A COMPARISON OF THE EFFECTIVENESS OF THE CONVENTIONAL AND MICROCOMPUTER-BASED METHODS IN KINEMATICS

NOMATHAMSANQA PRINCESS JOY MOLEFE
UDE (SECONDARY), HED, B.Ed.

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Supervisor: Dr. M. Lemmer
Co-supervisor: Prof. J. J. A. Smit

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SUMMARY

The study reported in this dissertation compares the learning effectiveness of two experimental methods that can be used in the teaching of kinematics to Grade 11 learners in Physical Science. The first method is the conventional ticker-timer experiment, while the second utilises high-technology microcomputer-based equipment. The purpose is to make recommendations for improved teaching of basic kinematics concepts and graphs, which learners have difficulties with (Halloun & Hestenes, 1985; McDermott et al., 1987).

A group of 48 Grade 11 learners from Thuto-Boswa Secondary School, Ventersdorp, were used in the empirical research. They were divided into two groups of comparable abilities. Group A used the conventional apparatus and group B the microcomputer-based apparatus. The results of the pre- and post-tests were analysed statistically to compare the learning effectiveness of the two methods in terms of the outcomes reached, the gains obtained as well as d-values. Three months after the experiments were conducted the learners were tested again to determine the long-term effect of the methods.

Both groups obtained a gain of approximately 0.2 in the pre- versus post-test analysis. The literature (e.g. Thornton, 1998) reveals larger gains with microcomputer-based experiments. Three possible reasons that could contribute to this discrepancy were investigated, namely the learners' acquaintance with the microcomputer, the educator's experience with the apparatus as well as the learners' cultural background and language. All three these factors were found to have a detrimental effect on the learning effectiveness, especially with the microcomputer-based method.

Recommendations are made in connection with the teaching of basic kinematics concepts and graphs to Grade 11 learners in South African secondary schools. In addition, it is emphasised that educators should be adequately computer literate before expensive high-technology equipment is purchased for classroom use. It is also pointed out that the implementation of the computer as teaching aid can be a first step to improve computer literacy of disadvantaged learners in our schools.
Key words:
Kinematics concepts, kinematics graphs, experimental methods, microcomputer-based methods.
OPSOMMING

Die studie wat in hierdie verhandeling gerapporteer word, vergelyk die leerdoeltreffendheid van twee eksperimentele metodes wat gebruik kan word om kinematika-begrippe en grafieke vir Graad 11-leerders in Natuur- en Skeikunde te onderrig. Die eerste metode is die konvensionele tydtikker-eksperiment, terwyl die tweede van hoëtegnologie mikrorekenaargebaseerde apparaat gebruik maak. Die doelwit is om aanbevelings ter verbetering van die onderrig van kinematika-begrippe en grafieke te maak, aangesien leerders probleme hiermee ondervind (Halloun & Hestenes, 1985; McDermott et al., 1987).

'n Group van 48 leerders van die Thuto-Boswa Sekondêre Skool, Ventersdorp, het aan die empiriese studie deelgeneem. Hulle is in twee groepe van vergelykbare vermoëns verdeel. Groep A het met die konvensionele apparaat gewerk, terwyl die mikrorekenaargebaseerde apparaat met Groep B gebruik is. Die resultate van voor- en natoetse is statisties ontleed om die leerdoeltreffendheid van die twee metodes te vergelyk ten opsigte van uitkomste bereik, wins (gain) sowel as d-waardes. Drie maande nadat die eksperimente gedoen is, is die leerders weer getoets om die langtermynuitwerking van die metodes te bepaal.

Vir beide metodes is 'n wins van ongeveer 0,2 in die voor-teenoor natoetsontledings verkry. Literatuur (bv. Thornton, 1998) het groter wins verkry met mikrorekenaar-gebaseerde eksperimente. Drie moontlike faktore wat kon aanleiding gee tot die verskil is ondersoek, naamlik die leerders se vertroudheid met mikrorekenaars, die opvoeder se ervaring met die gebruik van die apparaat sowel as die leerders se kulturele agtergrond en taal. Daar is gevind dat al drie hierdie faktore 'n nadelige uitwerking op die leerdoeltreffendheid gehad het, veral op die mikrorekenaar-gebaseerde metode.

Aanbevelings in verband met die onderrig van die basiese kinematika-begrippe en grafieke vir Graad 11-leerders in Suid-Afrikaanse sekondêre skole is gedoen. Daarby is dit beklemtoon dat opvoeders voldoende opleiding in rekenaargeletterdheid moet kry. Verder is daarop gewys dat die implementering van die rekenaar as onderrighulpmiddel die eerste stap kan wees om agtergeblewe leerders in ons land rekenaargeletterd te maak.
Sleutelwoorde:
Kinematika-begrippe, kinematika-grafieke, eksperimentele metodes, mikrorekenaar-gebaseerde metodes.
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CHAPTER 1
ORIENTATIVE INTRODUCTION

1.1 PROBLEM ANALYSIS AND MOTIVATION

Various research studies (e.g. Frauenknecht, 1998; McDermott et al., 1986) show that learners at secondary school level experience problems with kinematics concepts such as displacement and velocity as well as kinematics graphs (example, displacement-time and velocity-time graphs). Schuster (1983) tested learners' abilities to use different representations of a demonstrated motion as a criterion for their understanding of kinematics concepts. He came to the conclusion that success in conventional test questions regarding motion does not imply real understanding.

Learners develop their own ideas with respect to motion in the real world (Trowbridge & McDermott, 1980, Anderson 1987). Alternative conceptions about the kinematics concepts emerge from these ideas. Learners find it difficult to reconcile their alternative conceptions with scientific concepts and often do not change their conceptions even after teaching (Campanario, 2002).

Learners have difficulty in connecting graphs to physical concepts as well as connecting them to the real world (McDermott et al., 1986). These difficulties should be attended to, because the ability to draw and interpret graphs is crucial for developing an understanding of many concepts in Science. Because graphs can be regarded as a panacea for large amounts of information, graphs can aid learners in the ability to extract appropriate information. In the information age, learners find themselves bombarded by large amounts of information, which complicates learning.
The research reported in this dissertation aims to help learners to develop a deeper insight of kinematics concepts and graphs and to remedy alternative conceptions. The learning effectiveness in the attainment of the learning outcomes of two experimental methods are assessed, namely the ticker-timer method and the microcomputer-based method. The conventional method uses the ticker-timer and the ticker-tape, while the microcomputer-based method utilises modern equipment such as a motion detector. The apparatus and methods are described in paragraphs 5.1 and 5.4. In both methods the learners were actively engaged in the performance of the experiments. Interactive engagement has been proven to be more effective than traditional teaching strategies (Hake, 1998:2).

Research on the use of computers in a variety of situations suggests that microcomputer-based apparatus does not yield uniformly satisfactory results (Redish et al., 1996). However, Sokoloff and Thornton (1990) reported that introductory Physics learners' understanding of velocity graphs could be significantly improved by using the microcomputer-based laboratory. Sokoloff and Thornton (1990) found that the microcomputer-based laboratory activities they designed were effective for the following five reasons:

- learners focus on the physical world.
- immediate feedback is available.
- collaboration is encouraged.
- powerful tools reduce unnecessary, hard, uninteresting work.
- learners understand the specific and familiar before moving on to the more general and abstract.

Most of the researchers on the implementation of the microcomputer-based laboratory (MBL) agree that the computer has become an effective tool in the Physics laboratory, but that it has limitations (Lawson & Tabor, 1997; McKinney, 1997; Wellington, 1990), for instance:
• computers could give misleading impressions of the nature of Science.
• science is portrayed as clean and nice, not as problematic and messy.
• the important labour, hands-on experimentation and investigation are displaced.
• concepts such as electric current could be misrepresented.
• manipulative skills such as screwing a clamp to a stand will not be developed in learners.
• learners can play with the programme and not learn.
• learners are tempted to do things on the computer that should have been done in the laboratory.

Smerdon et al. (2000) and Rowand (2000) report that the availability of computers in schools and classrooms is growing in the United States. A survey by the Department of Education found that 99% of full-time public school educators had access to computers in their schools in 1999. South Africa is still behind in these figures. According to the School Register of Needs database of the South African Department of Education, only 38.5% of the secondary schools in South Africa had one or more computers in 2000. This figure is expected to grow as educators and learners become more computer-literate. There is therefore a need to study the feasibility of the usage of computers in the Science classroom in South Africa.

1.2 RESEARCH QUESTION

The research described in this dissertation attempts to give evidence as to which one of the teaching strategies (the one involving microcomputer-based apparatus or the one involving the conventional apparatus) is more effective in the teaching of kinematics concepts of displacement, velocity and the related kinematics graphs to South African learners. In the light of the fact that the computer has limitations and disadvantages on the one hand but could be an effective tool on the other hand, the research question is as follows: "How effective is
microcomputer-based experiments in teaching kinematics to Grade 11 Science learners in South African schools compared to conventional experiments? The research hypothesis based on the research question is formulated in paragraph 1.3.

1.3 HYPOTHESIS

Learning effectiveness achieved by using microcomputer-based apparatus is higher than with conventional apparatus in relation to the concepts of displacement, velocity and related graphs.

1.4 AIM OF THE STUDY

Based on the hypothesis in paragraph 1.3, the aim of the study is to compare the learning effectiveness achieved in teaching the kinematics concepts of displacement and velocity by microcomputer-based and conventional apparatus.

1.5 OBJECTIVES

Related to the research hypothesis in paragraph 1.3 and the aim of the study in paragraph 1.4, the specific objectives of this study are to:

- identify conceptual problems and alternative conceptions related to kinematics concepts and graphs through a literature survey;
- assess the learning effectiveness of the kinematics concepts of displacement and velocity by using the conventional apparatus and microcomputer-based apparatus;
- assess the learning effectiveness of displacement-time and velocity-time graphs by using the conventional apparatus (ticker-timer and paper tape) and microcomputer-based apparatus;
- compare the learning effectiveness of the two methods with regard to the outcomes reached;
determine the endurance of conceptual change obtained with the two methods;

• explain the results in terms of factors such as language and computer literacy; and

• make recommendations with regard to the use of microcomputer-based experiments in South African schools.

1.6 METHOD OF RESEARCH

1.6.1 Literature study

A thorough literature study was conducted to gain an in-depth understanding of learners' conceptual problems and alternative conceptions regarding kinematics concepts as well as the role kinematics graphs play in conceptualisation in Physics. During the course of this study, possible problem areas were identified.

A search on national and international publications was further conducted in order to gain knowledge of what other researchers have found out about the experimental methods utilised in the study.

Study material and recent publications on the topic of the study were obtained from:

• a DIALOG search in the Eric-Database of the Ferdinand Postma Library at PU for CHE; and

• recent publications on the subject in scientific and educational journals (local and abroad).

1.6.2 Empirical research

1.6.2.1 Population
The study focused on a group of forty-eight (48) Natural Science learners enrolled at Thuto-Boswa Secondary School (Ventersdorp) in Grade 11. Ventersdorp is a town in the North West Province of South Africa.

1.6.2.2 Research method

The method to acquire data was as follows:
The Grade 11 learners were divided into two similar groups. A pretest (Appendix C) was administered to the learners of both groups. The conventional method was used with the first group (group A) and the computer-based method with the second group (group B). Two afternoon sessions were spent on each experiment. A post-test with the same questions as the pretest was administered afterwards to all learners. The results of the pre- and post-tests were compared and evaluated in terms of the outcomes reached.

Approximately three months after the experiments were conducted, learners were given an additional questionnaire to determine the constancy and endurance of the results. Questions in which the one group outperformed the other to a certain extent (d=0.3) were used (Appendix D).

Lastly, factors that could influence the results were investigated. A questionnaire was given to group B to determine their acquaintance with computers. Soon after the experiment was done, interviews were conducted with all participating learners to determine the influence of their language and cultural background. The experience of the educator was also taken into account in the interpretation of results.

The statistical support services of the PU for CHE assisted in analysing the empirical data according to appropriate statistical techniques.

1.7 CONTENTS OF CHAPTERS
Chapter 1 offers an introduction to the study. The problem analysis and motivation for the study are followed by the research question, hypothesis, aims and objectives of the study as well as the method of research.

Chapter 2 provides a literature review on alternative conceptions on the kinematics concepts researched, namely displacement and velocity.

Chapter 3 gives a literature review on learners' interpretation of kinematics graphs.

Chapter 4 offers a literature review on the microcomputer-based and the conventional methods used in the teaching of kinematics.

Chapter 5 discusses the outcomes research strategy and assessment instruments used in the empirical study.

Chapter 6 provides the results of the empirical study and an analysis thereof.

Chapter 7 discusses general conclusions drawn from the research and recommendations based on the research results.
CHAPTER 2

LITERATURE REVIEW OF ALTERNATIVE CONCEPTIONS OF DISPLACEMENT AND VELOCITY

2.1 ALTERNATIVE CONCEPTIONS

After investigations and theoretical reasoning, it is common practice for the scientific community to come to a general agreement on what a particular concept means. Such an agreement may take the form of a definition or a generally accepted description of a concept. All other perceptions, descriptions or definitions not in line with scientifically accepted arguments are considered scientifically unacceptable and are referred to as alternative conceptions (Wesi, 1997:6-7). According to Thijs and Van den Berg (1995:318) an alternative conception in science refers to a conception that is contradictory to or inconsistent with the concept as intended by the scientists. Numerous synonyms for alternative conceptions exist. For example, preconceptions, spontaneous knowledge, folk knowledge, children’s ideas, naive ideas or children’s science are used. The term alternative conception is preferred in this dissertation.

Osborne et al. (1983:496) state that there seems to be a reason to believe that children and scientists use their experiences and long-term memory in a similar way in order to give meaning to the world around them. These authors propose three reasons why the views that children hold in general differ from those of scientists, namely:

- children tend to view things from a self-centered point of view because they have difficulty with the abstract reasoning ability of scientists.
- children use particular explanations for specific events and, unlike scientists, they are not concerned with the need for coherent and non-
contradictory explanations for a variety of phenomena.

- children's views are in general not integrated into a logic coherent system like the scientific practice.

Hewson (1988:34) describes learners' natural ideas about science as alternative conceptions and stresses that they should be taken seriously because learners are committed to those explanations as they seem intelligible and meaningful to them at the time. He adds that if educators addressed learners' conceptions, real learning might occur and learners could accept a scientific conception. Learners' conceptions about the real world are difficult to change, correct or modify through formal instruction. According to Treagust (1988:16), "It is, however, well documented that the task of changing alternative conceptions is extremely difficult, as they have often been incorporated securely into cognitive structures." Views formed from experiences outside the classroom may be more permanent and influential in children's lives than anything they are told at school (White, 1989:9).

2.2 CONCEPTUAL CHANGE

Posner et al. (1982) propose a model of conceptual change. There are two major components to their model of conceptual change, namely the conditions that need to be satisfied in order for a person to experience conceptual change and the person's conceptual ecology that provides the context in which the conceptual change occurs and has meaning. The conceptual change model has the following conditions that apply to conceptions that a learner either holds or is considering (Hewson & Hewson, 1983:732):

- Is there dissatisfaction with the existing conception?
- Is the conception intelligible to the learner? Do the pieces of the conception fit together for the learner?
- Is the conception plausible to the learner? If a conception is intelligible to the learner, does the learner also believe that it is true?
• Is the conception *fruitful* for the learner? Does the conception solve insoluble problems for him or her? Does it suggest new possibilities, directions and ideas?

