6 QUALITATIVE RESULTS

The qualitative research (interview) was used after the quantitative research (survey) to explore learners' knowledge and skills in more depth and to address the 'how' and 'why' questions (Smith & Bowers-Brown, 2010:117).

Qualitative data collection is an ongoing and iterative process. Data collection, processing, analysis and reporting are interconnected and do not consist of a number of consecutive steps to follow (Willis, 2007: 202; Denzin & Lincoln 2008:4). The researcher often went back to the transcripts and notes to verify conclusions. The researcher compiled a list of codes and grouped the codes into categories. This was discussed with the research supervisor and from there four groupings were identified for the interview responses as shown in Table 6.30.

**Table 6.30: Groupings identified from interviews with learners**

| Group | Grouping | Sub-Group |
|---|---|---|
| 1 | Performance | Grade 9 mathematics and natural sciences |
| | | Grade 10 mathematics and physical sciences |
| 2 | Basic concepts | Scale, labelling, and drawing graphs |
| | | Interpretation of graph, gradient |
| | | Speed and distance definition differences and similarities |
| 3 | Content | Level of difficulty, how to overcome difficulty |
| | | Types of graphs covered in grade 9 in mathematics and physics |
| | | Relationship between graphs in grade 9, in mathematics and kinematic graphs |

(Source: Analysis of survey data collected for this study)

The groups (1 to 3) identified from the interviews and presented in Table 6.30 are discussed below. The groups are discussed separately as follows:

**Group 1: Learners' performance**

The learners who were interviewed obtained higher marks in grade 9 mathematics and natural sciences than in grade 10 mathematics and physical sciences. They all agreed that grade 9 was much easier than grade 10. This clearly showed that there is a gap between grade 9 natural sciences and grade10 physical sciences which need to be narrowed as illustrated in the following excerpt of the interview:

**RESEARCHER:** Did your marks in mathematics and science drop, improve or did you maintain the same marks in grade 9 as in grade 10?

| | |
|---|---|
| **LEARNER 1:** | *''dropped in grade 10.''* |
| **RESEARCHER:** | I mean compare your performance in grade 10 physics with grade 9. |
| **LEARNER 2:** | ''When I take my question paper I compare them with those questions and the grade 10 questions are different ... difficult.'' |
| **LEARNER 3:** | ''dropped'' |
| **LEARNER 3:** | ''My maths this year is below 40''. |

Grade 9 natural sciences and mathematics would appear to be less difficult than in grade 10. Suggestions made to overcome the difficulty according to the learners (interviewees) are that grade 10 physics is more difficult that means the level of difficulty and content increases and therefore the grade tens must work harder and spend more time studying because understanding remains vital. The difficulty of grade 10 graphs is evident from the following extract:

| | |
|---|---|
| **LEARNER 1:** | *''I think it was much easier in grade 9''.* |
| **LEARNER 2:** | ''Some of them are difficult but not all of them. Some of them are not so difficult'' |
| **LEARNER 3:** | ''I was fine last year. Last year was fine but this year.... now it's difficult. |

The difficulty of graphs in grade 10 as expressed in the interview concurs with the poor performance in kinematics graphs as reflected in the quantitative analysis (paragraph 6.4).

Learners' views pertaining to the importance of graphs were also discussed in the interviews. All three of the learners agreed that graphs are important in science because it makes it easier to identify more information and relationships. The statements made by the interviewees demonstrating the importance of graphs in science are as follows:

| | |
|---|---|
| **LEARNER 1:** | *''It depends....now...so I did this before we did the speed/time and velocity/ time etc graph. So I thought science is better without graphs. But after doing that I found that graphs are much easier because there is shortcuts you can calculate the area, you can use the displacement/time graph to find the velocity it takes. And it's easier than to use formulas to calculate.''* |
| **LEARNER 2:** | ''In science graph will help us understand a lot of things.' |
| **LEARNER 3:** | ''yes graph are very important. They are important because I can see so much. |
| **LEARNER 3:** | Who obtained the lowest marks in both mathematics and science (in grade 9) among the three grade 10's interviewed, made the following statements. These statements clearly show that her lack of interest and understanding of graph is affecting her performance in both mathematics and physics. |
| **LEARNER 3:** | '' I do not understand graphs''<br>''People understand graph but not for me. I don't understand graphs. I hate it.'' |
| | ''From the start I failed maths... I fail maths'' |

## Group 2: Basic concepts

All of the three learners mentioned that they had not been taught how to use scale to draw a graph. One said she did not know that she had to label the axis of a graph. Two out of the three did not know that there was the need to give a heading to a graph. Only 21.9% of the participants from the quantitative study labelled the axis correctly and were able to use the correct scale and heading.

### Scale and labelling

| | |
|---|---|
| **LEARNER 3:** | ''I don't know how to label the graph''.<br>''I don't know scale.''<br>''I copied the numbers because the numbers are given in the Table.'' |

| | |
|---|---|
| **LEARNER 2:** | ''I didn't know that in the first place. I didn't know that I have to label a graph.'' |
| **LEARNER 2:** | '' I didn't label because I didn't understand. The time we wrote this according our teacher schedule we didn't do that.'' |
| **LEARNER 2:** | ''Yes, I didn't know that I have to use a scale'' |

**Speed and distance definitions**

In the interviews the learners failed to give scientific definitions of the concepts of speed and distance, as is shown in the excerpt:

Speed and distance was defined by learners as follows:

| |
|---|
| **LEARNER 1:** *''Speed is how fast you moved on that road. Distance is how far you moved.''* |
| **LEARNER 2:** ''Speed is how slow or how fast. Distance is how far you travelled.'' |
| **LEARNER 3:** .................................................................... [Silence]. |
| **LEARNER 1:** '*'Distance is the length used for calculations, distance moved ... travelled the length of something.*'' |
| **LEARNER 2:** *"Distance is how far you travelled."* |
| **LEARNER 3:** "Distance is the road you are travelling''. |

The learners found it difficult to distinguish scientifically between distance and speed. In the mean time both distance and speed are elaborated in their grade 9 mathematics textbook (refer to paragraph 4.8 - 4.9).

**Types of graphs**

Learners were asked which aspects and types of graphs they had come across in grade 9 natural sciences. They gave different descriptions to indicate the aspects of graphs they came into contact with in grade 9:

| | |
|---|---|
| **LEARNER 2:** | ''The one that you will choose, may be they will give you some questions and they give you a graph and after.... you have to follow you have to answer.'' |

| | |
|---|---|
| **LEARNER 2:** | Mentioned that they did not draw graphs but graphs were given and they had to use the graph to answer given questions. |
| **LEARNER 3:**<br>**LEARNER 3:** | "In NS mmm they give you a graph and you have to follow."<br>"We do bar graph in grade 9." |
| **LEARNER 3:** | "Our teacher also show us … Gave us some information and to draw graph" |
| **LEARNER 3:** | "The graphs in the textbooks are difficult. Hmm the one in the magazine is easy" |
| **LEARNER 1:** | *'"yee … but it depends on what type of graph it is, if its bar graph or histogram it is much easier than … line graph … or scatter"* |
| **LEARNER 1:** | *'It depends … now… so. I did this before we did the distance-time, speed-time, velocity-time and acceleration-time graphs. So thought science is better without graph. But after doing that I found that graphs are much easier because there is shortcuts you can use. To calcultate the area, you can use the velocity-time to find the displacement it takes and its easier than to use formulas to calculate".* |

The responses given by the learners confirmed that they had to use given graphs to answer sets of questions, or data would be given according to which to draw bar or pie graphs. The response and the results of the study (refer to paragraph 6.4) where 134 (66.7%) of the learners said they could draw bar graphs correspond with the results of the analysis of grade 9 natural sciences textbook (paragraph 4.6-4.7). Grade 9 natural sciences textbooks are dominated by bar graphs and pie graphs.