When teaching for conceptual change, the following procedure is recommended (Wesi, 1997:60-62):

(1) **Establishing existing knowledge**

According to the constructivist approach to teaching, an educator's role is one of a facilitator of the learning process. Learners are seen as actively involved in interpreting and constructing knowledge (Jacob, 1982:268).

According to this approach, learners' prior knowledge must first be established before the scientific concepts can be introduced. If learners' prior conceptions are scientifically acceptable, learners can be led through a process of knowledge construction on the basis of what they already know. If, on the other hand, learners' prior knowledge is not scientifically acceptable, it will be necessary to lead them through a process of discrediting their existing notions so as to pave the way for the establishment of the acceptable new concepts (Novodvorsky, 1997:242).

(2) **Discrediting learners' ideas**

Discrediting learners' ideas does not mean that the educator has to criticise learners' ideas. Learners must be allowed to explore their own alternative conceptions and use them to generate their own hypotheses. An educator must provide materials and opportunities for learners to test their ideas. In that way a conflict situation arises in learners' minds. This conflict in mental structures serves as the source of motivation for the child to seek closure (Jacob, 1982:268).
Where applicable, a conflict situation in learners' minds can be created by means of an experimental demonstration that is contradictory to their alternative conception. In this way learners will begin to doubt their conceptions and opt for the one that is not contradictory to experimental observation.

(3) The construction of knowledge

After learners' alternative conceptions have been discredited, they will be ready to assimilate scientifically acceptable knowledge that does not lead to contradictions and is not contradictory to experimental observations. Learners must be allowed to construct that knowledge themselves. Steps involved in leading learners through the process of knowledge construction include allowing them to discuss and interpret phenomena in such a way that it makes sense. Through the guidance of the educator the acceptable scientific concept can then be established. If the scientific concept were accepted, the learners will disregard their own naïve concepts in favour of the scientific ones (Novodvorsky, 1997:243).

2.3 LEARNERS' IDEAS ABOUT MOTION

Learners develop their own intuitive ideas about motion and how it can be represented through their day-to-day observations of objects such as cars, which change their positions as a function of time (Leinhardt et al., 1990:24). Learners' intuitive ideas about kinematics concepts are not necessarily in opposition with the way subject experts view these concepts. Frauenknecht (1998:153) agrees that motion is one of many observations of physical phenomena occurring in children's spheres of experience. These observations act as a support basis for the development of related conceptions on a cognitive level, usually under the guidance of an instructor.

The literature revealed the following problems that learners encounter with
kinematics concepts:

2.3.1 Confusion of related kinematics concepts

Learners generally encounter difficulties in distinguishing between different but related concepts such as speed and distance or change of velocity and acceleration (Frauenknecht, 1998:203-204).

Trowbridge and McDermott (1980) found that learners have difficulties in the understanding of kinematics quantities when they performed tasks on simple motion of real objects. In their experiments with two identical balls rolling on parallel tracks, Trowbridge and McDermott (1980) established the following confusion of concepts among learners:

- **Position-speed confusion:**
  When two objects reach the same position, they have the same speed. This means that learners use position criteria to determine the time when the speed of two balls is the same. They often identify the instant when one object passes the other as the time when the speed of the two objects is equal.

- **Displacement-velocity confusion:**
  The object that is ahead travels faster. This association of being ahead or being behind as being faster or slower can also be related to confusion between displacement and rate of change of displacement. Relative speeds are thus compared by simply comparing positions.

- **Confusion between velocity and change in velocity:**
  No discrimination is made between velocity and change in velocity and no consideration is given to the time intervals during which these changes in velocity take place.

- **Velocity-acceleration confusion:**
  Learners confuse acceleration with velocity. They view acceleration as a velocity that gets bigger and bigger without considering the time during
which it takes place.

According to Mokros and Tinkler (1987) learners are unable to compare the speed of two objects that cover different distances in different times. They conclude that velocity is conceptually more difficult than displacement. Velocity as the rate of change of displacement is more abstract and difficult to understand.

2.3.2 Average and instantaneous velocity

Learners do not understand the idea of instantaneous velocity as a value that refers to a specific instant. Instantaneous velocity described by \( \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} \) seems far removed from any direct observation (Trowbridge & McDermott, 1980).

Warren (1979) reports that learners have problems with differentiating between average velocity and instantaneous velocity. This causes difficulties with the idea that a body could momentarily be at rest and yet be accelerated, for instance when a ball reaches its highest point after being thrown vertically upwards. A situation where velocity increases and acceleration decreases is equally difficult for learners to grasp. An example is a ball rolling down a hill with a hollow curve in the slope.

2.3.3 Acceleration

Trowbridge and McDermott (1980) report the following findings regarding the concept of acceleration:

- even when learners realise that the concept of acceleration includes the idea of change in velocity, they ignore the corresponding time interval during which the change takes place.
- learners believe that the acceleration of two objects must be the same if
they are on the same incline, even when they observe that one object takes less time to undergo the same change in velocity.

- two balls that reach the same position are perceived to have the same acceleration.
- the definition of acceleration as the ratio of the change in instantaneous velocity is often merely memorised without any real understanding.

Conceptual difficulties with the concept of acceleration were found to be very persistent (Trowbridge & McDermott, 1980).

2.3.4 Rate of change

Jordaan (1992:107) distinguishes between two types of relationships in science:

- those where \( m = \frac{y}{x} \) acts as a defining equation for \( m \), for example \( a = \frac{\Delta v}{\Delta t} \).
  
  The variable on the left-hand side of the equation can fully be understood in terms of the right-hand side and;

- those relationships where each variable can be defined independent of the other variables, such as \( a = \frac{F}{m} \).

The equation for acceleration \( a = \frac{\Delta v}{\Delta t} \) is an example of a relationship that needs an understanding of the concept of rate of change. Many learners have difficulties in understanding such relationships. The concept of rate of change is crucial in kinematics and poor mastery thereof will prevent learners from fully understanding the relationship between various kinematics quantities and their graphical representations (Jordaan, 1992:107).

Trowbridge and McDermott (1980) found that learners seldom make a
connection between speed and the ratio of distance travelled to elapsed time. This is in spite of the fact that they can often give an acceptable textbook definition of speed.

Nickerson (1985:206) reports that learners frequently confuse 'rate' with 'amount'. This was found in answers to questions testing an understanding of velocity versus displacement and acceleration versus velocity. Nickerson (1998:206) contends that a possible reason is that "rate relationships represented by mathematical equations are inherently static and do not facilitate an appreciation of the fact that the relationship is actually dynamic".

2.3.5 Frames of reference

Research revealed that learners experience difficulties with describing motion according to reference frames:

- Thijs et al. (1987:46) quote Saltiel and Malgrange (1980), who found that learners think of velocity as an intrinsic property of an object and are generally not aware of the frame of reference used. For a boat crossing a fast flowing river for example, learners do not recognise that the component of the velocity produced by the propulsion system of the boat is independent of the speed of the current. The research of Aguirre (1988) confirms that learners believe that the speed as well as the path of a moving body are intrinsic properties of the body and are independent of any reference frame.

- Aguirre and Erickson (1984:441) found that many learners, instead of adopting a common reference point, tend to use several different reference points to describe the position of a body in a number of different locations.

- Panse (1994) studied learners' understanding of frames of reference and concluded that most learners have resistant alternative conceptions. Children often associate frames of reference with concrete objects and
regard particular phenomena as belonging to a specific frame of reference. The close link between frames of reference and relativity of motion indicates that this problem could affect learners' fundamental understanding of motion. The choice of reference point when describing a displacement is one example of the importance of a good understanding of frames of reference.

- another example mentioned by Panse (1994) is that the earth is usually taken as a frame of reference when dealing with velocities. When a learner is sitting stationary on a desk and is asked what his or her velocity is, the answer is usually zero. This learner is ignoring the fact that he or she is part of the planet earth, which possesses a number of complicated velocity components.

2.3.6 Sign convention and negative kinematics quantities

Many learners are hesitant to deal with directional information. They often do not state which direction was chosen as positive when dealing with calculations in kinematics, or when they have to describe an observed motion verbally. Goldberg and Anderson (1989:258) investigated possible reasons for learners' difficulty with negative velocity and concluded that in everyday life learners are familiar with the magnitude of velocity, namely speed. Everyday usage may cause them to think of the magnitude and direction as completely separate attributes.

Goldberg and Anderson (1989:258) also discovered that many learners believe that a negative quantity somehow implies a "lesser amount" of that quantity. They do not accept that a body could be moving negatively but rather less positively.
2.4 SUMMARY

This chapter dealt with problems that learners encounter and alternative conceptions that learners hold about kinematics concepts such as displacement, velocity and acceleration as revealed in the literature. The problems on kinematics concepts can briefly be summarised as follows:

- learners confuse related kinematics concepts such as distance and speed, displacement and velocity, and velocity and acceleration.
- learners do not understand the concept of instantaneous velocity.
- learners experience difficulties with the concept of acceleration.
- learners confuse rate with amount in answers to questions involving velocity versus displacement and acceleration versus velocity.
- learners use several reference points to describe the position of a body in a number of different locations, instead of using a common reference point. The velocity of the earth is believed to be zero.
- learners have difficulty with aspects of sign convention and negative kinematics quantities.
- learners see magnitudes and direction of vectors as separate attributes.

Conceptual problems with the concepts of displacement and velocity were investigated in the empirical study reported in Chapter 6. Problems with these basic concepts could influence learners’ understanding of kinematics graphs. A literature survey of learners’ interpretation of kinematics graphs is discussed in Chapter 3.
CHAPTER 3

LITERATURE REVIEW ON LEARNERS' INTERPRETATION OF KINEMATIC GRAPHS

3.1 INTRODUCTION

Phenomena can be represented in various ways in Physics. An important type of representation is by means of graphs. Graphs are particularly well-suited to describe kinematics phenomena, as they are one of the most effective ways to illustrate, describe and predict relationships between variables. The graphical representation of kinematics motion relates specific kinematics concepts to certain features of a graph (Frauenknecht, 1998:7).

The ability to draw and interpret graphs is of critical importance for the development of an understanding of many topics in physics (McDermott et al., 1987:503, 513). Graphs can specifically deepen students' understanding of concepts related to motion. Clement (1985) adds that mathematical literacy and understanding of the concepts function and variable are additional abilities that can be learnt from the teaching of graphical interpretations.

Graphs illustrate a specific motion in such a way that key aspects of the body's motion are immediately noticeable and information about the motion can readily be extracted from a graphical representation. Graphs also offer an excellent opportunity to demonstrate their importance in Physics as well as other learning areas. Graphs serve a useful purpose in the generation, communication and consolidation of information about a specific motion (Frauenknecht, 1998:8).
3.2 INFORMATION DERIVED FROM KINEMATICS GRAPHS

According to Frauenknecht (1998:84), important information about a motion can be derived from a graph in the following instances:

- interpreting, given quantitative or qualitative graphs of physical situations;
- construction of graphs from data tables followed by an analysis and interpretation of the graphs; and
- construction of graphs from described or observed physical situations in order to understand the situation better.

Graphs can generate additional information about the motion of objects with reference to kinematics graphs. This additional information can be contained in any of the following features (Frauenknecht, 1998:9-11):

3.2.1 The height of a graph

The height above the time axis of a kinematics graph gives the value of the kinematics quantity (e.g. displacement or velocity) that is plotted on the y-axis at a specific time. In view of the fact that the graph displays the relationship between continuously varying quantities that appear as discrete quantities in a data table, it is possible to determine the magnitude of the kinematics quantity at any intermediate time value that falls within the given time domain (Frauenknecht, 1998:9).

3.2.2 The slope of the graph

The slope or gradient of the graph gives the rate of change of the particular kinematics quantity and thus provides important information, which is not immediately available from the data that was obtained from an experiment (Frauenknecht, 1998:10). Information can be gained from the following aspects of the gradient:
the level of steepness gives information relating to how quickly the
kinematics quantity is changing.

a positive or negative gradient provides information about the direction of
a related kinematics quantity.

a zero or non-zero gradient indicates whether a kinematics quantity stays
at a constant value or not.

the constancy or variation in gradient could be indicative of a constant or
accelerated motion in a displacement versus time graph.

3.2.3 The area under the graph

The area under a graph gives information about the motion under observation in
much the same way as the feature of the gradient. For example, the area under
the velocity-time graph gives the change in displacement of the moving body
during a certain time interval. Areas under the time axis of a velocity-time graph
are viewed as negative and are subtracted from the area above the time axis
(Frauenknecht, 1998:10).

3.2.4 Intercepts with the coordinate axes

A kinematics graph generates information about the value of a kinematics
quantity when the time is chosen as zero, as it is simply read off from the vertical
axis intercept. The intercept with the horizontal axis yields immediate information
about the time values for which the kinematics quantity becomes zero
(Frauenknecht, 1998:11).

3.2.5 Position of graph with respect to the time axis

The position of a curved graph with respect to the time axis (i.e. above or below
the axis) provides certain information about the direction of the motion. Negative
values are only indicated for the vector quantities of displacement and velocity.
A crossing of the time axis in the velocity-time graph indicates a reversal in the direction of the motion of the body while in the displacement-time graph it has to be interpreted as a displacement in the opposite direction to the chosen positive reference direction (Frauenknecht, 1998:11).

3.3 CLASSIFICATION OF GRAPHING TASKS

Leinhardt et al. (1990) comment on research that has been undertaken with respect to learners' perception of functional relationships and their graphical representation. Their classification of the results of the research in terms of graphing tasks is significant as it approaches graphical representations in terms of content, the action of the learner as well as teaching strategies. Graphing tasks are described by a number of categories, which have implications for the proper development of learners' conceptions of kinematics graphs. The categories, according to Leinhardt et al. (1990), are as follows:

- actions of the learner;
- the situation (context and settings);
- variables; and
- focus.

These categories are discussed in the following sections.

3.3.1 Actions of the learner

The actions of the learner can be considered to be either focusing on interpretation or construction of graphs. In the case of interpretation, the emphasis could either be on a global or a local level. Accurately drawn graphs where specific data points of kinematics quantities are plotted on a system of axes, emphasise local aspects of the body's motion. An example is the accurate determination of the velocity of an object by measuring and interpreting the gradient of a displacement versus time graph.
Sketch graphs emphasise more global aspects of a body's motion and are normally interpreted in order to gain information about aspects such as whether the velocity increases or decreases. Specific tasks related to graphs that can be assigned to learners are (Frauenknecht, 1998:33-37):

3.3.1.1 Prediction tasks

One of the reasons learners can be assigned to construct kinematics graphs is in order to predict values of kinematics quantities that are not originally known. These quantities can be derived through interpolation, extrapolation or by drawing best-fit lines through a number of data points (Frauenknecht, 1998:33).

3.3.1.2 Classification tasks

Classification tasks rely on graph interpretation. Interpretation of motion graphs is used to classify similar events as belonging to a specific verbally described category (Frauenknecht, 1998:33).

3.3.1.3 Translation tasks

Translation tasks involve the ability to change from one type of representation of a motion to another. The representations used most frequently in kinematics include verbal, tabular, algebraic and graphical representations (Frauenknecht, 1998:36).

3.3.1.4 Scaling

Scaling is important for both graph construction and graph interpretation. In the case of the construction of the graph, the scaling ability or skill is essential for a proper transformation from a table of values to the accurate motion graph and
vice versa. Interpretation relies equally on scaling of both the time axis and the axis representing the specific kinematics quantity (Frauenknecht, 1998:37).

The following aspects have to be borne in mind when considering scaling:

- scales do not need to be the same on the two axes.
- an ordered pair is written in the order: independent variable; dependent variable.
- choose a scale so that an optimum amount of the available area on the graph paper is used.
- the symbol and unit of the kinematics quantity must be indicated on each axis.

3.3.2 Context and settings

Leinhardt et al. (1990:20) distinguish between the context in which a graphical representation is described and the setting for the instruction. The context of a representation refers to the degree to which familiar real-life aspects are used to make graphs more acceptable to learners. "The studies that include contextualised situations are often based on the assumption that it is easier for learners to deal with problems that build on familiar situations than to deal with abstract situations" (Leinhardt et al., 1990:20).

Settings refer to the location where the subject material is presented. It refers to the background that an instructor chooses for the presentation of the subject material and as such is a broader perspective on the subject material than context is (Leinhardt et al. 1990:20).

3.3.3 Variables

The nature of the data points used to construct accurate graphs plays an important role in the analysis or interpretation of a graph. The two main
categories of data points can be described as either abstract or concrete. In kinematics, variables are usually concrete, as they can be associated with everyday experiences (Leinhardt et al., 1990:23).

3.3.4 Focus

The focus of an action involving graphs is described as being either internal to the coordinate system, or on the co-ordinate system itself. A focus internal to the system of axes focuses on the actual graph. Sketch graphs often demand an internal focus because the axes are usually left unscaled. Actions such as accurate graph construction, which usually involves quantitative point-wise interpretation as well as scaling, demand a focus on the co-ordinate axes (Frauenknecht 1998:40).

3.4 LITERATURE REVIEW OF PROBLEMS THAT LEARNERS EXPERIENCE WITH GRAPHS

3.4.1 Understanding kinematics graphs

Through experience, learners develop their own ways to present the motion of everyday objects such as cars, bicycles, people and other objects, which change their positions. In the Physical Science class motion is described in a formal way. The following are examples of actions that learners have to be able to perform in order to satisfy an educator that they truly understand kinematics graphs (Frauenknecht, 1998:171-172):

- the ability to choose a realistic system of axes;
- the ability to plot coordinates correctly;
- the ability to read off values correctly from a graph;
- the correct determination of the velocity from a displacement-time graph;
- the ability to correctly translate the height or slope of a given graph into a slope or height of a required related graph.
Understanding kinematics graphs is the ability to perform any translation between kinematics' representations involving graphs correctly so that the resulting answer is acceptable to a subject expert in the field. A learner who truly understands kinematics graphs must be able to construct and interpret graphs in the context of original, non-textbook style problems where set piece memorisation of previously learned recipes will not suffice to solve the problem (Frauenknecht, 1998:172).

McDermott et al. (1987) divide difficulties experienced by students with graphs into two categories, namely:

- difficulty in connecting graphs to physical concepts; and
- difficulty in connecting graphs to real-life situations.

These two categories of difficulties are discussed in section 3.4.1.1 and 3.4.1.2.

### 3.4.1.1 Connecting graphs to physical concepts

McDermott et al. (1987:504-507) identify the following difficulties that learners encounter when attempting to connect graphs to physical concepts:

- discriminating between the slope and the height of a graph (i.e. determination of the feature of the graph that corresponds to a particular physical concept). Clement (1985) refers to this difficulty as the slope-height confusion;
- interpreting changes in height and changes in slope (especially in curved graphs);
- relating one graph to another (e.g. translation of a position-time graph to a velocity-time graph);
• matching narrative information with relevant features of a graph (e.g. the association of the slope of a particular line on the graph with the acceleration of a particular engine, as given in the problem under consideration); and
• interpreting the area under a graph (e.g. students often find it difficult to envisage a quantity associated with square units, i.e. area under a v-t graph, as representing a quantity with linear units, i.e. the displacement of the moving object).

These difficulties are related to the information about motion that learners have to derive from graphs as discussed in section 3.2 above.

3.4.1.2 Connecting graphs to real-life situations

From learners' responses to three demonstrated motions, McDermott et al. (1987:507 – 510) identify difficulties in connecting graphs to real-life situations. They classify these difficulties as
• representing continuous motion by a continuous line;
• separating the shape of a graph from the path of the motion;
• representing a negative velocity on a velocity-time graph;
• representing constant acceleration on an acceleration-time graph; and
• distinguishing between different types of motion graphs.

The second difficulty, namely to separate the shape of the graph from the path of the motion, is referred to by Clement (1985) as a graph-as-picture error. When given a graph, students appear to treat it as a literal picture of the situation, or when constructing a graph, they attempt to reproduce the spatial appearance of the motion.

After several years of research, McDermott (1993:297) reports that only a few out of several hundred students in a standard calculus-based course successfully
completed tasks on the representation of motion in graphs of position, velocity and acceleration versus time. Students also experienced difficulties with the reverse process, namely to visualise real motion from its graphical representation. Practice in translating both ways (from motion to graphs and from graphs to motion) is necessary to acquire the skills required to interpret graphs. To answer questions on graphs correctly, more is needed than to remember a procedure (e.g. how to calculate a slope). Detailed interpretation of the graph is required to extract information from a graph (McDermott et al., 1987:507).

3.4.1.3 Categories of misconceptions regarding graphs

Frauenknecht (1998:434-436) categorises misconceptions found in literature in his study into five classes:

- Kinematics quantities and conventions;
- graphing skills;
- graphical representation in kinematics;
- mathematical association; and
- graph to graph transformations.

Frauenknecht (1998:437) suggests the following factors as causes of the identified misconceptions:

- learners' preconceptions of kinematics concepts such as speed, distance and velocity;
- students are not intellectually ready for the formal, abstract approach that is required;
- graphing skills are often not explicitly taught;
- poor standards of instruction; and
- poor understanding of kinematics.

3.4.2 Mathematical contents and procedures
Learners experience difficulties with specific aspects of Physical Science because they lack certain mathematical skills required for a proper grasp of that particular section. Jordaan (1992:102) gives three examples of such contents, types and procedures, namely:

- changing the subject of the formula;
- construction and interpretation of graphs; and
- ratio and proportion.

These mathematical operations and concepts play an important role in the understanding of kinematics graphs, as explained in the following sections:

3.4.2.1 Changing the subject of the formula

When learners are provided with the kinematics equation \( v = u + at \), they are expected to be able to change the subject, e.g. from \( v \) to \( a \) so that it becomes: 
\[
a = \frac{(v - u)}{t} \quad \text{(Frauenknecht, 1998:173).}
\]
In these equations, the symbols have their usual meanings.

3.4.2.2 Construction and interpretation of graphs

For constant accelerated motion, the velocity versus time graph (abbreviated \( v-t \) graph) of \( v = u + at \) is a straight line with intercepts on the ordinate equal to \( u \) and on the time axis at \( t \) equal to \( -\frac{u}{a} \). The confidence with which a learner can recall a straight-line equation \( y = mx + c \) contributes to the ability to draw a graph of velocity versus time for the case \( v = u + at \), as indicated in Figure 3.1 (Frauenknecht, 1998:173).
The answer to questions concerning the mathematical meaning of graphs should not only give an indication of a learner's level of understanding, but should also bring to light specific alternative conceptions that a learner might have (Frauenknecht, 1998:174).

3.4.2.3 Ratio and proportion

Arons (1990:3) states: "One of the most severe and widely prevalent gaps in cognitive development of learners at secondary and early college levels is the failure to have mastered reasoning involving ratios." Gamble (1986:355) is of opinion: "In Physics, it is impossible for learners to understand certain laws or relationships unless they share fully with educators the meaning of the word proportional." A large number of learners suffer from these disabilities regarding ratio and proportion and are amongst the most serious impediments in their study of Science (Arons, 1990:3).

Consider the following table of distance $s$ (in metres) against time $t$ (in seconds) for a body travelling in a straight line from a position of rest (Gamble, 1986:355):
The ratio of $\frac{s}{t}$ and $\frac{s}{t^2}$ yields an interesting pattern if the (0; 0) coordinate were not included.

<table>
<thead>
<tr>
<th>$s$ [m]</th>
<th>0</th>
<th>5</th>
<th>20</th>
<th>45</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t$ [s]</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

Learners should note that the ratio of $\frac{s}{t}$ increases uniformly, while the ratio of $\frac{s}{t^2}$ remains constant and can be written as

$$\frac{s}{t^2} = k = 5,$$

where $k$ is called the constant of proportionality (Frauenknecht, 1998:175-176).

The fact that learners experience great difficulties with proportional reasoning has been well-documented (Jordaan 1992; Brasell & Rowe 1993). This can seriously affect their understanding of kinematics graphs, as they might not see the link between proportionality and a straight-line graph passing through the origin. Jordaan (1992) proceeds to point out that this could cause problems for learners with contents that require proportional reasoning.

Brasell and Rowe (1993:65) suggest that the formal operational structures required for proportional reasoning are necessary for co-relational reasoning in graphing. They say that graphical representation of the relationship between two dynamic variables assists to illustrate to learners the proportionality concept in a visual manner. This often leads to a better understanding of concepts such as rate and rate of change.
Gamble (1986:355) puts the problem into perspective: "Given that learners find difficulty with proportionality we must explore the many ways in which this can affect their learning of Physics." Gamble (1986:355) refers to the fact that many secondary school learners do not understand the word 'proportional' as a shorthand notation for a particular and special form of relationship between two variables whose graphical representation is a straight line passing through the origin.

Fourie (1991) tested Grade 11 and 12 learners' ability to reason proportionally and reports that no aspect of proportional reasoning has been completely mastered by high school learners. His findings were that learners:

- were not able to give a graphical interpretation of any proportionality involving a square, for instance, $\Delta s \propto t^2$ for motion with constant acceleration; and
- could not interpret data tables as a direct or inverse proportionality.

Arons (1983:578) points out that one way of helping learners to master a mode of reasoning is to allow them to view the same reasoning from another perspective, which is graphical representation. He suggests that educators should encourage learners to view the steepness of a straight line as a property of a system that it describes. For example, the steepness of a distance versus time graph should be associated with speed.

The following example illustrates how a graph can assist in defining a proportionality constant as a physical quantity in terms of a ratio of the original quantities (Frauenknecht, 1998:181):

Consider an object with displacement equal to zero at time $t = 0$ and moving with constant velocity so that $s \propto t$. If the proportionality were changed to an equal sign, then
The graph of $s$ versus $t$ is in this case a straight line through the origin:

$$s = k.t$$ \hspace{1cm} (1)

From equation (1) follows

$$k = \frac{s}{t},$$

which equals the slope of the graph, assuming that the slope $=- \frac{\Delta s}{\Delta t} = \frac{s_2 - s_1}{t_2 - t_1}.$

The slope $\frac{\Delta s}{\Delta t}$ equals the velocity $v$ of the object. Hence, $k = v.$

Equation (1) can now be written as:

$$s = vt \quad \text{and}$$

$$v = \frac{s}{t} \hspace{1cm} (2)$$

Equation (2) defines velocity in terms of the ratio of $s$ and $t.$

3.4.3 Interpretation of graphs by learners

McKenzie and Padilla (1986:32) contend that producing graphs and interpreting
data are activities that do not come easily for many learners. Subjects such as Physical Science, Biology, Geography and Economics presented at school and at tertiary level make use of graphs to display the relationship between two variables over a number of measurements. Learners are found to be unable to answer higher-order questions about graphs (Frauenknecht, 1998:187). It appears that learners often do not understand that a graph is a symbolic representation of a dynamic relationship between two (or sometimes) three variables.

A number of studies report important findings with respect to the nature and extent of learners' difficulties with graphs. Padilla et al. (1986) applied a test for assessing the ability of learners in grades 7 to 12 to construct and interpret line graphs. They found that although most learners had little difficulty in reading data from a given graph or plotting data points on a graph, higher-order graphing skills were seriously lacking. Examples of skills that were most difficult include the scaling of axes, assigning variables to the axes, interpolation and extrapolation.

Brasell and Rowe (1993) conducted a study among 93 learners to test their ideas of usefulness, difficulty and interest in graphs. Their findings were as follows:

- error rates were higher for items that described the physical event in colloquial language rather than an unambiguous scientific description of the event.
- learners tend to select incorrect graphs, which were temptingly similar to a picture of the event.
- learners failed to link the colloquial or informal description of an event with a scientific description of a relevant variable.

3.5 USE OF TEMPLATES

Linn et al. (1987:247) introduced the idea of a template, which is described as a stereotypic sequence of activities that are used repetitively in solving problems.
An example of a template is the first worked out example of a physics problem that a learner uses as a representation of how problems falling in this class could be solved. When that learner encounters another question relating to the same class of problems, he or she would often attempt to fit it to the template that he/she has created for that particular class of problems. Linn et al. (1987:247-251) propose the following main links:

3.5.1 Recognition of graph features

Graph features that learners should be able to recognise include aspects such as identifying the title of a graph, location of axes, labelling the axes with appropriate variables and their units and recognising the meaning of graphically represented data. An example is the construction of a perpendicular pair of axes with time indicated on the horizontal axis and velocity indicated on the vertical axis. This includes the ability to be able to read off a specific velocity value at a given time value.

3.5.2 Using appropriate graph templates

Learners take their first example of a particular phenomenon as a prototype and use their solution as a template to interpret the next example. Linn et al. (1987:251) give the following example to test whether a learner has developed an appropriate template for interpreting motion graphs correctly: The question is: Which graph best shows the change in the speed of a ball which started from rest at the top of a slope and was then allowed to roll down the slope?
Learners who lacked scientifically correct templates would opt for A or C. They choose A because it represents the situation iconically. C is also chosen because velocity is confused with displacement. The correct answer is B if motion took place in the absence of friction.

3.5.3 Graph design skills

Graph design skills are described in terms of the ability to apply templates used in a specific subject domain to new problems. For instance, assume that a learner is familiar with a template relating to the drawing of the graph $y = 3x - 1$. He or she will put $x = 0$ and $y$ will be equal to $-1$. Then $y = 0$ and $x$ will be equal to $1/3$ and will proceed to draw the graph correctly (Frauenknecht, 1998:193).

If confronted with drawing the graph of $y = x^2 + x - 2$, he or she would again put
x = 0 so that y will be equal to −2. If y were equal to zero, then x will be equal to −2 or 1. In this way a learner has obtained key coordinates for the drawing of the new graph, however, using a known procedure from a similar but different situation (Frauenknecht, 1998:193).