Bar graphs and pie charts were frequently done in their workbooks in grade 9 natural sciences and mathematics (paragraph 4.6 to 4.9). Pie charts were displayed in 80 % of the textbooks and 60% illustrated bar graphs. Scatter plots were done in grade 9 mathematics as well. However learners seldom come across line graphs. Graphs concepts were not taught in the natural sciences class; however, learners came across application of graphs in Ohm's law and the drawing and interpretation of bar graphs in natural sciences (paragraph 4).

### Group 3: Content

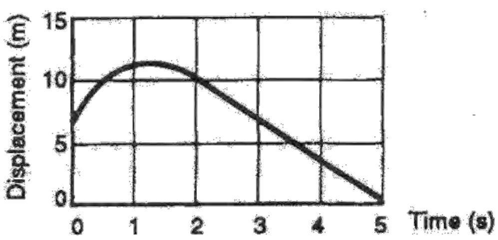
Content covered in grade 9 mathematics include gradient, interpretation of graph and drawing of graph (paragraph 4.6 and 4.7). All the learners mentioned that they were taught how to calculate the gradient from a given formula and determine the gradient from a graph in grade 9 mathematics class.

### Gradient and graph interpretation

Questions related to calculation of gradient, identifying decreasing, increasing, positive, negative gradients were discussed to determine the learners' level of reasoning.

| | |
|---|---|
| **LEARNER 3:** | ''VI/HI that's how we do gradient in my school, VI is vertical interval and HI is horizontal interval.'' |
| **LEARNER 2:** | ''In grade 9 the graph that I remember is the one that we are putting different soil into ...... we don't really know. |
| **LEARNER 1:** | *''m in the equation y= mx+c m is the gradient.''* |

The learners were asked in the interview to explain their responses to item 5.1.3 in the questionnaire. The item was:




(Source: Beichner, 1994:760)

**5.1.3 Between 3 and 5 seconds the gradient is**

a) positive
b) negative
c) zero

**5.1.4 Between 3 and 5 s the gradient of the graph**

a) stays the same
b) decreases
b) increases

| | |
|---|---|
| Their responses with regard to item 5.1.3. were: | |
| **LEARNER 2:** | ''Negative because it has large speed, speed is not small '' |
| **LEARNER 2:** | ''those numbers are under the line increasing because ya increase the time is between ........... is increasing.'' |
| **LEARNER 3:** | '' X values are your positive and Y values are your negative''. |
| The learners reasoned as follows with regard to item 5.1.4: | |
| **LEARNER 3:** | ''... it is increasing because the line is longer therefore it's a positive gradient.'' |
| **LEARNER 2:** | '' ... it is increasing because the highest number on the y-axis is positive therefore it's a positive gradient'. |
| **LEARNER 1:** | *''because the numbers that are given are above it is positive gradient, it is going up.............. but it is moving.... it is a gradient though''.* |

Interpretation of graphs and calculation of gradient was taught intensively in grade 9 mathematics classes. This is a true reflection of the results of the quantitative analysis (survey), according to which more than 70% of the learners were able to distinguish between positive, negative and zero gradients. However, the interview results indicated that they do not have a good understanding of the concept of gradient. The reasoning given by the learners above was not scientifically correct, e.g. "the line is longer therefore it's a positive gradient". With reference to the question asked they should have referred to the definition of gradient in terms of the ratio of changes in displacement and time or ($\Delta y/\Delta x$).

The poor performance of interpreting the kinematics graphs may be contributed by position-speed confusion. Learners usually have the perception that objects are at the same position when the objects have the same speed (Trowbridge & McDermott, 1980:1022).
The aspects of kinematics graphs that learners were able to attempt were mainly taught in the mathematics class and not in the natural sciences class.

## 6.7 SUMMARY

The Cronbach's alpha coefficient was calculated to determine whether there was consistency in the manner in which participants answered the questions for each individual section, groupings and constructs. A Cronbach's coefficient alpha of 0.7 and above denotes consistency, reliability and validity of the questionnaire. When necessary a question had to be deleted to obtain a Cronbach's coefficient alpha greater than 0.7 which was needed to determine an average mean value for the questions in the groups.

ANOVA – tests were conducted to test for differences in the response to the questions. A test for differences was done between the demographic factors (parameters) within section A: Gender, age, performance in mathematics, performance in natural sciences (NS1 and NS2); within and between schools, home languages, and number of times in grade 10. Different schools, different home languages, performance in natural sciences, performance in mathematics, and age showed statistically significant differences in the responses but gender made no difference in how the boys and girls responded to the questions.

The quantitative data analysis revealed that learners struggle with basic concepts of kinematics such as speed, distance, dependent and independent variables. This was affirmed by the qualitative data analysis. Problems associated with gradient and graphs in both physics and mathematics were identified across all the interviewees.

The conclusion drawn from assessing the discrepancies when merging quantitative (QUAN) and qualitative (QUAL) research methods, prove to favour both the QUAN and the QUAL data results (Creswell, 2010:60). In this study the QUAL results complemented the QUAN results. The results showed possible reasons for deficiencies in learners' knowledge and emphasized learners' resources for the study of kinematics graphs.

The next chapter (chapter 7) gives an overview of each chapter, recommendation, limitation and final conclusion of the study.

# CHAPTER 7

# CONCLUSIONS AND RECOMMENDATIONS

## 7.1 INTRODUCTION

This chapter presents summaries of both the literature review and the empirical research findings. It also includes the highlights of the findings, recommendations, limitations and the final conclusions derived from the research. Recommendations for practice in the classroom are based on the research results from chapter six in the form of general contributions made towards the curriculum, research, teaching and learning.

## 7.2 OVERVIEW

The subsequent section offers an overview of the literature review from chapters 2 and 3, as well as chapter 4, which deals with a comparative analysis of graphs in natural sciences and mathematics textbooks. These were completed before the empirical study. The literature review contributed towards achieving the aim and objectives of the empirical study and provided a framework for the interpretation of the results.

### 7.2.1 Overview of chapter one: (Orientation of the study)

Chapter one provides an introductory detailed plan for this study. This includes the context of the research, a short literature review, the research questions, aims and objectives, a general overview of the research design and methodology, as well as an outline of the study.

The aim of the study was to determine and analyze learners' conceptual resources for learning kinematics graphs in grade 10 physical sciences. The objectives of the study were:

**Objective one:** Identify the conceptual resources related to graphs that grade 10 physical sciences learners have obtained in their studies of natural sciences and mathematics in the GET Band.

**Objective two:** Statistically analyze the coherence and integration of the learners' resources.

**Objective three:** Make recommendations for smooth learning progression of graphs from natural sciences in the GET Band to physical sciences in the FET Band.

### 7.2.2 Overview of chapter two: (Overview of learning progressions and conceptual resources for learning)

Chapter two constitutes the literature review which includes an overview of learning, the constructivist learning theory, alternative conceptions and conceptual change. Learners' conceptual and epistemological resources and learning progression in relation to understanding and learning of kinematics graphs form part of chapter two.

Learning involves progression, and for learning to take place a conceptual change has to occur. The identification and gradual refinement of learners' conceptual resources contribute towards effective learning and construction of a learning progression.

Application of the learning progression approach suggested by Bruner (paragraph 2.6.1) can be applied in the following order for successive understanding and interpretation of kinematics graphs.