3.5.4 Graph problem-solving skills

According to Frauenknecht (1998:193, 194), this is the learner's ability to solve graphing problems in a subject domain, which is new or unfamiliar to him or her. For instance, consider the following figure (Figure 3.4):

![Figure 3.4: Graph to test learners' graph problem-solving skills](image)

A learner who can determine the displacement of an object from its velocity-time graph from the figure without having received any instruction in kinematics graphs, would have demonstrated his or her ability to advance to the highest level of cognitive accomplishments in graphing. The identification of the area between the graph and the time axis as representing the change in displacement of the body appears advanced and is classified into the category "problem-solving skills" (Frauenknecht, 1998:193).
3.7 SUMMARY OF LEARNERS’ DIFFICULTIES REGARDING KINEMATICS GRAPHS

In conclusion, the following difficulties were revealed with respect to the interpretation of kinematics graphs (Frauenknecht, 1998:197):

- general difficulty with construction of graphs to represent an observed physical situation in the case where data points are not explicitly provided;
- the transformation from a graph to a mathematical description in terms of an algebraic formula or equation is a problem for many learners;
- scaling of axes is not handled successfully, especially by early secondary learners;
- iconic representation where the graph is viewed as a picture of the observed scene;
- a confused understanding of variables and parameters as in the formula \( v = u + at \), which leads to the following problems:
  - confusion between independent and dependent variables; and
  - being unable to bring to the Science class what has been learned about variables in the Mathematics class.

Problems with gradient lead to the following difficulties:

- not understanding slope as a measure of rate of change;
- slope-height confusion when attempting to interpret graphs in terms of real-life situations;
- particular difficulties with the varying gradient of curved graphs;
- not differentiating between a positive and a negative gradient; and
- not always accepting that parallel lines have equal gradients.

Similar problems were addressed in the empirical study reported in this dissertation. The effectiveness of two different experimental methods to remedy such problems regarding kinematics concepts and graphs were compared. The discussion of the empirical study in chapters 5 and 6 are preceded (Chapter 4) by a literature survey of the two experimental methods.
4.1 INTRODUCTION

Ticker-timer and tape experiments have conventionally been used to teach learners kinematics concepts and the related graphs (Horn et al., 1986). As the trolley moves along the rail at either constant velocity or accelerated motion, dots are produced by a ticker-timer at equal time intervals on a tape attached to the trolley. Measurements of distances between dots and calculations of the time duration between dots are recorded in a table. The learners then draw displacement-time and velocity-time graphs.

All these measurements, calculations and drawing of graphs can be done in seconds by a computer. As formulated in section 1.2, the research question of this study is to determine the effectiveness of microcomputer-based experiments in teaching kinematics and whether it should be used in South African schools. A literature study has been conducted on the conventional and microcomputer-based methods of teaching kinematics.

4.2 MICROCOMPUTER-BASED LABORATORY

A microcomputer-based laboratory (MBL) contains a number of microcomputers equipped with a sensing probe for collecting data on physical phenomena in real time, as well as special software for recording and displaying the results (Sokoloff & Thornton, 1990:858). MBL tools have been developed for learners to use to collect physical data that are graphed in real time on a computer screen. The
kinematics concepts through traditional instruction. Their research along with the
development of user friendly microcomputer-based laboratory tools, have
allowed them to extend their computer-supported, active learning laboratory
curricula to dynamics. This enabled them to develop a strategy for more active
learning of these concepts in lectures using Interactive Lecture Demonstrations
(ILDs).

Assessment with the use of FMCE indicated that learners' understanding of
dynamics concepts is significantly improved when these learning strategies
substitute the traditional ones (Sokoloff & Thornton, 1997:346).

Hake (1998) analysed the effect of different methods on diverse student
populations in high schools, colleges and universities. He reported on the
interactive-engagement versus traditional methods in instruction of mechanics.
The results suggest that the classroom use of interactive engagement methods
could increase the results of a mechanics course more than is obtained in the
traditional practice.

In the empirical study reported in this dissertation, the validity of the results of
Sokoloff and Thorton (1998) and Hake (1998) were tested in the South African
context (Chapter 5).

4.3 LITERATURE REVIEW OF THE CONVENTIONAL METHOD

When velocity and acceleration are to be determined accurately in experiments,
it is important to measure small time intervals, distances and displacements
accurately. This is possible with the use of a ticker timer and ticker tape (Hom et
al., 1986).

When considering the motion of an object either at constant velocity or changing
velocity, relationships exist between:
- the displacement and time elapsed;
- the velocity and time elapsed; and
- the acceleration and time elapsed.

Relationships between quantities can be illustrated by means of a graph (Horn et al., 1986:24-25).

The conventional method used in most schools consists of a trolley, which pulls behind it a strip of paper passing through a ticker timer (Hom et al., 1986). To achieve motion with a uniform velocity, one end of the runway needs to be lifted in order to compensate for the friction of the trolley and the resistance of the tape passing through the timer. A steeper incline produces motion with uniform acceleration.

The motion of a body is best described by graphs of its motion. These graphs enable one to see at a glance any changes in the state of motion of a body far more easily than lists of figures and measurements (Hom et al.; 1986:38).

A discussion was held with the learners before the experiments were conducted (Hom et al., 1986). The purpose was to acquaint learners with concepts and information necessary to draw graphs and to help them to execute the experiments. The following information was discussed:

- rectilinear motion is motion in a straight line. That is what we will be dealing with in experiments because the runway that will be used is straight, so the trolley will be moving in a straight line.
- the Greek letter \( \delta \) means difference. Therefore \( \delta = \text{final value} - \text{initial value} \).
- origin is a fixed point relative to which all displacements are measured.
- displacement is a vector that points from an object's initial position to the final position and has a magnitude that is equal to the shortest distance between two positions. The unit for displacement is the metre.
• distance is the actual path taken. It may be equal to or larger than the displacement and its unit is the metres.

• speed is how fast the object is moving and does not reveal direction. Speed = distance/ time. The unit of speed is metre per second.

• velocity is how fast the object moves plus direction.

• velocity also has the unit of metre per second.

When dealing with rectilinear motion, one direction is chosen as positive and the opposite direction as negative. When the trolley moves away from the ticker timer or from the motion detector in the ticker time and motion detector experiments, the direction is chosen as positive. When the trolley moves towards the ticker timer or the motion detector, the direction is chosen as negative.

4.4 COMPARISON OF MBL AND TRADITIONAL METHODS

Thornton and Sokoloff (1990) report that introductory Physics learners' understanding of velocity graphs could be significantly improved by using the MBL curriculum that they have developed. These authors evaluated the effect of their curriculum by using a set of multiple-choice velocity questions. They then demonstrated that learners who were given four hours of group learning (guided discovery and active engagement), MBL proved significantly more successful in choosing the correct graphs than with learners who only received traditional instruction.

Redish et al. (1997) investigated whether computer activities could successfully teach basic Physics concepts to a large group of learners without a large investment in time. They focused on the learning of the concept of instantaneous velocity, which plays an important role throughout introductory Physics. These concepts are known to be difficult for many learners. They targeted those difficulties with one hour of active engagement microcomputer-based laboratory (MBL) activities. The results were compared to those obtained by two other
classes taught by the same professor.

In the first class, three full lecture hours were used to teach the concept of velocity. MBL apparatus was utilised in a demonstration with much student interaction and discussion. In the second class, the tutorial system was in place but the professor reduced the lecture time to a single hour, which was more typical of a traditional lecture with little learner interaction.

In both classes, the questionnaire was given as part of an examination and, contrary to Thornton and Sokoloff (1990), those questions had not previously been given to the learners as homework. Results proved that a larger improvement was gained with four hours of MBL than with one hour of traditional tutorial. These results were consistent with those reported by Thornton and Sokoloff (1990). Therefore, it is concluded that it is not only the extra time that is responsible for the improvement of learners' understanding of the concept of velocity, but that the MBL activities also play a significant role (Redish et al, 1997:46, 49).

4.5 CONTRIBUTING FACTORS

Before discussing the empirical research executed in this study, attention should be paid to other factors that could affect the results apart from the experimental method and teaching strategy. Contributing factors could be the learners, the educator and the language.

The group of learners involved in the research reported in this dissertation is from a very low-income group. Their parents do not check schoolwork and they do not have sufficient school textbooks.
Hewson (1987:159) states that African students in South Africa often find Science particularly difficult. Low pass-rates in the final examinations in Biology and Physical Science is evidence of this difficulty.

Haycock (2001:1,2) reports that in the USA there has been much discussion about the achievement gap that separates low-income and minority youngsters from other young Americans. Significant differences also exist in the rates at which different groups of learners complete high school. In the 18 to 24 year age group, 90% of whites and 94% of Asians have completed their high school studies. Among African Americans, the rate dropped to 81%.

Research shows that what educators do, matters more than all the other factors (Haycock, 2001). Haycock (2001) reports that the effects that educators have on learning are cumulative and exist regardless of race, class or prior achievement levels. Some of the classes showing greatest gains are filled with low-income learners and some with high socio-economic status learners. Small-gain classrooms also consist of the same learner status.

The learners among whom this research was done are English second-language speakers. In a second-language situation the learners may be involved in either an immersion or a submersion programme (Nkopodi, 1998:13).

Swain (1978) describes an immersion programme as a situation where children from the same linguistic and cultural background who have had no prior contact with a school’s language are put together in a classroom setting where the second language is used as a medium of instruction. Immersion programmes carried out in Canada showed that the immersed children performed just as well as the native speakers of the language in which they were immersed (Swain, 1978). The second situation, a submersion programme, is a situation where some children with little or no knowledge of the school language are taught in the same class with children already fluent in the school’s language. The results of
submersion programmes were found to be opposite to the results of immersion programmes. Submerged children had an inferior performance compared to those learners learning in their vernacular (Swain, 1978).

In the South African context it is children from upper to middle class families who are involved in submersion programmes, that is, private schools, while most children from working class families are involved in modified immersion programmes, that is, state schools. These South African children often come from societies that have negative attitudes towards the use of their vernacular as media of instruction (Nkopodi, 1998).

According to Nkopodi (1998), when English is the medium of instruction, a poor level of English competence becomes an additional obstacle to learning.

4.6 CHAPTER SUMMARY

This chapter discussed the advantages of the MBL tools as compared to the traditional method and the factors that should be guarded against when using the MBL tools. The use of the ticker timer and motion detector was described. A comparison was made between the microcomputer method and the traditional method. Different authors stipulated the success of the microcomputer method as opposed to traditional instruction.

Apart from the empirical method and teaching strategy, factors such as the learners' background, language and the educator can affect the results. Learners involved in this research are from low socio-economic status families. An educator has more effect on learning than all other factors. English is a medium of instruction, but the learners involved are second-language speakers. Language could therefore become an obstacle to effective learning.

The next chapter discusses the empirical study conducted to assess and
compare the learning effectiveness of these two methods in teaching kinematics concepts and the related graphs in a South African school.
CHAPTER 5

EMPIRICAL STUDY

5.1 INTRODUCTION

The aim of the empirical study was to compare the learning effectiveness achieved in kinematics concepts and graphs when computer-based technology and conventional apparatus were used in demonstrations. The expected outcomes of the experiment are given in section 5.2. The questionnaires are discussed in section 5.3. Learners' understanding of basic kinematics concepts (displacement and velocity) and kinematics graphs (displacement-time and velocity-time graphs) were addressed. The experimental methods are described in section 5.4.

A group of 48 Grade 11 learners from Thuto-Boswa Secondary School, Ventersdorp in the North-West Province, South Africa, took part in the study. The mother tongue of most of these learners is Setswana, while some of them speak Xhosa and Zulu. English, the medium of instruction, is the second or even third language for all of them. A group of these learners is shown in Photograph 1.

Photograph 1: Some of the learners from Thuto-Boswa Secondary School, Ventersdorp who took part in the study.
The learners were divided into two groups of comparable abilities and size, called Group A and Group B. Group A used the conventional apparatus (Photograph 2) and Group B the microcomputer-based apparatus (Photograph 3). Two afternoons (approximately 8 hours) were used for each one of the experiments. All experiments were presented in the form of demonstrations where learners were actively involved. Demonstrations with constant velocity were done on the first afternoon while accelerated motion was studied on the second afternoon.

Photograph 2: The conventional ticker-timer experiment is demonstrated by the educator to learners of Group A.

Photograph 3: The set-up of the microcomputer-based apparatus, showing the motion detector attached to the computer, which was used with Group B learners.
5.2 EXPECTED OUTCOMES OF THE EXPERIMENTS

In kinematics graphs, learners have to be able to represent a physical concrete motion in an abstract graphical form. For a learner to fully perceive such graphs of motion, the following outcomes (objectives) have to be accomplished:

The learners should be able to:

(1) conceptualise the displacement and velocity of a moving object;
(2) conceptualise zero and negative displacements and velocities;
(3) abstract the change in position and change in velocity of a moving object from its actual movement;
(4) connect a one-dimensional motion to a two-dimensional graphical representation;
(5) derive abstract kinematics concepts and their changes from different kinematics graphs;
(6) apply the knowledge obtained to different motions of an object.

Outcomes (1) to (3) are prerequisites for the higher-level outcomes (4) to (6).

Accomplishment of these outcomes in the two experiments was tested through questionnaires, as discussed in section 5.3 to follow.

5.3 QUESTIONNAIRES

Three questionnaires were compiled and used in the empirical study. The first questionnaire served as pre- and post-test (Appendix C) and was given before and after each experiment was conducted. The composition of this questionnaire is discussed in section 5.3.1. Three months after the experiments were performed, a second questionnaire (Appendix D) was completed by both groups to determine whether the experiments had long-term results (section 5.3.2). A third questionnaire (Appendix E) probed the experience of the learners with computers (see section 5.3.3). This questionnaire was completed by Group B learners after they had performed the microcomputer-based experiment.
5.3.1 Pre- and post-tests

A questionnaire was compiled to probe the learners' knowledge before and after performance of the experiments. The questionnaire is attached as Appendix C. A variety of test items was used, e.g. multiple choice items, definitions and applications. In order to compare the results of this investigation with that of other researchers, question 13 is similar to that asked by Thornton and Sokoloff (1990:862). The other items were typical questions asked in South African examinations for Grade 11 or 12.

The questionnaire probed the achievement of the outcomes stated in section 5.2. Table 5.1 lists the items used to test different aspects of each outcome.

Table 5.1: Aspects of the outcomes tested in the questionnaire.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Aspect tested</th>
<th>Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Definition of kinematics concepts</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Confusion between related concepts</td>
<td>3 &amp; 7 &amp; 8</td>
</tr>
<tr>
<td>2</td>
<td>Frames of reference</td>
<td>4 &amp; 5</td>
</tr>
<tr>
<td></td>
<td>Negative vectors</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>Representation of positions of an object on a straight line</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Drawing a graph</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Readings from position-time graphs</td>
<td>11</td>
</tr>
<tr>
<td>5</td>
<td>Interpretation of position-time and velocity-time graphs</td>
<td>9, 12 &amp; 13</td>
</tr>
<tr>
<td>6</td>
<td>Applications</td>
<td>14</td>
</tr>
</tbody>
</table>

The results of this questionnaire are discussed in section 6.2.

5.3.2 Long-term effect
Three months after the experiments were performed, a second questionnaire (Appendix D) was given to the learners to establish long-term effects of the two experiments. Treagust (1988:16) points out that conceptual change is extremely difficult, as alternative conceptions are often incorporated securely into learners' cognitive structures. It is, however, possible that a teaching strategy could accomplish durable conceptual change.

This second questionnaire consisted of questions from the first questionnaire (pre- and post-test) for which a high d-value (refer to section 6.1.2) was obtained. The results are described in section 6.3.

5.3.3 Computer experience of group B learners

The learners who participated in the study all live in a rural area. The socio-economic status of most of their families is very low. Some do not even have a television set at home. So, affording a computer is impossible for them. Most of them had never previously touched, operated a computer or seen work done on it. To verify these details and determine how they experienced the demonstration with the micro-computer, Group B learners were requested to complete an additional questionnaire. The results are given in section 6.4. This information was used in the interpretation of the results of the pre- and post-tests.

5.4 EXPERIMENTAL METHODS

The empirical study aimed at comparing the effectiveness of two experimental methods to accomplish the outcomes given in section 5.2. The method and apparatus used in these experiments are described in the next section.

5.4.1 The two methods

In both experiments the motion of a trolley on a runway was represented graphically. The trolley first moved with constant velocity and then with constant
acceleration. The experimental methods differed mainly in the way that the results were processed:

- in the conventional method the ticker-timer made dots on a tape attached to the trolley. The learners processed the tape manually by measuring displacements and calculating time durations and velocities. Graphs were then plotted by hand.
- in the microcomputer-based method a motion detector determined the changing position of the trolley at small time intervals. The data was processed by the computer connected to the motion detector. The software package, Vernier, was used. Graphs were displayed on the screen in real time.

In both experiments learners were actively involved:

- in the conventional ticker-timer experiment small groups of five learners each made their own ticker-tapes. The tapes were then processed step by step under the guidance of the educator. Questions were asked throughout the process to ensure understanding.
- the prediction-observe-explain method (White & Gunstone, 1992) was used with the microcomputer-based experiment. For each motion, the learners had to predict the form of the graphs, which were thereafter displayed on the computer. Differences between the predicted and observed graphs were discussed and explained.

The experimental methods are described in more detail in the following sections (5.4.2 and 5.4.3).

5.4.2 Conventional ticker-timer experiment

Three experiments were performed by group A learners with the conventional ticker-timer, namely:

Experiment 1: The period of the ticker-timer
Experiment 2: Constant velocity motion
Experiment 3: Uniform accelerated motion

The worksheets used in these experiments are attached as Appendix A.

In the first experiment the period of the ticker-timer was determined by steadily pulling the paper tape by hand through the timer while measuring the time with a stopwatch. The number of spaces between the dots was counted. The period of the timer was then calculated by using the formula:

\[
\text{Period of timer} = \frac{\text{Time duration}}{\text{Number of spaces}}
\]

The period of the ticker-timer was found to be approximately 0.02 seconds, which corresponds to a frequency of 50 Hz.

In the second experiment, a trolley moved along the runway at constant velocity. The runway was raised at the ticker-timer end to compensate for friction. The trolley was given a gentle push. A part of the tape where the spaces were evenly spaced was processed.

The educator guided the learners in processing the tape. First they had to mark the tape using letter symbols and then they measured the displacements AB, AC, AD, AE, etcetera (Appendix A, Figure 1). Five spaces were left between two consecutive letters. The time that passed during each interval of five spaces was calculated as five times the period. The data was used to plot a displacement versus time graph. The next step was to calculate the average velocity for each interval of five spaces and finally, the velocity versus time graph of the motion was plotted.

The third experiment related to accelerated motion. The runway had to be set in such a way that the trolley could accelerate down the slope. In this case successive dots were not evenly spaced, but the distance between the dots was increased. Five-spaced intervals were marked, displacements were measured...
and average velocities over the intervals were calculated. Graphs of displacement versus time and velocity versus time were drawn. The learners were asked to write down conclusions and answer questions.

5.4.3 Microcomputer-based method

The experimental method described by Sokoloff and Thornton (1997) was used with Group B students. The worksheets used are attached as Appendix B. It consists of two pairs of identical sheets: one used for predictions and the other one for the results. The procedure was as follows:

- the educator described the demonstration and performed it without the microcomputer-based measurements. Learners were requested to make predictions of the forms of the displacement and velocity versus time graphs.
- the learners recorded their predictions on the chalkboard.
- the educator carried out the demonstration with the motion detector. The data and graphs were displayed on the computer in real time.
- the educator then discussed the results with learners in the context of the demonstration and their predictions. Learners completed the worksheet identical to the prediction sheet (Appendix B). They took the sheet home for later reference and study purposes.

A series of short, simple experiments was performed. The sequence started with the most basic demonstrations of learners' movements. This was done to convince learners that the motion detector measures motion in an understandable way (Sokoloff & Thornton, 1997:4). The learners would then 'trust' the apparatus and devices with more advanced motions.

The following demonstrations for constant velocity were done on the first day. In each case displacement versus time and velocity versus time graphs were drawn.
Demonstration 1: A learner stood still, half a metre away from the motion detector.

Demonstration 2: The second learner walked away from the detector with constant velocity.

Demonstration 3: The third learner walked away, turned and then walked towards the detector.

Demonstration 4: The last learner walked away from the detector, stood still for a moment and then walked further away.

Demonstration 5: Demonstrations 1 to 4 were repeated, this time using a runway and trolley.

During the demonstrations learners were asked questions such as what the displacement or velocity is at $t = 0$ s, $t = 4$ s.

During the second day, a runway was raised at one end to obtain an accelerated motion. Displacement versus time and velocity versus time graphs were drawn for each movement. The procedure was similar to that for constant velocity motion. Five different experiments were done, namely:

Demonstration 1: Trolley accelerating away from the detector.

Demonstration 2: Trolley accelerating towards the detector.

Demonstration 3: Trolley decelerating away from a detector.

Demonstration 4: Trolley decelerating towards a detector.

Demonstration 5: Trolley decelerating away, turning and accelerating towards.

The results of the empirical study described in this chapter are given and discussed in the next chapter (Chapter 6).
CHAPTER 6

RESULTS OF THE EMPIRICAL STUDY AND DISCUSSION OF RESULTS

6.1 ANALYSIS OF RESULTS

6.1.1 Introduction

The results of the empirical study are presented and discussed in this chapter. A comparison is made statistically of the learning effectiveness of the two methods in teaching kinematics concepts and graphs. The outcomes reached (section 5.2) and the gains obtained (section 6.1.2) are compared. The effect sizes (section 6.1.2) of differences are also discussed.

6.1.2 Statistical analysis of results

The average normalised gain affords a consistent analysis of pre- or post-test data on conceptual understanding over diverse student populations in high schools, colleges and universities (Hake, 2002:3, 8). It is defined as follows:

\[
\text{Average normalised gain} = \frac{\text{Actual average gain}}{\text{Maximum possible gain}}
\]

The actual learning gain obtained for an item in each of the experiments was calculated by subtracting the pre-test percentage from the post-test percentage. The maximum possible gain is 100% minus the pre-test percentage. The average percentage actual learning gain for the questionnaire is the percentage value of the difference between the averages obtained by the two groups in the pre- and post-tests.

To illustrate the calculations, the average normalised gain for Group A in item 1a (Table 6.1) was determined as follows:

\[
\text{Actual average gain} = 98\% - 85\% = 13\%.
\]
\[
\text{Maximum possible gain} = 100\% - 85\% = 15\%
\]
The average normalised gain is thus \[ \frac{13\%}{15\%} \]

\[ = 0.86 \]

Expressed as a percentage, the average normalised gain is 86%.

This means that for question 1a, Group A, had a gain of 0.86 or 86%.

To determine the effect sizes of the experiments on the results, d-values, were calculated. To obtain a d-value, the difference between the means obtained by the conventional Group A and the experimental or Group B was divided by the largest standard deviation of the two groups. The values of the means and standard deviations were obtained by statistical processing of the data.

For question 1a, the d-value was calculated as

\[
d\text{-value} = \frac{\text{mean of conventional group} - \text{mean of experimental group}}{\text{largest standard deviation}}
\]

\[ = \frac{0.15 - 0.10}{0.4472136} \]

\[ = 0.11 \]

The d-values were interpreted as follows:

\[ 0.2 \leq d < 0.5 \Rightarrow \text{small effect} \]

\[ 0.5 \leq d < 0.8 \Rightarrow \text{medium effect} \]

\[ d \geq 0.8 \Rightarrow \text{large effect} \]

In cases where \( d \geq 0.8 \), the difference is regarded as practically significant. For question 1a, \( d < 0.2 \) so the difference between the effect on learners of the two methods is insignificant.

6.2 RESULTS OF PRE- AND POST- TESTS

6.2.1 Table of results

The learning effectiveness obtained by the two experimental methods was determined by means of the first questionnaire (Appendix C) that served as pre- and post-tests (section 5.3.1).
Table 6.1 shows the results obtained in the pre- and post-tests by the groups that worked with the conventional apparatus (Group A) and the microcomputer-based apparatus (Group B). The gains and d-values (section 6.1.2) were calculated for each item as well as for the averages obtained by the groups in the questionnaires.

### Table 6.1 Results of the pre- and post- tests for Group A (conventional method) and Group B (microcomputer method).

<table>
<thead>
<tr>
<th>Item</th>
<th>Group A</th>
<th>Group B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-test (%)</td>
<td>Post-test (%)</td>
</tr>
<tr>
<td>1a</td>
<td>85</td>
<td>98</td>
</tr>
<tr>
<td>1b</td>
<td>75</td>
<td>80</td>
</tr>
<tr>
<td>1c</td>
<td>35</td>
<td>90</td>
</tr>
<tr>
<td>1d</td>
<td>50</td>
<td>80</td>
</tr>
<tr>
<td>2</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>2M</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>3.1</td>
<td>25</td>
<td>35</td>
</tr>
<tr>
<td>3.2</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>3.3</td>
<td>20</td>
<td>35</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td>6a</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>6b</td>
<td>15</td>
<td>50</td>
</tr>
<tr>
<td>7a</td>
<td>85</td>
<td>80</td>
</tr>
<tr>
<td>7b</td>
<td>30</td>
<td>65</td>
</tr>
<tr>
<td>8a</td>
<td>45</td>
<td>75</td>
</tr>
<tr>
<td>8aM</td>
<td>40</td>
<td>65</td>
</tr>
<tr>
<td>8b</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>8bM</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>9.1</td>
<td>15</td>
<td>40</td>
</tr>
<tr>
<td>9.2</td>
<td>80</td>
<td>90</td>
</tr>
<tr>
<td>9.2M</td>
<td>40</td>
<td>45</td>
</tr>
<tr>
<td>10.1</td>
<td>5</td>
<td>40</td>
</tr>
<tr>
<td>10.2</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>11a</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>11b</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>11c</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>11d</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>12c</td>
<td>45</td>
<td>34</td>
</tr>
<tr>
<td>12d</td>
<td>65</td>
<td>50</td>
</tr>
<tr>
<td>13.1</td>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>13.2</td>
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<td>55</td>
</tr>
<tr>
<td>13.3</td>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td>13.4</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>13.5</td>
<td>50</td>
<td>30</td>
</tr>
<tr>
<td>14</td>
<td>20</td>
<td>50</td>
</tr>
<tr>
<td>Ave.</td>
<td>31.5</td>
<td>45.3</td>
</tr>
</tbody>
</table>
6.2.2. General discussion of results of pre- and post-tests

Table 6.1 shows the results of the first questionnaire on basic kinematics concepts and graphs for the ticker-timer and microcomputer experiments.

On average, the two groups performed similarly (refer to the last row in Table 6.1). In the pre-tests the Group A obtained an average of 31.5% and Group B 30.8%. In the post-tests the average percentage of Group A increased to 45.3% and Group B to 43.8%. Both groups had a gain of approximately 0.2. This value for the gain is in accordance with the gains found in traditional courses presented by experienced lecturers to university students (Hake, 1998).

In another study Redish (1997) reported a gain of 0.2 for traditional methods, while a gain of 0.4 followed from interactive engagement. Microcomputer-based laboratories (MBL) could even yield a gain of 0.6 or larger (Hake, 1998). In this empirical study the learners were interactively involved. Possible reasons for the lower gain were investigated and the results are reported in section 6.4.

Although large gains (even up to 1.0) were obtained in some items (refer to Table 6.1), negative gains (a decrease in performance) were obtained in some other items. A possible reason for the negative gains could be that learners were confused by a huge amount of knowledge in a short period of time. The higher percentages in the pre-test could also have resulted from guesses, while the learners tried to figure out the answers in the post-test but their knowledge and understanding were not well-established.

The two methods therefore seem to be equally effective. However, differences in gains were obtained in individual items. These results are discussed in section 6.2.3. The items were grouped according to the expected outcomes (section 5.2 and 5.3.1). In section 6.2.4 the items for which the effect sizes were medium to large are discussed.

6.2.3 The outcomes reached by the two groups

6.2.3.1 The first outcome

The first outcome of the experiments was to conceptualise the displacement and velocity of a moving object (See section 5.2). Table 6.2.1 shows the items that tested for this
outcome. The group that performed best in each item is given, as well as the d-value that indicates the effect size of the experiment conducted by this particular group relative to the other group.

**Table 6.2.1:** Items that tested for the first outcome

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Aspect</th>
<th>Items</th>
<th>Largest gain</th>
<th>d-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Definition of kinematics concepts</td>
<td>1. Define the following concepts. Illustrate each concept by means of a sketch or example. (a) distance (b) displacement (c) speed (d) velocity</td>
<td>(a) Group B (b) Group B (c) Group A (d) Group A</td>
<td>(a) 0.11 (b) 0.29 (c) 0.50 (d) 0.35</td>
</tr>
<tr>
<td>1</td>
<td>Confusion between related concepts</td>
<td>3. Two cars A and B travel from Ventersdorp to Potchefstroom. Car A leaves before car B. Both cars reach Potchefstroom at the same time. (Answer questions 3.1 to 3.3) 3.1 How do the distances travelled by the two cars compare? 3.2 How do the times car A and car B have travelled compare? 3.3 How do the average speed of the two cars compare?</td>
<td>3.1 Group A 3.2 Group B 3.3 Group A</td>
<td>3.1 0.55 3.2 0.00 3.3 0.10</td>
</tr>
<tr>
<td>1</td>
<td>Confusion between related concepts</td>
<td>7. The following represents a boy walking from home to school along the irregular path indicated. (a) What distance did the boy walk? (b) What is his displacement when he reaches his school?</td>
<td>(a) Group A (b) Group B</td>
<td>(a) 0.25 (b) 0.34</td>
</tr>
<tr>
<td>1</td>
<td>Confusion between related concepts</td>
<td>8. Two cars, car A and car B, travel from Koster to Ventersdorp with equal average speed. The two cars use different routes to Ventersdorp. Car A reach Ventersdorp before car B. (a) Compare the distances travelled by car A and car B. Motivate your answer. (b) Comment about their displacements during the trip. Motivate your answer.</td>
<td>(a) Group A</td>
<td>(a) 0.26</td>
</tr>
<tr>
<td>(b) Group B</td>
<td>(b) 0.22</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Only in items 1 (c), 1 (d) and 3.1 the d-values were larger than 0.3, meaning that small to medium differences occurred in the responses by the two groups to these items. In all three these items Group A outperformed Group B. It can thus be deduced that outcome 1 was best reached through the conventional ticker-timer method. Group A obtained larger gains than Group B in the items where the concepts of speed and velocity were defined, namely in items 1c and 1d.