- Practical investigation (Enactive representation)
- Investigate the relationship between position-time, velocity-time and acceleration-time motions in experiments and demonstrations.
- Drawing of graphs (Iconic representation).
- Drawing position-time graphs, velocity-time and acceleration-time graphs.
- Interpretation and calculations (Symbolic representation based on scientific language). Interpreting graphs and identifying the relationships between variables. This includes calculation and interpretation of gradients, area under the curve, etc. in kinematics graphs.

Steedle and Shavelson (2009:699) put forward that research on learners' understanding of scientific phenomena in order to develop learning progressions reflects a relatively coherent set of ideas. These ideas obtained from the learners may be scientifically accurate, completely inaccurate, or somewhere in between (i.e., productive, but incomplete or inaccurate). That is to say the conceptual resources learners may possess from GET band grades may be scientifically accurate or inaccurate; complete or incomplete and this can have a negative or positive effect in learning kinematics graphs in grade 10.

The escalated and landscape approach can be utilized in the curriculum to produce students and adults who are scientific graphical literates, something that is essential in the 21st century.

Graphical literacy includes learners and adults who are able to read and understand scientific graphs, are capable of using graphs and have the ability to read and interpret graphs in mathematics and science textbooks as well as magazines, newspapers and journals.

### 7.2.3 Overview of chapter three: (Graphs as conceptual resources)

Chapter three provides an overview of definitions and descriptions of graphs, structure of graphs, types of graphs, importance of graphs, conceptual resources and difficulties with graphs, learning progression with regard to graphs, implication of learning progression on conceptual understanding of kinematics graphs in the South African curriculum and difficulties regarding kinematics graphs.

Conceptual resources identified by different authors for learning kinematics graphs are: Conversion of units; direct and indirect proportions; calculating gradient; representing and drawing points on a graph; adding the title and the labels on the axes of a graph; understanding symbols in kinematic equations, deducing relationships of variables using direct or inverse proportion drawing and interpreting line graphs. Identification and monitoring of learners' conceptual resources is of utmost importance in identifying, understanding and dealing with inconsistencies that may be found related to learners' ability to comprehend and solve problems related to graphs correctly.

Researchers have identified learning difficulties regarding kinematics graphs. Conceptual resources in kinematic graphs that are challenging to learn are among the identified difficulties. These conceptual resources in kinematics graphs that are challenging to learn become a central part in the development of learning progression in physical sciences.

### 7.2.4 Overview of chapter four: (Comparative analysis of graphs in natural sciences and mathematics textbooks of South Africa)

Chapter four describes the comparative analysis of types and number of graphs in mathematics and natural sciences textbooks used by the schools that participated in this study. It was divided into sub-sections under the following sub-headings: The knowledge and skills and basic requirements of the curriculum with regard to graphs; knowledge and skills related to graphs found in grade 9 natural sciences and mathematics textbooks; the influence of textbooks on teaching and learning graphs; dependency on textbooks; the uses and shortcomings of textbooks; and disconnections in textbooks.

Analysis of middle school science textbooks revealed that the instructional materials are not always presented in a logically connected way, making it difficult for students to understand the major concepts being taught (Kesidou & Roseman, 2002; Stern & Roseman, 2004). Hubisz found out that the terms velocity, speed, acceleration, and change in velocity were wrongly used in middle school science textbooks, causing confusion (Hubisz, 2003:50). The comparative analysis of South African textbooks used by the participating schools confirmed these findings.

The mathematics textbooks analyzed in the study written by different authors have similar content, but this is not the case with the natural sciences textbooks. The content of textbooks is determined by the curriculum, therefore there should not be much difference between the contents of the textbooks (Boostrum, 2001). However, the natural sciences textbooks written by different authors differed significantly in terms of content related to graphs.

### 7.2.5 Overview of chapter five: (Research methodology)

Chapter five describes the research design and methodology for this study. This study used a non-experimental, descriptive quantitative design to obtain numerical data about learners' conceptual resources that can be productively used to learn kinematics graphs in grade 10. Chapter five further explains the statistical procedures used in this study and issues related to reliability and validity. The study also used qualitative research through interviews to gain thorough insight in order to propose a learning progression of kinematic graphs from the GET to the FET phase.

### 7.2.6 Overview of chapter six: (Results of the empirical study and discussion of results)

Chapter six reports on the findings derived from the survey and interview results as stipulated in Tables 6.1 to 6.20 and provide an analysis of the results of the study. The data was presented, analyzed, interpreted and discussed. In chapter six it became evident what resources the grade 10 participants have and what they struggle with. These findings are summarized and discussed in the next paragraph.

## 7.3 SUMMARY AND DISCUSSION OF FINDINGS WITH REGARD TO THE RESEARCH OBJECTIVES

The summary of the findings discussed in this section are related to conceptual resources, coherence and integration of learners' resources, and recommendations for smooth learning progression of graphs from natural sciences in the GET band to physical sciences in the FET. This is in accordance to the research objectives.

### 7.3.1 Findings with regards to research objective one

Based on the arguments on learning in chapter two one can conclude that having pre-knowledge about a topic, or possessing conceptual resources contribute towards effective learning. Therefore the poor performance in kinematics graphs can be attributed to the fact that learners do not have all the necessary conceptual resources to learn kinematics graphs in the FET phase.

All the interviewees agreed that they were taught in grade 9 mathematics how to calculate the gradient from a given formula and to determine the gradient from graphs. That was why they were able to attempt the gradient related problems. This implies that if kinematics graphs are introduced in grade 9, learners will find it easier to understand in grade 10, which narrows the gap between grade 9 and grade 10. The interviewees confirmed that there is currently a huge gap between grade 9 and grade 10 sciences.

### Conceptual resources

The conceptual resources the grade 10 participants have for effective learning of kinematics graphs as obtained from the analysis of the results (paragraph 6.4.1) of the study are:

| | |
|---|---|
| Gradient: | Calculating gradient. |
| Deducing information from a graph: Identifying positive, negative and zero slopes. | |
| Identifying trends: | Decrease, increase, remains the same. |
| Drawing graph: | Plotting points. Table to graph, graph to Table. |
| Units: | Know the units of basic kinematics concepts |

From the analysis of paragraph 6.4.1 and 6.4.2, the following items were identified as the items with which the learners struggled most:

- Understanding and identifying variables.
- Determining equations from line graphs in mathematics and physics.
- Identification of zero gradients.
- Interpretation of the point of intersection of line graphs in mathematics and physics.
- Differentiation between position and speed.
- Graphical representation of velocity changes.
- Interpretation of kinematics graphs.
- Scaling

Specifiers, framework of graphs and labels (Friel *et al.*, 2001) as discussed in paragraph 3.2 are essential basic resources learners need to learn kinematics graphs effectively. Contrary to this requirement, the results of the study show that only 21.9% of the learners could use scales and labelled the graph correctly. This is a major problem in graphs according to Rangecroft (1991a & 1991b). The choice of scale to use is a fundamental factor for all types of graphs. Determining the right scale for numbering the axes of a graph is one of the most challenging parts of graph construction (Cothron *et al.,* 2006: 258).

### 7.3.2 Findings with regard to research objective two

The Cronbach's alpha coefficient of the questionnaire was above 0.7, which denotes consistency, reliability and validity of the questionnaire. The questions can therefore be understood in the same way by a different population.

The learners with high or low marks in grade 9 natural sciences and mathematics believed that there is no significant difference between their performance and interpretation of graphs. However, a practically significant difference between learners' performance in grade 9 mathematics was found with regard to gradient. The results of the empirical study confirm that calculating gradient is one of the conceptual resources the learners did acquire in grade 9. Hence learners with higher marks in grade 9 obtained higher percentages in the gradient questions. Differences can be attributed to their conceptual understanding and pre-existing knowledge.