Learners of both groups obtained very low percentages in item 3. In this item learners had to relate the distance, time and speed of two cars. Problems with answering such questions were pointed out by Frauenknecht (1998) and Trowbridge and McDermott (1980) as discussed in section 2.3. For instance, in item 3.1 learners think that if two moving objects leave a certain place at different times, they automatically travelled different distances. They do not consider the points of departure and arrival. According to the learners in item 3.3, if objects arrive simultaneously at a certain point, it means that they were travelling with the same speed. Trowbridge and McDermott (1980) called this position-speed confusion.

In item 3.1, Group A obtained a positive gain, while the performance Group B decreased in the post-test, resulting in a negative gain. The conventional experiment seemed more effective in resolving the position-speed confusion that was discussed in section 2.3.1. A possible reason is that in the conventional ticker-timer experiment the learners themselves measured distances, calculated speed and plotted the graphs. In item 3.2 both groups
obtained negative gains. The reason may be that the concept of time was not emphasised in the experiments.

Item 7 is an illustration of the definition of the concepts of distance and displacement that were defined in item 1(a) and (b). In the pre-test learners performed similarly in items 1(a) and 7(a), showing that they can apply the definition of distance given in item 1(a) to the situation of item 7(a). Their weak performance in the pre-test in item 7(b) on the concept of displacement in comparison to their ability to define the concept in 1(b), shows their incapability to apply the definition. It can be deduced that they knew the definition of displacement, but did not understand it properly. Both experiments improved their understanding tremendously, with gains of 0.50 and 0.58.

Item 8 again tested for difference in distance and displacement. While item 1 requested definitions and item 7 asked questions regarding a sketch, item 8 gave a word problem similar to item 3. Both groups performed better in the comparison of the distances in item 8(a) than in 3(a), especially in the post-test. Problems with the different times of departure in item 3(a) seem to be reluctant to change.

Very low percentages were obtained by both groups in item 8(b) regarding displacement. This confirms the poor understanding of the concept, as revealed in item 7(b).

6.2.3.2 The second outcome

The performance of the learners in the items on the second outcome is given in Table 6.2.2. The second outcome was on the conceptualisation of zero and negative displacements, velocities and accelerations.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Aspect</th>
<th>Items</th>
<th>Largest gain</th>
<th>d-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Frames of reference</td>
<td>4. Is a passenger sitting in a motor car travelling at 60 km.h⁻¹ moving? Motivate.</td>
<td>Group B</td>
<td>0.30</td>
</tr>
</tbody>
</table>
The two groups performed similarly (d≤0.3) in all these items related to outcome 2. The gains were positive for both groups.

In item 5 learners had to realise that displacement is a vector, measured from an original position (reference point) in a specific direction. Both groups performed poorly in this item in the pre-test (0% and 5% correct responses). The learners revealed problems regarding choosing a reference point to describe displacement. This is in accordance with the findings of Panse (1994), as described in section 2.3.5. However, both groups had a 100% gain in item 5. During both experiments the concept of a frame of reference and the difference between distance and displacement were emphasised.

Problems with negative vectors was pointed out by Goldberg and Anderson (1989) as discussed in section 2.3.6. This was confirmed by the low percentages (between 10% and 20%) that the learners obtained in item 6. Although both groups had a gain of approximately 0.4 in item 6(b), the gain was small (approximately 0.15) for item 6(a).
6.2.3.3 The third outcome

The third outcome was that learners should be able to abstract the change in position and change in velocity of a moving object with time from its actual movement. The performance of learners in the items on the said outcome is given below in Table 6.2.3.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Aspect</th>
<th>Items</th>
<th>Largest gain</th>
<th>d-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.</td>
<td>Representation of positions of an object on a straight line</td>
<td>2. [Diagram: A, B, C, D] A, B, C and D show, at equal time intervals, the position of an object moving away from 0 towards the right. The time from A to B = time from B to C = time from C to D. How is the speed of the object changing from A to D? The object moves (a) slower at D than at A (b) with the same speed at D than at A (c) faster at D than at A (d) I cannot tell.</td>
<td>Group B</td>
<td>0.16</td>
</tr>
</tbody>
</table>

Although a larger gain was obtained by Group B, the effect size is negligible (d=0.16). Both groups of students had already obtained a high mark in the pre-test (75%). Group A maintained this percentage in the post-test, while Group B obtained a gain of 0.4. This result is unexpected, because Group A learners observed the increase in space between successive dots on the ticker-tape as the trolley moved faster. Seemingly, these learners did not make the connection between the observation and the situation in the question.

6.2.3.4 The fourth outcome

The performance of learners in the items given on the fourth outcome is shown below in Table 6.2.4. The outcome was on connecting a one-dimensional motion to a two-dimensional graphical representation.
Table 6.2.4: Performance of the learners in the items on the fourth outcome.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Aspect</th>
<th>Items</th>
<th>Largest gain</th>
<th>d-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Drawing a graph</td>
<td>10. A motorist drives along a straight, level road. His displacement from his starting point is determined every second. The following table is obtained:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Displacement [m]</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Time [s]</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Readings from displacement-time graph</td>
<td>10.1 Use the data from the table to draw a displacement-time graph on the graph paper. Name the axes, choose your own scale and plot the points. 10.2 Again draw a displacement versus time graph for the motion. This time you must use the given scale</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>10.1 Group A</td>
<td>0.09</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>10.2 Group B</td>
<td>0.24</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>11. Answer the following questions using the displacement-time graph of the motion of an object.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>11a. At what point is the object furthest from its original position? .......</td>
<td>11a. Group B</td>
<td>0.31</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11b. Describe its position relative to the origin (place where it started) at point C. ........</td>
<td>11b. Group B</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11c. Describe its position relative to the origin at point E. ......</td>
<td>11c. Group A</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11d. At what point is it standing still? ....</td>
<td>11d. Group B</td>
<td>0.61</td>
</tr>
</tbody>
</table>
It is interesting that although Group A plotted graphs by hand, whilst for Group B the graphs were displayed on the screen, the latter group had a larger gain in item 10. It may be explained by the improved understanding of the meaning of points on a graph found with Group B in item 11. In item 11 Group B performed statistically significantly better than Group A in questions 11b and 11d. Group B also outperformed Group A in 11a with an effect size of $d \geq 0.3$, while the performance of the two groups was comparable only in 11c. The reason for this good performance of the computer group, group B, could possibly be due to the discussions during the performance of the experiments. For instance, when the learner was moving away from the motion detector, the observers were asked what his position was relative to the detector and how it changed.

6.2.3.5 The fifth outcome

The fifth outcome was that learners should be able to abstract kinematics concepts and their changes from different kinematics graphs. The performance of the learners in the items on the outcome are summarised in Table 6.2.5.

In item 9.1 the learners had to compare the speed of two cars whose motions were depicted on a displacement-time graph. They displayed position-speed confusion again, as found in item 3 (section 6.2.3.1) by deducing that the two cars had the same speed at the point where the two graphs met. The question on the initial positions (item 9.2) were well-answered because it is easier to read positions from the displacement-time graph. Although Group A did better with a medium effect of $d \geq 0.3$ than Group B in items 9.1 and 9.2, Group B could give a better motivation in item 9.2. This implies that more of Group B learners that gave the correct answer to item 9.2 could also motivate their answer. Group B learners thus displayed a better understanding of displacement-time graphs.

The gains for item 12 were negative for both groups. This result shows that learners have real problems with gradients, as Frauenknecht (1998) found as discussed in section 3.2.2 in the literature survey. Group B learners performed better with effect size $d \geq 0.3$ in this item. The reason could be that in the conventional experiment no graph with negative gradients could be plotted due to time constraints. For group B learners graphs were displayed in real-time on the computer so a larger variety of motions could be investigated. The consequence thereof is evident in the results of item 13.
Table 6.2.5: Performance of the learners in the items on the fifth outcome.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Aspect</th>
<th>Items</th>
<th>Largest gain</th>
<th>d-value</th>
</tr>
</thead>
</table>
| 5.      | Interpretation of displacement-time and velocity-time graphs | 9.1 Two cars A and B move on a straight road. Use the displacement-time graph below to choose the correct answer to the question. At the instant \( t = 2 \text{ s} \), the speed of car A is
(a) greater than the speed of car B.
(b) less than the speed of car B.
(c) equal to the speed of car B. |
|         |        |       | 9.1 Group A  | 0.42    |
|         |        |       | 9.2 Group A  | 0.34    |
|         |        |       | 9.2(Motivation) Group B | 0.45    |
| 5.      |        | 12.   | 12. Group B  | 0.35    |
|         |        | Group B |              |         |

Did the two cars start at the same place? Motivate your answer.

12. Consider the following graphs and write down the letter or letters (A, B, etc.) of those with a negative gradient

- A
- B
- C
- D
An object can move in either direction along the + distance axis. Choose the correct velocity-time graph for each of the following questions. Which graph shows the object

13.1 moving away from the origin at a steady (constant) velocity? .......... 13.1 Group A 13.1 0.84
13.2 standing still? .......... 13.2 Group B 13.2 0.50
13.3 moving toward the origin at a constant velocity? .......... 13.3 Group A 13.3 0.51
13.4 reversing direction? .......... 13.4 Group B 13.4 0.23
13.5 increasing its speed at a constant rate? ............. 13.5 Group A 13.5 0.32

In the conventional ticker-timer experiment, Group A only dealt with constant velocity motion and constant accelerations (increase in speed). Consequently, they outperformed Group B in items 13.1, 13.3 and 13.5 with large d-values. The situations in items 13.2 and 13.4 (standing still and reversing direction) were demonstrated to Group B learners only, with a consequently better performance.

The results of item 13 showed that learners have more problems with regard to the concept of acceleration than with constant velocity. This was also true with the results of
Trowbridge and McDermott (1980). Reference should be made to section 2.3.3 in the literature study.

Item 13 was also included in the pre- and post-tests of Thornton and Sokoloff (1990: 864). They reported large positive gains with microcomputer-based experiments. Although smaller gains were obtained in the empirical study, on average Group B learners outperformed Group A learners. Possible reasons for the smaller gains obtained in this study are discussed in section 6.4.

6.2.3.6 The sixth outcome

In the sixth outcome the learners were expected to apply the knowledge obtained to different motions of an object. In the last item of the questionnaire (item 14) the motion of a girl on her bicycle was presented in a graph. The learners had to choose one of the given options that best describes how she moved.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Aspect tested</th>
<th>Items</th>
<th>Largest gain</th>
<th>d-value</th>
</tr>
</thead>
</table>

14. The motion of a girl on her bicycle is depicted by the following velocity-time graph:

```
velocity
```

Choose the correct answer:

From the graph follows that the girl
(a) cycles over a hill
(b) moves faster and then slower
(c) moves slower and then faster
(d) reverses direction during the ride.
Although Group A achieved a higher gain, the effect size is small (d=0.2). The situation illustrated in the graph was new to both groups. McDermott et al. (1987) discussed learners' difficulties with connecting graphs with real-life situations (section 3.4.1.2). Some of these difficulties were reflected in the learners' answers to item 14. For instance, the learners who chose option (a) did not separate the shape of the graph from the path of the motion. This is in accordance with the graph-as-picture error described by Clement (1985) and discussed in section 3.4.1.2.

6.2.4 Largest d-values

To determine the effect size of differences in pre- and post-tests for the two groups, the d-values were calculated. The results are recorded in the last column of Table 6.3. For approximately 80% of the items or part of items listed in Table 6.1, the d-values are small (less than 0.5). This implies that the experimental method used (whether conventional or computer-based) had a small to medium effect on the results. Only in item 13.1 did the groups performed statistically significant different (d > 0.8).

The items with largest d-values (d ≥ 0.3) were selected and summarised in Table 6.3. The experiment that yielded the largest gain as well as the d-values are given for each item in Table 6.3.

Table 6.3: The questions in which medium to large (d ≥ 3) effect sizes were obtained by the two groups follow below:

<table>
<thead>
<tr>
<th>Item</th>
<th>Largest gain in</th>
<th>d-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Define the following concepts. Illustrate each concept by means of a sketch or example. (c) speed (d) velocity</td>
<td>Group A</td>
<td>0,50</td>
</tr>
<tr>
<td></td>
<td>Group A</td>
<td>0,35</td>
</tr>
<tr>
<td>3.1 Two cars A and B travel from Ventersdorp to Potchefstroom. Car A leaves before car B. Both cars reach Potchefstroom at the same time. How do the distances travelled by the two cars compare?</td>
<td>Group A</td>
<td>0,55</td>
</tr>
</tbody>
</table>
9.1 Two cars A and B move on a straight road. Use the displacement-time graph below to choose the correct answer to the question.

At the instant \( t = 2 \) s, the speed of car A is

(a) greater than the speed of car B.
(b) less than the speed of car B.
(c) equal to the speed of car B.

11. Answer the following questions using the displacement time graph of the motion of an object.

(a) Where is the object furthest from its original position?
(b) Describe its position relative to the origin (place where it started) at point C.
(c) Where is it standing still?

<table>
<thead>
<tr>
<th>Group A</th>
<th>0.42</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group B</td>
<td>0.31</td>
</tr>
<tr>
<td>Group B</td>
<td>0.50</td>
</tr>
<tr>
<td>Group B</td>
<td>0.61</td>
</tr>
</tbody>
</table>
12. Consider the following graphs and write down the letter or letters (A, B, etc.) of those with a negative gradient.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>D</td>
</tr>
</tbody>
</table>

| Group B | 0.35 |

13. An object can move in either direction along the + distance axis. Choose the correct velocity-time graph for each of the following questions. Which graph shows the object

13.1 moving away from the origin at a steady (constant) velocity

13.2 standing still

13.3 moving towards the origin with a constant velocity

13.4 reversing direction

13.5 increasing its speed at a constant rate

<table>
<thead>
<tr>
<th>Group A</th>
<th>0.84</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group B</td>
<td>0.50</td>
</tr>
<tr>
<td>Group A</td>
<td>0.51</td>
</tr>
<tr>
<td>Group B</td>
<td>0.23</td>
</tr>
<tr>
<td>Group A</td>
<td>0.32</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>D</td>
</tr>
<tr>
<td>E</td>
<td>F</td>
</tr>
<tr>
<td>G</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>v</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>v</td>
<td>t</td>
</tr>
<tr>
<td>v</td>
<td>t</td>
</tr>
<tr>
<td>v</td>
<td>t</td>
</tr>
<tr>
<td>v</td>
<td>t</td>
</tr>
</tbody>
</table>
In the items with $d \geq 0.3$ given in Table 6.3, the one group outperformed the other with medium to large effect. It is interesting to note that Group A performed best in the first two items (items 1 and 3.1) that tested outcome 1. Outcome 1 was concerned with the conceptualisation of the basic kinematic concepts. It thus seems as if the ticker-timer experiment was more successful in establishing these basic concepts. All the other items listed in Table 6.3 deal with the higher-order outcomes 4 or 5. In these items the performance was dominated by the microcomputer-based experiment. It can thus be deduced that the latter experiment more successfully attended to these outcomes. A possible reason is that with the microcomputer experiment a larger variety of movements could be demonstrated and discussed.

6.3 LONG-TERM EFFECT

Treagust (1988) pointed out (refer to section 2.1) that learners' conceptions are difficult to change, correct or modify, as they have been incorporated into the learners' cognitive structures. The long-term effect that the two experimental methods had on the learners was determined by giving them selected questions three months after the experiments. The questions in which the one group outperformed the other (Table 6.3) were selected. The questionnaire is attached as Appendix D.

6.3.1 Table of results

Table 6.4 compares the results obtained in the post-test (in August 2002) with those found three months afterwards (November 2002) in order to determine the long-term effect of the experimental methods.
### Table 6.4: Long-term effect

<table>
<thead>
<tr>
<th>No.</th>
<th>Ticker-timer experiment</th>
<th>Microcomputer experiment</th>
<th>d-values (TT vs MC)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ave % in Aug 02</td>
<td>Ave% in Nov 02</td>
<td>Gain</td>
</tr>
<tr>
<td>1a</td>
<td>88.9</td>
<td>55.6</td>
<td>-38</td>
</tr>
<tr>
<td>1b</td>
<td>77.8</td>
<td>55.6</td>
<td>-29</td>
</tr>
<tr>
<td>2.1</td>
<td>33.3</td>
<td>5.6</td>
<td>-83</td>
</tr>
<tr>
<td>2.2</td>
<td>22.2</td>
<td>50.0</td>
<td>36</td>
</tr>
<tr>
<td>2.3</td>
<td>38.9</td>
<td>33.3</td>
<td>-14</td>
</tr>
<tr>
<td>3.1</td>
<td>33.3</td>
<td>27.8</td>
<td>-17</td>
</tr>
<tr>
<td>3.2</td>
<td>88.9</td>
<td>94.4</td>
<td>50</td>
</tr>
<tr>
<td>4c</td>
<td>33.3</td>
<td>38.9</td>
<td>8</td>
</tr>
<tr>
<td>4d</td>
<td>50.0</td>
<td>72.2</td>
<td>44</td>
</tr>
<tr>
<td>5a</td>
<td>16.7</td>
<td>11.1</td>
<td>-34</td>
</tr>
<tr>
<td>5b</td>
<td>11.1</td>
<td>22.2</td>
<td>13</td>
</tr>
<tr>
<td>5c</td>
<td>11.1</td>
<td>38.9</td>
<td>31</td>
</tr>
<tr>
<td>5d</td>
<td>0.0</td>
<td>55.6</td>
<td>56</td>
</tr>
<tr>
<td>6.1</td>
<td>33.3</td>
<td>5.6</td>
<td>-83</td>
</tr>
<tr>
<td>6.2</td>
<td>55.6</td>
<td>50.0</td>
<td>-10</td>
</tr>
<tr>
<td>6.3</td>
<td>27.8</td>
<td>33.3</td>
<td>8</td>
</tr>
<tr>
<td>6.4</td>
<td>27.8</td>
<td>38.9</td>
<td>15</td>
</tr>
<tr>
<td>6.5</td>
<td>33.3</td>
<td>5.6</td>
<td>-83</td>
</tr>
<tr>
<td>Av</td>
<td>38.0</td>
<td>38.6</td>
<td>1.0</td>
</tr>
</tbody>
</table>

### 6.3.2 Discussion of results

On average (Av), the gain of Group B is approximately twice as large as for Group A. The d-value showed a small to medium effect (d ≥ 0.3). For nine of the items or part of an item listed in Table 6.4, Group A had a negative gain, showing a decrease in performance. This was the case in lesser items (namely seven items) for Group B. It can thus be deduced that the microcomputer experiment seems to have a larger learning effect over the long-term.
In an item for item comparison, no consistency in best performance was found for any one of the experimental methods. In some items where Group B outperformed Group A in the post-test, the opposite effect was recorded after three months.

The negative gains obtained by both groups in items 1a, 1b, 2.1, 2.3 and 5a show that the learners have difficulties with the basic kinematics concepts. This confirms the findings of Frauenknecht (1998) and Trowbridge and McDermott (1980) as discussed in section 2.3. Difficulties to differentiate between related concepts such as speed and velocity remained.

6.4 CONTRIBUTING FACTORS

The results of the pre- and post-tests showed no significant differences in the average gains between the two groups, although differences occurred in individual questions (section 6.2). The average gains were of the order of 0,2. The literature (see section 4.5) reveals that higher gains (even > 0,6) were generally obtained in interactive-engagement methods used to teach kinematics concepts and graphs (e.g. Hake, 1998 and Redish, 1997). Possible factors that could contribute to the lower gains obtained in this empirical study are discussed in this section. As pointed out in section 4.5, possible factors that could affect the results are the background of the learners, the language factor and the experience of the educator. Mention should be made that the learners and the educator who took part in this study were acquainted with the ticker-timer, while the computer was new to all of them.

6.4.1 Learners' acquaintance with computers

The acquaintance of the learners of Group B with computers was determined in the third questionnaire of this study (section 5.3.3). The purpose of the questionnaire was to probe the learners' experience with, and interest in computers. The questionnaire is given as Appendix E.
6.4.1.1 Table of results

Table 6.5 summarises the responses of Group B learners to the questionnaire concerning their acquaintance with computers.

Table 6.5: Responses of Group B learners to the questionnaire

<table>
<thead>
<tr>
<th>Items</th>
<th>% Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Select the one statement that best describes your previous encounters with computers:</td>
<td></td>
</tr>
<tr>
<td>a) I often work on a computer.</td>
<td>a) : 4</td>
</tr>
<tr>
<td>b) I have worked on a computer before, but not many times.</td>
<td>b) : 22</td>
</tr>
<tr>
<td>c) I have never worked on a computer before.</td>
<td>c) : 74</td>
</tr>
<tr>
<td>2. Select one statement:</td>
<td></td>
</tr>
<tr>
<td>a) It was the first time that I saw work done on a computer a few times.</td>
<td>a) : 58</td>
</tr>
<tr>
<td>b) I have seen how work is done on a computer.</td>
<td>b) : 34</td>
</tr>
<tr>
<td>c) I often see work done on a computer.</td>
<td>c) : 8</td>
</tr>
<tr>
<td>3. My interest in computers is</td>
<td></td>
</tr>
<tr>
<td>a) very high</td>
<td>a) : 58</td>
</tr>
<tr>
<td>b) high</td>
<td>b) : 12</td>
</tr>
<tr>
<td>c) medium</td>
<td>c) : 30</td>
</tr>
<tr>
<td>d) low</td>
<td>d) : 0</td>
</tr>
<tr>
<td>e) very low</td>
<td>e) : 0</td>
</tr>
<tr>
<td>4. Which statement best describes how fascinated you were by the computer used during the lesson on graphs of motion?</td>
<td></td>
</tr>
<tr>
<td>a) Very fascinated</td>
<td>a) : 71</td>
</tr>
<tr>
<td>b) Fascinated</td>
<td>b) : 25</td>
</tr>
<tr>
<td>c) Somewhat fascinated.</td>
<td>c) : 4</td>
</tr>
<tr>
<td>d) I was not fascinated by the computer.</td>
<td>d) : 0</td>
</tr>
<tr>
<td>5. In this item you may mark any number of options.</td>
<td>Only a) :8</td>
</tr>
<tr>
<td>During the computer lesson my focus was mainly on the</td>
<td>Only b) :8</td>
</tr>
<tr>
<td>a) computer itself</td>
<td>Only c) :0</td>
</tr>
<tr>
<td>b) graphs displayed on the screen</td>
<td>a) &amp; b) :21</td>
</tr>
<tr>
<td>c) explanation of the educator</td>
<td>a) &amp; c) :0</td>
</tr>
<tr>
<td></td>
<td>b) &amp; c) :50</td>
</tr>
<tr>
<td></td>
<td>a) &amp; b) &amp; c) :13</td>
</tr>
</tbody>
</table>
In response to question 6, learners said that the following was outstanding about the lesson:

- seeing a person's movement on the computer in a form of a graph.
- computers make them like Science.
- they would like to learn more about computers next time.
- they understood the graphs displayed on the computer better than the educator because the computer can visualise.

6.4.1.2 Discussion of results

From the results (Table 6.5), the following can be deduced:

- the majority of learners said that they have never worked on a computer before and that it was the first time that they even saw work done on a computer. However, the majority was very interested and fascinated by the computer.
- only half of the learners (50%) said their focus was on the graphs displayed on the screen and the explanation by the educator during the lesson. The computer distracted 21% of the learners from the explanation of the educator.
- most of them stated that they prefer to be taught by experimentation rather than the telling method.

These results show that learners with little or no experience of computers can be distracted by this new tool with a consequent lowering of learning effectiveness. The students who were used in the studies by Hake (1998) and Redish (1997) most likely were much more acquainted with the use of computers. This factor could certainly contribute to the lower gain obtained in the empirical study reported in this dissertation.
6.4.2 Language factor

Language could be a second contributing factor to the weaker performance of learners as discussed in section 4.5. The learners who were involved in this research were mainly Setswana-speaking. English, which is the second or even third language of these learners, was used in the questionnaire and in the class.

To determine the influence of language and cultural aspects on students' perceptions of kinematics concepts, the learners were firstly requested to define the basic kinematics concepts using their mother tongue, Setswana. Secondly, their understanding of these concepts was probed in interviews.

The learners described the concepts as follows in Setswana (the English translations of the Tswana is given in brackets, where needed):

- speed: lobelo.
- distance: sekgala.
- velocity: lobelo le kopane le tshupo ya selo seo. (Translated: Speed + direction)
- displacement: sekgala se se gaufi kgotse se se khutswane. (Translated: short distance)
- acceleration: koketso ya lobelo. (Translated: increase in speed)
- deceleration: phokotso ya lobelo. (Translated: decrease in speed)
- instantaneous velocity: lobelo lo le khutswane. (Translated: short speed)
- relative velocity: lobelo lo bapisiwa le sengwe. (Translated: speed related to something)

Most of these kinematics concepts cannot be translated into Setswana with a single term. The concepts have to be described. Disadvantages are that the scientific meaning could be lost in a description (e.g. the words "rate of" is omitted in the description of acceleration), and the description may be wrong (e.g. in case of the concept displacement as given above).

Secondly, interviews were conducted with the learners to check for language and cultural aspects that could influence their perceptions of distance, speed and acceleration. Alternative perceptions identified in the interviews are discussed below:
The concept of speed
Examples of learners' alternative ideas are:

- if asked which one of a dog and human being is faster, learners responded by saying it is a dog, as it is four-legged and a human being is only two-legged.
- learners say that using a bicycle from school to home is faster than walking because a bicycle is faster than human feet.

The concept of speed is thus not formalised as a measurable entity independent of circumstances, such as the number of legs, or the means of travel.

The concept of distance
As for distance from home to school by feet compared to a bicycle, 5 learners out of 24 responded that the distance is shorter with the bicycle. This is consistent with findings of Lemmer (1999), who explained such alternative non-formal perceptions of distance and speed in terms of an organistic world view. This idea is due to a space perception that differs from the formal measurable space of the scientist (Lemmer, 1999). The idea that the distance between home and school depend on the means of travel, could explain their problems with items such as 3, 7 and 8 in the pre- and post-test (Appendix C) as discussed in section 6.2.3.1.

The concept of acceleration
According to the learners, a bicycle accelerates more than feet. To the term "accelerate", they connected the meaning of "going faster". This results from the terminology that they use for acceleration given above.

Comparisons
Learners were also asked to explain what happens when a car overtakes a lorry. Instead of referring to the difference in speed, they said that it is possible because a car is smaller or has light weight and a lorry is heavier and has a heavy weight. The lorry with the bigger mass always moves slower. The comparison of the speed of two cars called A and B and with no reference to their mass or type (as in item 9.1 – section 6.2.3.5) may not make sense to these students.

These ideas obtained from the learners are supportive of Nkopodi (1998) described in section 4.5, showing the effect of language and cultural aspects on learners' conceptions.
The everyday usage of the concepts of distance, speed and acceleration thus differed from the scientific meanings. The learners have not yet adopted the mechanistic world view of the scientist (Lemmer, 1999 & 2003). It can consequently be expected that these learners will find the kinematics concepts and graphs more difficult than learners who were raised with a mechanistic world view. The language and cultural factors could definitely contribute to difference in results with Western learners.

6.4.3 Experience of the educator

The educator who performed both the experiments was experienced in executing experiments with the ticker timer. It was the first time that she used the computer method. This could also contribute to the results of the computer method yielding the same average gain as the conventional method. It can be expected that with experience of the teacher, the computer method could yield better results than the ticker-timer method, as was found with experienced lecturers in the study of Redish (1997).

From the results described in section 6.4, it is evident that all three the factors mentioned could contribute to the gains obtained in the pre- and post-tests.

The results of the empirical study are summarised in Chapter 7. Recommendations are made in connection to the teaching of kinematics concepts and graphs in South African secondary schools.
CHAPTER 7
CONCLUSIONS AND RECOMMENDATIONS

7.1 OVERVIEW

Kinematics concepts and graphs present problems to learners at school and introductory university level (Clement, 1982; Halloun & Hestenes, 1985; McDermott et al., 1987 and Whitaker, 1983). An important source of these problems is alternative conceptions or common sense ideas about motion. These problems and causes were discussed in the literature survey of chapters 2 and 3.

The empirical study confirmed that South African learners too experience conceptual problems in kinematics. The average of the pre-test obtained by all learners taking part in the study was 31.1% (refer to Table 6.1). After each group of learners had been taught for two successive afternoons (approximately 6 hours), the average percentage increased to 44.6%. The averages obtained by the two groups utilising the two different teaching methods were similar with $d = 0.07$. A detailed discussion of the results of the pre- and post-test is given in section 6.2 and summarised in section 7.2.

Both experimental methods entailed interactive engagement, which proved to give better results than traditional teacher-centered strategies (Hake, 1998; Redish, 1997). The small gain (approximately 0.2) obtained in the empirical study, however, shows the reluctance of change of alternative conceptions and ideas. This reluctance was confirmed by the additional questionnaire answered by the learners three months after the experiments had been done (section 6.3 and 7.3). As the learners in the two groups were not English first-language speakers, language and cultural factors also influenced the outcomes as indicated in section 6.4.2.

The gains obtained in the empirical study (especially for the microcomputer-based experiment) were smaller than found in similar research (e.g. Hake, 1998). Three possible reasons that could contribute to these discrepancies were investigated and are discussed in section 6.4 and summarised in section 7.4.
Conclusions of the empirical study and recommendations for the teaching of kinematics concepts and graphs at Grade 11 level are made in sections 7.5 and 7.6.