The learners repeating grade 10 and those doing grade 10 for the first time showed no significant difference in their conceptual resources. Both groups answered the questions consistently correctly or incorrectly. This is contrary to Georghiades' view (paragraph 3.9 and paragraph 2.2).

The differences between the home languages is practically significant with $p<0.05$. The learners who have the same home language as the language of instruction and the questionnaire tended to show a better understanding and response rate than those for whom the language of instruction is a second or third language.

The correlation was very low between learners' perception of their competency in drawing graphs and the application thereof, as well as between the explanation and application of basic concepts related to kinematics graphs (Correlation $0.15<x<0.5$, refer to paragraph 6.4.3, 6.4.4 and 6.4.5). The inconsistency can be attributed to varying responses to scaling, labelling, plotting points and graph heading. This illustrates a need to place emphasis on teaching and learning skills of drawing graphs and understanding basic concepts.

The participants did not apply knowledge consistently in different problems related to graphs. Their reasoning in similar problems set in different situations is inconsistent. For example, a learner may give a reason for explaining why a graph has a negative gradient. The same learner then gives a different reasoning for a similar graph in another problem.

The learners could not solve questions related to application of graphs in kinematics, but showed underlying knowledge when tested separately. For example, they were able to calculate the gradient of a graph, but could not apply this knowledge when determining the velocity from a displacement–time graph. They have the ability to communicate and reason using graphs within the mathematics or physics context, but often lack the ability to use the knowledge to solve problems in another context (Dwain, 2008).

The items which learners enjoyed most and answered well in different contexts were related to identifying positive and negative gradients. What students learn is significantly influenced by their individual differences, such as pre-existing knowledge, age and gender (McDermott, 1984). However, in this study the statistical analysis of the quantitative data reveals the following, as indicated in paragraph 6.4.

The parameters that did not have an influence on the conceptual resources learners have acquired to enhance their learning of kinematics graphs are:

- Number of years spent in one grade e.g. grade10
- Gender. These factors did not provide any significant difference with $p>0.05$.

There was a practical significant difference among the following parameters where $p< 0.05$:

- Age
- Schools
- Performance in mathematics
- Performance in natural sciences
- The conceptual resources learners have obtained from natural sciences and mathematics from previous learning
- The home language

### 7.3.3 Findings with regard to research objective three

As mentioned in paragraphs 2.6.1; 2.7.6; 3.7; 3.8.1 and 3.9 the researcher suggests that learning progression for kinematic graphs should determine:

1) How kinematics graphs concepts logically and successively build on other concepts?

2) What grade level is appropriate to introduce kinematics graphs concepts?

3) What the critical connections between ideas that students need to make in order to understand the nature of graphs as it pertains to kinematics?

The literature review revealed that learners who are given direction and help become experts (e.g. Abbott 2002:13). This was confirmed by the empirical results. For example, learners who were taught how to calculate gradient did much better than those who were not. Referring to paragraph 2.2, learners cannot discover new knowledge on their own (Driver *et al*., 1994:6) which is in accordance to the results of the study where learners could not use the correct scale to draw a graph because they were not taught how to use a scale in the natural sciences class. Correspondingly, the researcher has argued the view that drawing of graphs was not well answered by the learners because it was not taught in the natural sciences class.

Bright and Friel (1996, 1998) outline the possible benefits of focusing on particular transitions between graphs to promote understanding of more difficult graphs, as discussed in chapter three. One can use these transitions to highlight the structural relationships between graphs.

For example, the use of bar graphs showing data grouped by frequencies may be made easier for students if instruction includes opportunities to transform a line plot into a bar graph and to highlight similarities and differences between these two representations. Similarly, stem plots and histograms are closely linked, with stem plots providing a natural transitional device for one to use for grouping data into equal-width intervals when constructing a histogram. In fact, by turning a stem plot on its side, one can easily imagine a histogram superimposed on top of the leaves of the stem plot. Learners can therefore learn certain skills using types of graphs that are easier to comprehend, and can then transfer those skills to more complex graphs such as line graphs.

Scaling is an essential skill needed to understand bar graphs and other graphs (Rangecroft, 1994). Learners' knowledge of bar graphs can thus form the foundation for learning scaling of line graphs. The text book analysis shows that bar graphs are the main type of graph learned in grade 9 natural sciences and mathematics. The results of the study also show that the learners were able to answer the questions related to bar graphs correctly. Elementary knowledge and skills (lower anchor) can thus be used in grade 9 and before, while higher level (upper anchor) knowledge of kinematics graphs is attended to in grade 10 onwards. The intermediate level can overlap between grade 9 and 10.

## 7.4 RECOMMENDATIONS

The following recommendations are made based on the findings of the study:

A Table with the physical quantities and units, as well as graph terminology should be given to learners in grade 8 and 9 to learn. The grade 8 learners can learn it without any calculations. Simple calculations should be included in grade 9. In this way learners can gradually develop the language for kinematics graphs and acquire enough scientific vocabulary to enhance learning and understanding of kinematics graphs. This type of Table should be included in all grade 9 textbooks, since research has proved that educators and learners alike depend on textbooks.

In grade 9 the science teachers should teach the basics of graphs required by the curriculum. Learners should be guided to draw graphs correctly and completely, e.g. with the appropriate scales, axes labels and graph headings. They should also know how to calculate the gradient of a line graph and the area under a graph. In grade 10 physical sciences they can attach meaning to the gradients and areas of line graphs. This can contribute to a smooth transition in the learning progression from grade 9 to grade 10.

## Recommendation for practice in the classroom

Line-of-best-fit (paragraph 3.2.4, figures 3.1 to 3.3) can be introduced in grade 9 and can serve as a resource to help learners to join the points and draw the appropriate corresponding kinematics graphs more easily in grade 10.

Graphing should be taught using data collected by the learner through activities and experiments performed by the learner personally or in group work. This will add meaning and the learner can discover the relationship between the dependent and independent variables.

According to Robbins (2005) the definition of quantitative data deviates from the emphasis on units in physics. However, the definition of Cothron *et al.* (2006) (referred to section 3.2), which includes units, should be used in school textbooks. Problems such as these must be identified and correct scientific definitions and concepts emphasized in class. It should also be kept in mind that the modern learner is exposed to internet where there is a vast range of information.

## Recommendation for curriculum

The researcher makes the following recommendations for curriculum development:

Scientific skills such as drawing and interpretation of line graphs and understanding of variables should be introduced, developed and assessed in grade 9 natural sciences.

Scaling, the dependent, independent and constant variables should be taught in the mathematics as well as in the science class. In science, more than in any other subject, students should be involved in predicting relationships between variables and attempting to qualify these relationships (McKenzie & Padilla, 1986).

To overcome the latter concern grade 9 natural sciences textbooks should explain the basic skills and concepts related to kinematics graphs in more detail than in the mathematics textbooks. Grade 9 natural sciences textbooks can increase learners' interest in kinematics graphs if more illustrations of graphs related to kinematics are presented in the textbook (Duncan *et al.,* 2011:143).

If learners can be taught line graphs and are evaluated continuously using a checklist as indicated in Table 7.1 below, this will go a long way to alleviate the difficulties learners experience in understanding kinematics graphs.

**Table 7.1: Checklist for evaluating line graph**

| Criteria | Self | Peer | Teacher |
|---|---|---|---|
| Title written correctly | | | |
| Dependent and independent variables indicated | | | |
| X axis correctly labelled including units | | | |
| Y axis correctly labelled including units | | | |
| X axis correctly subdivided into scale | | | |
| Y axis correctly subdivided into scale | | | |
| Data pairs correctly plotted | | | |
| Data trend summarized with line-of-best-fit | | | |
| Data trend summarized with sentences | | | |
| Points joined together in best-fit line | | | |

Source: (Cothron *et al.,* 2006:113)

### Recommendation for education

Proposed recommendations for teaching kinematics graphs are:

A separate natural sciences textbook checklist to select textbooks should be introduced. This could include the following:

- Importance of graphs
- Introduction of skills for drawing graphs
- Explanation of dependent, independent and constant variables
- Graph construction information
- Types of graphs

Assessment by means of a construct map as discussed in paragraph 7.4.5 can be used to determine the conceptual resources learners have obtained in grade 9 that are relevant for a smooth learning progression towards kinematic graphs.

Although the current mathematics textbooks include the resources that the learners need for studying and understanding kinematics graphs, questions that should be addressed are:

➢ Are the learners taught all the concepts in grade 9?

➢ What effect do the textbooks that do not cover these resources have on the learners that use them?

- ➢ If learners are taught, and they understand the graph-related concepts in mathematics, why do they still struggle with kinematics graphs in physics? Could the problem be their inability to transfer the knowledge from mathematics to physical sciences?

**Recommendation for future studies (Future research)**

Empirical studies on comparing learners' perception of graphs in physical sciences and life sciences and their ability to transfer the knowledge and skills from one subject to the other is rare in South African education. The impact of this empirical study focused on the perception on graphs in natural sciences and mathematics.

Further research is suggested to:

- Determine whether the significant difference between the learners' perceptions on graphs in physical sciences in grade 10 can be linked to skills and knowledge acquired in natural sciences grade 9.
- Generalize the findings and include factors that enhance learners' conceptual resources to learn kinematics graphs.
- Determine how to enhance the coherence of learners' conceptual resources in the learning of kinematics graphs.
- Investigate how respondents perceive the physical sciences component of natural sciences in comparison to the life sciences component.

## 7.5 LIMITATION OF THE STUDY

A follow-up session after transcribing the interview would have ensured that participant's words and meanings were interpreted without error.

Only three participants took part in the qualitative study. Although the research is concerned with depth of study rather than quantity of data, additional participants would have enabled larger generalization of the findings and the consistency.

Responding to the questions after school when they were tired after a full day of schooling was taxing for some, and they could have spent more time thinking.

## 7. 6 FINAL CONCLUSIONS

Finally, one can conclude that the grade 10 learners who participated in the study do not have adequate conceptual resources (prior knowledge) to solve kinematics graph problems. Their resources are not coherent, i.e. learners do not apply knowledge consistently in different problems. From the results and discussions of the empirical study it is evident that the hypothesis of the study is true. The learners do not efficiently integrate knowledge from mathematics and physical sciences contexts. They do not use their knowledge of graphs from mathematics in physical sciences to enhance their understanding of kinematics graphs. Understanding the conditions to apply existing knowledge to new knowledge is a crucial part of learning (Bao & Redish, 2006).

Factors such as the knowledge and skills learners have acquired previously and the type of textbooks used influence their conceptual resources. The more scientific knowledge and skills the learners have acquired in the lower grades and in everyday experiences, the broader their conceptual resources are. Textbooks with more information, examples and problems on graphs will assist learners to build rich resources that can be used to learn and understand kinematics graphs.

The strategy to improve understanding of kinematics graphs is to progressively integrate mathematics and physics from grade 9. Line graphs should be treated in more detail in grade 9 to develop proper conceptual resources for kinematics graphs in grade 10. Transitions among graphs (e.g. between bar graphs and line graphs) should be attended to. Activities to bring out the definitions and understanding of variables (e.g. constant, independent, dependent, speed and distance) should be incorporated in GET natural sciences curriculum. Learners in grade 10 should thus have more prior knowledge (conceptual resources) about graphs if they come across relevant aspects of graphs in both mathematics and natural sciences in the GET Band.

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# APPENDICES

# APPENDIX A
# QUESTIONNAIRE

**APPENDIX A**

LEARNERS' CONCEPTUAL RESOURCES FOR LEARNING KINEMATICS GRAPHS

QUESTIONNAIRE

The purpose of this questionnaire is to obtain information that can be used to determine your resources for understanding line graphs in Grade 10 Physical Sciences.

Name:........................................... School.............................. Grade: ......

INFORMED CONSENT

I understand that participating in this research project is completely voluntary and no pressure may be placed on me to participate. I understand that it is not a test that will count any marks. I herby give permission that this questionnaire may be used for research purposes.

.......................................... ....................

Signature Date

**SECTION A: DEMOGRAPHIC INFORMATION**

Carefully read the following questions and cross the answer of your choice. Please answer these questions as honest as possible.

1. **Gender**

| | |
|---|---|
| 1 | 2 |
| Male | Female |

2. **What is your age?**

| | | | | | |
|---|---|---|---|---|---|
| 13 | 14 | 15 | 16 | 17 | 18 |

3. **What is your highest mark in Natural sciences last year [physical sciences – NS1]?**

| | | | | | |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| Below 40% | 40-59% | 60-69% | 70-79% | 80-90% | 91-100% |

4. **What is your highest mark in Mathematics last year?**

| | | | | | |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| Below 40% | 40-59% | 60-69% | 70-79% | 80-90% | 91-100% |

5. **What is your highest mark in life science-NS2 last year?**

| | | | | | |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| Below 40% | 40-59% | 60-69% | 70-79% | 80-90% | 91-100% |

6. **For how long have you been doing grade 10?**

| | | |
|---|---|---|
| 1 | 2 | 3 |
| Once | Twice | More than twice |

7. **Home language**

| | | | | | |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | Other specify |
| Asian | English | Afrikaans | Setswana | Sotho | |

1

**SECTION B: GRAPHS IN SCIENCE**

**CAREFULLY READ THE STATEMENTS BELOW AND CHOOSE THE APPROPRIATE RESPOND.**
Choose 1 if you totally disagree. (Never)
Choose 2 if you do not agree.
Choose 3 if you are undecided [not sure]
Choose 4 if you partially agree with reason.
Choose 5 if you totally agree.

**1. Graphs are very important in science**

| 1<br>I totally disagree. | 2<br>I do not agree | 3<br>I'm not sure | 4<br>I partially agree | 5<br>I totally agree |
|---|---|---|---|---|

**Please explain your answer**........................................................................................

**2. I understand how to interpret science graphs.**

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|

**3. I can do better in physical science if I understand scientific graphs.**

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|

**4. I can identify trends from a graph.**

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|

**5. I can identify the relationship between two variables from a line graph.**

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|

**6. I am very competent in interpreting bar graphs.**

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|

**7.. I can draw bar graphs.**

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|

**8. I am very competent in drawing line graphs.**

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|

**9. I am very competent in interpreting line graphs.**

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|

**10. Science without graphs would be better.**

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|

**Please explain your answer**........................................................................................

..........................................................................................................................................

**11. I can explain in words what a point on a graph stands for.**

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|

**12. I can draw a table using information from a graph.**

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|

**13. I am able to draw a graph from a data table.**

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|

2

**14. A graph communicates information effectively.**

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|

**Give a reason for your answer……………………………………………………………………**

**15. If I understand graphs I can solve science problems.**

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|

**<u>SECTION C:</u> Basic concepts and graphs in kinematics**

**1. <u>Variables & concepts</u>**

1.1 Explain in your own words the following concepts. *Illustrate* each concept with an example.

(a) Variable……………………………………………………………………………………………

(b) distance……………………………………………………………………………………………

(c) speed ……………………………………………………………………………………………

1.2. Circle the correct SI unit for measuring time:

(A) t (B) s (C) T (D) m

1.3. What is the SI unit used to measure……?

1.3.1 Speed…………………………………… 1.3.2 Distance ……………………………

1.4. Identify the VARIABLES from the investigative questions.

Investigative question: How does the time taken affect the distance travelled?

a) Independent variable: ………………………………

b) Dependent variable: ………………………………

c) Constant: ……………………………………………

2. **<u>Plotting graphs and variables</u>**

2.1 The time that a bus travels to cities along its journey are given in the table.

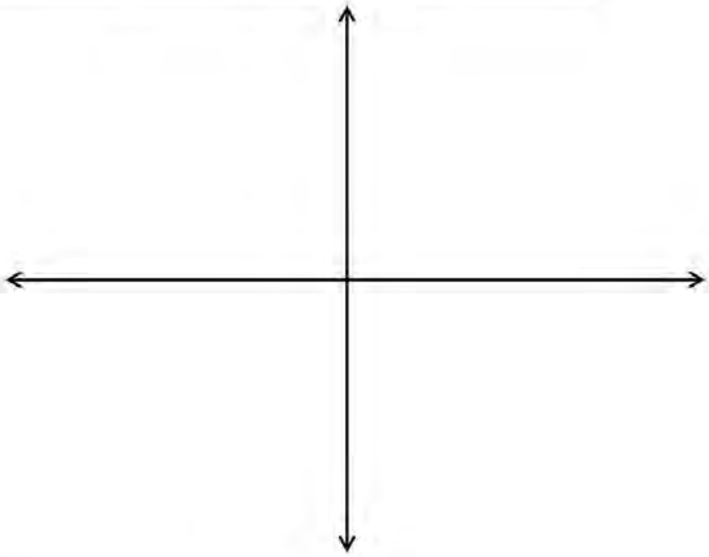
| Time taken (hours) |
|---|
| 2 |
| 4 |
| 5 |
| 6 |
| 9 |

Use the data in the table above to draw the time values on the given time axis.


3

2.2 The minimum daily temperature is measured for 5 consecutive days. Represent the data on the axis system given below.

| Day | Minimum temperature |
|---|---|
| 1 | +3 |
| 2 | 0 |
| 3 | -4 |
| 4 | -2 |
| 5 | +2 |



2.3

2.3.1 Complete the table using the graph above.

| | | | | | | |
|---|---|---|---|---|---|---|
| x-values | | | | | | |
| y-values | | | | | | |

2.3.2 Write an equation using the variables x and y that describes the set of ordered pairs.....................................................................................................................

**3. Types of graphs**

| | **Wood Type (moisture in wood)** | **Energy available after evaporation of moisture in the wood(MJ/kg)** |
|---|---|---|
| A | Completely dry and ash free wood | 20 |
| B | Sun dried wood already dropped from the tree | 17 |
| C | Mature branches stripped from the tree | 12 |
| D | Living plant material cut from the tree and used immediately | 8,4 |

3.1 Draw a BAR graph that reflects the results shown in the table.

3.2 Write a sentence that describes the relationship between moisture in wood and energy available for heating

……………………………………………………………………………………………………………………

**Integration of mathematics and physics**

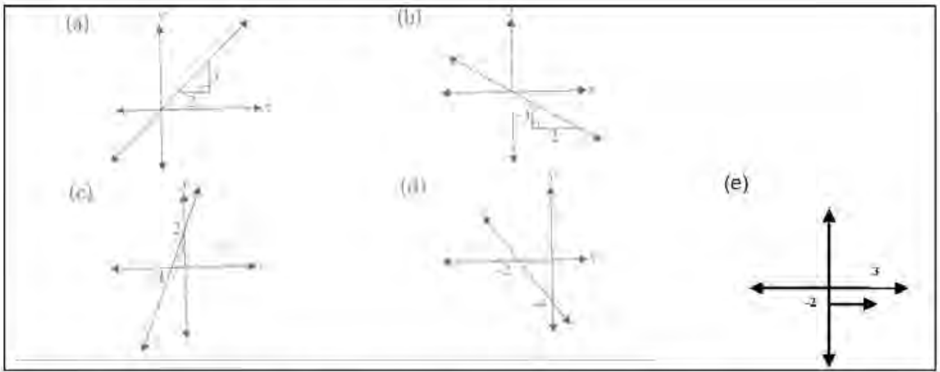
**4. Mathematics prior knowledge**

NOTE: The *gradient* of a straight-line graph is same as the *slope* of the graph.

4.1. Give two formulas you studied in mathematics that can be used to calculate the gradient of a straight line graph.

……………………………………………………………………………………………………………………

4.2 Study the following graphs.




4.2.1 Indicate for each graph if it has a negative, positive or zero gradient.

(a) ……………………… (b) ………………………

(c) ……………………… (d) ……………………… (e)………………………

4.2.2 Write down the y-intercept of each one of the graphs?

(a) ……………………… (b) ………………………

(c) ……………………… (d) ……………………… (e) ………………………

5

4.3 The formula of a straight-line graph is in the form y= mx+c.

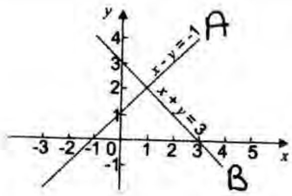
4.3.1 What feature does *c* represent in graphs?

…………………………………………………………………………………………………………

4.3.2 What feature does *m* represent in graphs?

…………………………………………………………………………………………………………

4.4 Graphs A and B intersect each other as shown in the sketch. Choose the correct answers:




4.4.1 Where the 2 graphs intersect,

A. the lines are equal

B. x – y = x + y

C. $x_A = x_B$ and $y_A = y_B$

D. $x_A = y_A$ and $x_B = y_B$

4.4.2 For x > 1,

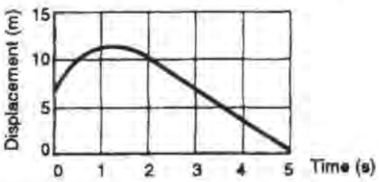
A. $y_A > y_B$

B. $y_A < y_B$

C. $y_A = y_B$

**5. Kinematics graphs**

5.1 Study the following displacement-time graph:




Choose the correct answers:

5.1.1 Between 0 and 1 s the gradient is
(a) positive
(b) negative
(c) zero

5.1.2 Between 0 and 1 s the gradient of the graph
(a) stays the same
(b) decreases
(c) increases

5.1.3 Between 3 and 5 seconds the gradient is
(a) positive
(b) negative
(c) zero

5.1.4 Between 3 and 5 s the gradient of the graph
(a) stays the same

(b) decreases
(c) increases

5.1.5 Approximately at what time is the gradient zero?
(a) 0 s
(b) 1.3 s
(c) 5 s

5.2 Mpho, a long distance athlete, jogs at a constant speed. The following table shows his distance from his starting point at certain times.

5.2.1 Complete the table by filling in the missing numbers:

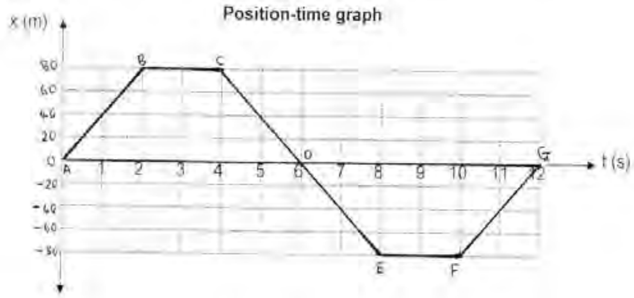
| Time in seconds | T | 0 | 1 | 2 | 3 | |
|---|---|---|---|---|---|---|
| Distance in meters | | 0 | 20 | 25 | | 60 |

5.2.2 Draw a graph using the data in the table in question 5.2.1.
Scale: Represent 1 cm for 2 s on the horizontal axis and on the vertical axis, let 1 cm represent 10 m.

………………………………………………………………………………………………………

**6. Interpretation of graphs**

6.1 The graph illustrates the position-time graph of a girl that is initially moving Eastwards with a constant velocity. The velocity is the gradient.




6.1.1 What is the velocity (gradient) of the girl for the interval A→ B?
………………………………………………………………………………………………………

6.1.2 For each of the intervals, state whether the gradient is positive, negative or zero?

Interval AB:……………………………… Interval BC:………………………………

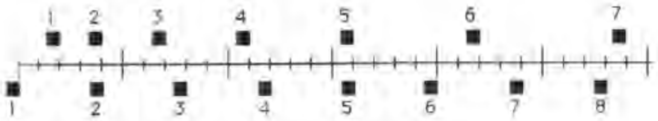
Interval CD:……………………………… Interval DE:………………………………

Interval EF:……………………………… Interval FG:………………………………

7

6.1.3 The girl initially moves Eastwards. Name all the intervals where she moves westwards.
……………………………………………………………………………………………………………

6.2 The positions of two blocks at successive constant time intervals are represented by the numbered squares in the figure below. The blocks are moving to the right

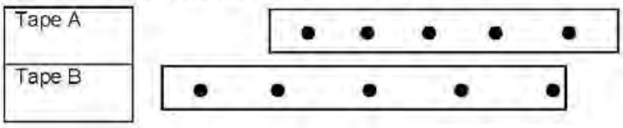



6.2.1 Do the blocks ever have the same speed?
A No
B Yes, at instant 2.
C Yes, at instant 5.
D Yes, at time during the interval 2 and 5.
E Yes, at some time during the interval 3 and 4.

6.2.2 Are the blocks at the same position?
A No
B Yes, at instant 2.
C Yes, at instant 5.
D Yes, at time during the interval 2 and 5.
E Yes, at some time during the interval 3 and 4.

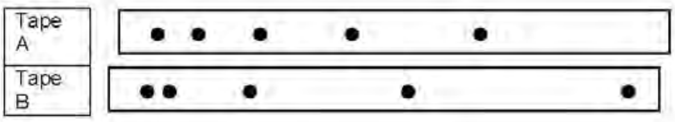
6.3 The dots show the positions of two blocks at successive constant time intervals. The blocks are moving to the right.

6.3.1 Which of the two tapes represents the larger speed?



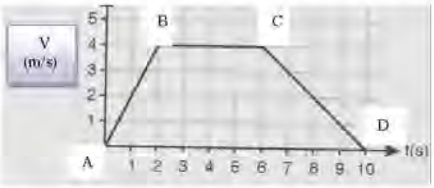

6.3.2 Explain your answer ……………………………………………………………………………

6.3.3 Which of the tapes represents the greater acceleration? ………………………




6.3.4 Explain your answer……………………………………………………………………………………

6.4 The graph below shows the velocity of a delivery van.



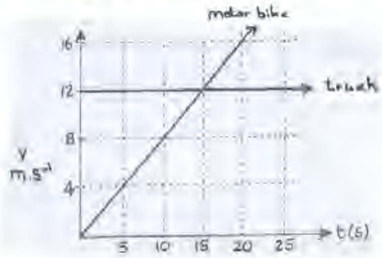

6.4.1 At what time(s) was the velocity of the van 2 m/s? ……………………………………………

6.4.2 At what time(s) was the van not moving?
……………………………………………………………

6.4.3 Did the van ever move in the negative direction?

……………………………………………………………………………………………

6.5 The velocity-time graphs for a motor bike and a truck are shown in the sketch below. The motor bike starts from rest at an intersection. At the instant the lights turn green and a truck passes the motor bike from behind at a constant velocity of 12m/s.




6.5.1 Which vehicle has the largest velocity after 20 s?
A. The truck
B. The motor bike
C. It is not possible to tell.

6.5.2 Which vehicle is ahead after 20 s?
A. The truck
B. The motor bike
C. It is not possible to tell.

6.5.3 At the point where the two lines cross, the motor bike and the truck
A. overtake each other
B are colliding
C. have equal speeds
D. are at the same position
E. have covered the same distance

**Thank you.**

9

# APPENDIX B

# PERMISSION LETTER FROM DEPARTMENT OF EDUCATION

**education**

Lefapha la Thuto
Onderwys Departement
Department of Education
**NORTH WEST PROVINCE**

Teemane Building
8 OR Tambo Street
Private Bag X1256
POTCHEFSTROOM 2520
Tel.: (018) 299-8166/8295
Fax: (018) 297-7574
e-mail: palesab@nwpg.gov.za
akhula@nwpg.gov.za

**DR KENNETH KAUNDA DISTRICT**

CES: Professional Support Services

30 March 2009

Mrs Grace Djan
Potchefstroom High School for Girls

**PERMISSION TO CONDUCT RESEARCH IN THE USE OF GRAPHS AS AN EFFECTIVE TOOL TO BETTER THE UNDERSTANDING OF SOME SCIENTIFIC PRINCIPLES IN HIGH SCHOOLS**

The above matter refers.

Permission is hereby granted to you to conduct research in two high schools in the Dr Kenneth Kaunda District under the following provisions:

- the activities you undertake at schools should not temper with the normal process of teaching and learning;
- you inform the principal of your identified schools of your impending visit and activity;
- you provide my office with a report in respect of your findings from the research: and
- you obtain prior permission from this office before availing your findings for public or media consumption.

Wishing you well in your endeavour.

Thanking you

**DR S H MVULA**
**DISTRICT EXECUTIVE MANAGER**
**DR KENNETH KAUNDA DISTRICT**

*"A vibrant, top achieving district offering accessible quality education"*
*"Business unusual: All hands on deck to speed up change"*

## APPENDIX C

## SAMPLE LETTER OF APPROVAL FROMS SCHOOLS

Mrs Djan

I,...................................... principal of .................................., herby grant permission for learners to be used in the research for your further studies.

Best wishes

------------------------------

Principal

## APPENDIX D

## SAMPLE OF CONSENT NOTE FROM LEARNERS

### QUESTIONNAIRE FOR GRADE 10 PHYSICAL SCIENCE LEARNERS

The purpose of this questionnaire is to obtain information that can be used to determine your resources for understanding line graphs in Grade 10 Physical Sciences.

Name:........................ School........................ Grade:10A

INFORMED CONSENT

I understand that participating in this research project is completely voluntary and no pressure may be placed on me to participate. I understand that it is not a test that will count any marks. I herby give permission that this questionnaire may be used for research purposes.

........................................ ........................................
Signature Date

**SECTION A: DEMOGRAPHIC INFORMATION**

Carefully read the following questions and cross the answer of your choice. Please answer these questions as honest as possible.

1. **Gender**

| | |
|---|---|
| 1 | 2 |
| Male X | Female |

2. **What is your age?**

| | | | | | |
|---|---|---|---|---|---|
| 13 | 14 | 15 | 16 | 17 | 18 X |

3. **What is your highest mark in Natural sciences last year [physical sciences –NS1]?**

| | | | | | |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| Below 40% X | 40-59% | 60-69% | 70-79% | 80-90% | 91-100% |

4. **What is your highest mark in Mathematics last year?**

| | | | | | |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| Below 40% X | 40-59% | 60-69% | 70-79% | 80-90% | 91-100% |

5. **What is your highest mark in life science-NS2 last year?**

| | | | | | |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| Below 40% | 40-59% X | 60-69% | 70-79% | 80-90% | 91-100% |

6. **For how long have you been doing grade 10?**

| | | |
|---|---|---|
| 1 | 2 | 3 |
| Once | Twice X | More than twice |

7. **Home language**

| | | | | | |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | Other specify |
| Asian | English | Afrikaans | Setswana X | Sotho | |

# APPENDIX E

## SAMPLE OF LEARNERS RESPONSE CODES

**APPENDIX E** SAMPLE: CODED RESPONSE

| SECTION C | QUESTION NO. | WHAT IS TESTED | L1 | L2 | L3 | L4 | L5 | L6 | L7 | L8 |
|---|---|---|---|---|---|---|---|---|---|---|
| | 5.1.1 | Displacement - time; Is gradient positive, negative or zero. | C | A | G | A | A | A | G | A |
| | 5.1.2 | Displacement - time; Is gradient same, decreases or increases. | C | A | G | A | C | C | G | C |
| | 5.1.3 | Displacement - time; Is gradient positive, negative or zero. | B | A | G | A | C | C | G | C |
| | 5.1.4 | Displacement - time; Is gradient same, decreases or increases. | B | C | G | C | A | A | G | A |
| | 5.1.5 | Time gradient is zero. | C | A | G | A | A | A | G | A |
| | 5.2.1 | Fill distance-time table of a girl jogging at constant speed | A | B | C | B | C | A | D | A |
| | 5.2.2 | Draw graph from a distance-time data | B | A | G | G | G | G | G | G |
| | 6.1.1 | Velocity from a position-time graph-gradien | B | G | G | H | G | G | G | G |
| | 6.1.2 | Position - time graph; Is gradient positive, negative or zero. | | | | | | | | |
| | | AB | D | D | D | D | G | D | G | B |
| | | BC | B | D | D | B | G | G | G | G |
| | | CD | D | D | B | D | G | G | G | G |
| | | DE | A | A | A | A | G | G | G | G |
| | | EF | A | A | A | B | G | D | G | B |
| | | FG | B | A | B | D | G | D | G | B |
| | 6.1.3 | Name all intervals where the girl moves Westwards | G | G | G | G | G | G | G | G |
| | 6.2.1 | Instant at which blocks have the same speed | A | A | G | D | G | G | A | G |
| | 6.2.2 | Instant at which blocks have the same position | A | A | G | D | G | G | A | G |
| | 6.3.1 | identify tape with larger speed | A | B | B | B | G | G | G | G |
| | 6.3.2 | Explain your answer | I | B | B | H | G | G | G | G |
| | 6.3.3 | Dots show position of two blocks-identify one with greater acceleration | A | A | A | A | G | G | G | G |
| | 6.3.4 | Explain | C | A | H | A | G | G | G | G |
| | 6.4.1 | Time van was not moving | F | A | E | H | H | G | G | G |
| | 6.4.2 | Time van is moving in negative direction | H | A | B | E | H | H | G | H |
| | 6.4.3 | Did the van move in negative direction | B | B | A | A | A | A | G | A |
| | 6.5.1 | Which vehicle has the largest velocity | A | B | B | A | G | G | B | G |
| | 6.5.2 | Which vehicle is ahead after 20s? | B | A | B | B | G | G | B | G |
| | 6.5.3 | Select what happens(to the truck and motor bike) when the two lines cross | A | A | C | B | G | G | E | G |

SAMPLE: RESPONSE CODES (Codes for the variety of response given by learners)

| SECTION | QUESTION NO. | Response | Code |
|---|---|---|---|
| B | | | |
| | 10 | Highly disagree | 1 |
| | | Do not agree | 2 |
| | | Undecide | 3 |
| | | Partially agree | 4 |
| | | Highly agree | 5 |
| | Motivation | Useful with examples. Mentions application of graph. | A |
| | | Graphs are easy to understand | B |
| | | Very involving. Do not like graphs | C |
| | | Visualize and grasp concepts faster, better. Mentions effectiveness of graph. | D |
| | | Not sure ( with reason(s) | E |
| | | Do not know how to draw, interprete, don't undrstand graphs. Yes graphs are difficult | F |
| | | No attempt | G |
| | | Other | H |
| | 14 | Highly disagree | 1 |
| | | Do not agree | 2 |
| | | Undecided | 3 |
| | | Partially agree | 4 |
| | | Highly agree | 5 |
| | Motivation | Easy to read, distinguish and interpret information, fast | A |
| | | Valuable information are clearly depicted | B |
| | | Confusing and difficult, don't understand the graph | C |
| | | Lots of information into meaningful easy to read, and understand format. | D |
| | | Using variety of methods to interpret wide range of answers | E |
| | | Fun and interesting, attractive,accurate | F |
| | | No attempt | G |
| | | Other | H |
| | | Not sure, I don't understand. | I |
| | | Never worked with graph in science | J |
| | 1.1(b) | Length in meters or kilometres. | A |
| | | How far things are away from each other. | B |
| | | Actual path travelled from one point to the order or or the Amount of space between the two points (places). | C |
| | | Distance between two points | D |
| | | Km or m | E |

SAMPLE: RESPONSE CODES (Codes for the variety of response given by learners)

| | | | |
|---|---|---|---|
| | | Gives examples | F |
| | | No attempt | G |
| | | Other | H |
| | | Use correct formula | I |
| | | Time taken to travel | J |
| C | | | |
| | 6.1.2 | Negative | A |
| | Interval AB | Zero | B |
| | | I don't understand | C |
| | | Positive | D |
| | | Cordinates | E |
| | | No attempt | G |
| | | Other | H |
| | 6.5.3 | Overtaking | A |
| | | Colliding | B |
| | | Have equal speed | C |
| | | At the same position | D |
| | | Have covered the same distance | E |
| | | Faster/slower | F |
| | | No attempt | G |
| | | Other | H |

## APPENDIX F

## SAMPLE OF LETTER OF REQUEST FROM RESEARCHER

**REQUEST FOR PERMISSION TO USE LEARNERS IN A RESEARCH STUDY**

I have registered with the University of Northwest Potchefstroom campus for a study that will lead to Master degree in Science Education.

The study involves a research in the use of graphs as an effective tool to better understanding of Physical Sciences.

The research will enhance the understanding of learners in general of certain scientific principals. To this effect, sample of learners in your school will be needed to conduct the research experiment.

I wish to request the learners in grade 10 doing physical sciences.
I am willing to accept an appropriate date and time conducive to the school.

Hoping to receive a conducive responsive from you.

Thanks for your cooperation.
Kind regards.

Yours truly,
……………………..

# APPENDIX G

# GRADE 12 PYSICAL SCIENCES EXAMINATION PAPER FOR FEBRUARY/MARCH 2010 (PAPER ONE) QUESTION 14.2

QUESTION 14

During an experiment to determine the work function of a certain metal light of different frequencies was shone on the metal surface and the corresponding kinetic energies of the photoelectrons were recorded as shown in the table below.

| **Frequency of incident light (x 1014 Hz)** | **Kinetic energy of photoelectrons (x 10-19 J)** |
|---|---|
| 6,6 | 0,7 |
| 8,2 | 1,6 |
| 9,2 | 2, 2 |
| 10,6 | 3,0 |
| 12,0 | 3,8 |
| 6 | 6 0 |

14.2 Use the data in the table above to draw a graph of kinetic energy versus frequency on the graph paper provided. (6)

## APPENDIX H

## GRADE 12 PHYSICAL SCIENCES PAPER ONE FEBRUARY/MARCH 2010

## MEMORANDUM: QUESTION 14.2

| Criteria | Marks |
|---|---|
| Relevant heading | √ |
| Axes labelled correctly with units. | √ |
| Appropriate scale. | √ |
| Plotting all the points. | √√ |
| Line of best fit. | √ |