7.2 COMPARISON OF EFFECTIVENESS OF THE EXPERIMENTAL METHODS

On average the same learning gain of approximately 0,2 was obtained for both methods. The learning effectiveness of both methods seems to be equally effective. However, the learners performed differently in individual items that were aimed at different outcomes. In general, the ticker-timer method proved to be more effective in teaching the more basic outcomes, while the microcomputer method resulted in enhanced insight in graphs.

7.3 LONG-TERM EFFECT

Group B learners, those exposed to the microcomputer method, displayed a bigger gain over three months than Group A learners, although the better result is not statistically significant (d = 0.38). The indication is thus that the microcomputer method seems to have a more enduring effect on learning kinematics concepts and graphs. However, both groups still experienced difficulties, such as differentiating between related kinematics concepts. Negative gains were also obtained, showing a reduction in knowledge. This confirms research results (e.g. Treagust, 1988) that learners' alternative conceptions are difficult to change, correct or modify, as they are deeply incorporated into their cognitive structures.

7.4 FACTORS THAT COULD INFLUENCE THE RESULTS

Other researchers like Thomton and Sokoloff (1998), who also used a microcomputer in demonstrations, found a gain of almost 0,5 from Interactive Lecture Demonstrations (ILD). They also found a gain of up to 0,5 when using the MBL tools, Thomton and Sokoloff (1990). These gains are much bigger than the gain of 0,2 obtained in the empirical study reported in this dissertation.

Factors that could influence the results of the empirical study were identified, namely:

- learners' acquaintance with the microcomputer.
- educator's experience with the apparatus.
- learners' cultural background and language.
The first two factors favour the conventional method because the learners and the educator were familiar with the ticker timer. As for the computer, the educator was somewhat familiar with it, but the learners were totally computer illiterate. According to Rowand (2000) reporting on the study conducted in the USA, educators who were asked to focus on the uses of computers in the classroom, reported 23% of public school educators feeling well prepared and 10% very well prepared to use computers in their teaching. According to Rowand (2000) educators with less years of teaching experience felt more prepared to use computers than educators with more years of teaching experience. Incorporation of computers in teaching must thus take the preparedness of educators seriously into account in South Africa.

The results of the empirical study that the same gain was obtained with both methods notwithstanding these factors show the potential of the computer method. It could be expected that the computer method would become more effective with increase in experience of the learners and the educator.

The learners' cultural background and language increased their difficulties with kinematics concepts, which will be carried over to problems regarding the interpretation of kinematics graphs.

7.5 CONCLUSION

In the environment of the empirical study, both the conventional and microcomputer-based methods yielded similar learning effectiveness, although the ticker-timer experiment seemed more effective in teaching basic kinematics concepts, while the microcomputer was more effectively in applications on kinematics graphs. The microcomputer-based method has the potential to develop into a more effective teaching aid with improved computer literacy (and language) of both teachers and learners.

7.6 RECOMMENDATIONS

The results obtained in this study indicate that both methods can be used in the teaching of kinematics. The conventional ticker-timer method should be used first to establish basic
concepts and thereafter the microcomputer method for more advanced application and insight.

Success with microcomputer-based demonstrations is not guaranteed. The educator should be well trained and make use of interactive engagement strategies. Attention should be paid to it in teacher training programmes, especially as computers become more available in our schools.

Apart from improving learning, exposure to the use of computers is the first step in making the learners themselves computer literate. The ideal is a science laboratory where every learner performs microcomputer-based experiments him/herself as is done abroad. In the USA, according to Smerdon et al. (2000), 84% of the public school educators had computers available in their classrooms in 2000. They assigned learners to use it for Internet research, practising drills and solving problems.

Computers, apparatus connected to computers (such as the motion detector) and accompanying software, are expensive and have to be maintained and upgraded from time to time. Therefore, before any huge expenses are made, educators should be computer literate and trained to use the apparatus effectively so that they could also train the learners. Only then could the computer become one of the most effective teaching and learning tools in Science education.


FRAUENKNECHT, R. 1998. Secondary and early tertiary students' understanding of
graphs of motion. Stellenbosch: University of Stellenbosch. (Thesis – D. Phil.)


REDISH, E.F., SAUL, J.M. & STEINBERG, R.N. 1997. The effectiveness of active-


APPENDIX A:

WORKSHEETS: TICKER-TIMER EXPERIMENTS

Experiment 1: The period of the ticker-timer

AIM: To determine the period of the ticker-timer

APPARATUS: Ticker-timer, ticker-tape, stopwatch.

METHOD:
1. Thread a long piece of paper tape through the ticker-timer.
2. Switch on the ticker-timer and then pull the paper tape steadily through the timer from the moment the stopwatch is activated.
3. Pull the tape for about 4 seconds. Stop the ticker-timer and stopwatch simultaneously.
4. Count the number of spaces between successive dots. Record the time on the stopwatch.
5. Calculate the period of the ticker-timer by using the equation:

\[
\text{Period of timer} = \frac{\text{Time duration}}{\text{Number of spaces}}
\]

RESULTS:

Number of spaces between the dots = ..............

Time taken to make this number of spaces = ..............

\[
\text{Period of timer} =
\]

CONCLUSION:

The period of the ticker-timer is .............. s.

This means that the distance (space or interval) between two successive or consecutive dots will always be covered in a time of ........... s.
Experiment 2: Constant velocity motion with the ticker-timer

AIM: To investigate displacement versus time and velocity versus time relationships of constant velocity motion.

APPARATUS: Ticker-timer, trolley, runway, leads, cell holder with cells

SKETCH OF APPARATUS:

METHOD:
1. Assemble the ticker-timer on the runway.
2. Place a trolley on the runway and compensate for friction by raising the runway slightly at the ticker-timer end until a point is found where the trolley, if pushed, will move down at constant speed.
3. Feed one end of the ticker-tape through the ticker-timer and attach it on the trolley with prestick.
4. Start the ticker-timer and give the trolley a gentle push.
5. Remove the tape and analyze it as follows:
   5.1 Choose a piece of the tape where the dots are evenly spread (trolley moved at constant velocity)
   5.2 Mark the first dot A. Mark every sixth dot as B, C, D, E, etc.
   5.3 Measure displacements AB, AC, AD, AE, etc. as indicated in Figure 1 (next page).
   5.4 Calculate the time interval that is represented by each group of five small time intervals, i.e. the time that passes between marks A and B, between B and C, etc. Complete the first two columns of Table 1.
   5.5 Plot a displacement vs. time graph.
   5.6 For each interval (AB, BC, CD, etc.) calculate the change in time, change in displacement and average velocity (Refer to Figure 2). Record the results in the last three columns of Table 1.
   5.7 Use the data to draw the velocity vs. time graph for the motion of the trolley.
6. Answer the questions.
**Figure 1:** Displacements from first dot A

![Diagram of displacement from A to E with points B, C, D, and E]

- \( s_A = 0 \)
- \( s_B \)
- \( s_C \)
- \( s_D \)
- \( s_E \)

**Figure 2:** Change in displacement and velocity

![Diagram showing \( \Delta s_{AB}, \Delta s_{BC}, \Delta s_{CD}, \Delta s_{DE} \)]

<table>
<thead>
<tr>
<th>Change in displacement</th>
<th>Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta s_{AB} = s_B - s_A )</td>
<td>( v_{AB} = \frac{\Delta s_{AB}}{\Delta t_{AB}} )</td>
</tr>
<tr>
<td>( \Delta s_{BC} = s_C - s_B )</td>
<td>( v_{BC} = \frac{\Delta s_{BC}}{\Delta t_{BC}} )</td>
</tr>
<tr>
<td>( \Delta s_{CD} = s_D - s_C )</td>
<td>( v_{CD} = \frac{\Delta s_{CD}}{\Delta t_{CD}} )</td>
</tr>
<tr>
<td>( \Delta s_{DE} = s_E - s_D )</td>
<td>( v_{DE} = \frac{\Delta s_{DE}}{\Delta t_{DE}} )</td>
</tr>
</tbody>
</table>

**RESULTS:**

- Frequency of ticker timer:
- Period of ticker timer:
- Time for 5-space interval:
Table 1: Readings for constant velocity motion

<table>
<thead>
<tr>
<th>Time interval $Δt$ [s]</th>
<th>Change in displ. $Δs$ [cm]</th>
<th>Velocity $v$ [cm/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

GRAPHS:
Use the graph paper provided on draw the displacement vs. time and velocity vs. time graphs for the motion of the trolley.

QUESTIONS:
1. What is the form of the displacement versus time graph?
   
   Explain the form of this graph.

2. What is the form of the velocity versus time graph?
   
   Explain the form of this graph.
Experiment 3: Uniform acceleration with the ticker-timer

AIM: To investigate the displacement-time and velocity-time relationships for a trolley uniformly accelerated in a straight line.

APPARATUS: Runway, trolley, block of wood, ticker-timer, ticker-tape, leads, cell holder with cells.

SKETCH OF APPARATUS:

METHOD:
1. Set up the apparatus that were used in experiment 1, but raise the end of the runway so that the trolley accelerates down the slope in approximately 2 seconds.
2. Switch the timer on and allow the trolley to move down the slope while pulling the paper tape through the timer.
3. The figure shows what the tape looks like. It can be seen that successive dots are not evenly spread. The velocity of the trolley is clearly changing.

   ![Dot Pattern]

4. Starting from a point where the dots are clearly separated, mark the tape into five-space intervals.
5. Complete the necessary measurements and record them in Table 2.
6. Use the data in the table to do the following:
   (a) Draw a graph of total displacement (s) versus time (t).
   (b) Draw a graph of velocity (v) versus time (t) on another system of axes.
   (c) Draw a tangent to the graph in (b) and find the gradient.
7. Answer the questions.

RESULTS:

Table 2:

<table>
<thead>
<tr>
<th>Total time (t in seconds) for each five-space interval</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total displacement (s in metres) from the first dot</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Displacement (Δs metres) in each interval</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time (Δt seconds) for each interval</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average velocity (v = Δs/Δt in metres per second) for each interval</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increase in velocity (Δv metres per second) for each successive interval</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average acceleration (a = Δv/Δt in metres per second square)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
DISCUSSION OF RESULTS:

Use the table to answer the following questions:

1. Were the displacements for each section approximately constant? ........
2. Was there an approximately constant increase in the average velocity? ........
3. What can be deduced from your answers in 1. and 2?

GRAPHS:

Draw the displacement versus time graph and velocity versus time graph for uniform accelerated motion on the provided graph paper.

QUESTIONS:

Use the graphs to answer the following questions:

1. Is the displacement directly proportional to time? ........
2. What does the gradient of the displacement-time graph represent? ..................
3. Does the velocity-time graph pass through the origin? .................
4. What does the gradient of the velocity-time graph represent? ................
APPENDIX B

WORK SHEETS: MICROCOMPUTER-BASED EXPERIMENTS

PREDICTION SHEET: Constant velocity motion

Demonstration 1:
(a) Sketch below on the left axes your prediction of the distance-time graph for a learner that is standing still half a metre away from the motion detector.
(b) Sketch below on the right axes your prediction of the velocity-time graph for a learner that is standing still half a metre away from the motion detector.

Demonstration 2:
(a) Sketch below on the left axes your prediction of the distance-time graph for a learner walking away from the origin (motion detector) at a constant velocity.
(b) Sketch below on the right axes your prediction of the velocity-time graph for a learner walking away from the origin (motion detector) at a constant velocity.

Demonstration 3:
(a) Sketch below on the left axes your prediction of the distance-time graph for a learner walking towards the origin (motion detector) at a constant velocity.
(b) Sketch below on the right axes your prediction of the velocity-time graph for a learner moving towards the origin (motion detector) at a constant velocity.
Demonstration 4:
(a) Sketch on the left axes below your predictions for the distance-time graph for a learner walking away from the detector, standing and then walked further away.
(b) Sketch on the right axes below your predictions for the velocity-time graphs of a learner walking away from the motion detector, standing and then walking further away.

Demonstration 5:
(a) Sketch below on the left axes your prediction of the distance-time graph for a learner walking away from the origin (motion detector) at a constant velocity, turning and then walking towards the motion detector.
(b) Sketch below on the right axes your prediction of the velocity-time graph for a learner moving away from the origin (motion detector) at a constant velocity, turning and then moving towards the motion detector.

Demonstration 6:
Instead of a walking learner, the motion of a trolley running down a ramp will be graphed. Sketch on the given axes your prediction of the distance-time and velocity-time graphs of the indicated motions.

Demonstration 6.1:
A trolley is standing still half a metre away from the motion detector.
Demonstration 6.2:
A trolley is moving away from the origin (motion detector) at a constant velocity.

Demonstration 6.3:
A trolley is moving towards the origin (motion detector) at a constant velocity.

Demonstration 6.4:
A trolley moves away from the origin, stops, and moves back towards the origin.
PREDICTION SHEET: Accelerated motion

Sketch on the given axes your prediction of the distance-time and velocity-time graphs of the indicated motions.

**Demonstration 1:**
A trolley is accelerating away from the detector.

**Demonstration 2:**
A trolley is accelerating towards the detector.

**Demonstration 3:**
A trolley is decelerating away from the detector.

**Demonstration 4:**
A trolley is decelerating towards the detector.

**Demonstration 5:**
A trolley is decelerating away, turning and accelerating towards.
APPENDIX C

QUESTIONNAIRE: Basic kinematic concepts and graphs

NAME: ........................................................................................................................

GRADE: .................. GROUP: ............. DATE: ....................

1. Define the following concepts. Illustrate each concept by means of a sketch or example.

(a) distance

(b) displacement

(c) speed

(d) velocity
2. A, B, C and D show, at equal time intervals, the position of an object moving away from O towards the right. The time from A to B = time from B to C = time from C to D. How is the speed of the object changing from A to D? The object moves

(a) slower at D than at A
(b) with the same speed at D than at A
(c) faster at D than at A
(d) I cannot tell.

Motivate your answer:

3. Two cars A and B travel from Ventersdorp to Potchefstroom. Car A leaves before car B. Both cars reach Potchefstroom at the same time. (Answer questions 3.1 to 3.3)

3.1 How do the distances traveled by the two cars compare?

3.2 How do the times car A and car B have traveled compare?

3.3 How do the average speeds of the two cars compare?

4. Is a passenger sitting in a motorcar travelling at 60 km.h⁻¹ moving? Motivate.
5. Consider the following figure representing the position of 4 cars A, B, C and D.

![Diagram showing the positions of cars A, B, C, and D.]

A learner states that the displacement of car D is 100 m. Comment on this statement.

6. Vector \( \vec{A} = 5\text{km, north} \)

   (a) What is vector \(-\vec{A}\)?

   (b) Illustrate vector \( \vec{A} \) and vector \(-\vec{A}\) by means of a sketches.

7. The following represents a boy walking from home to school along the irregular path indicated.

![Diagram of a boy's irregular path from home to school.]

(a) What distance did the boy walk?

(b) What is his displacement when he reaches his school?
8. Two cars, car A and car B travel from Koster to Ventersdorp with equal average speed. The two cars used different routes to Ventersdorp. Car A reached Ventersdorp before car B.

(a) Compare the distances traveled by car A and car B.

Motivate your answer: ....................................................

.................................................................

.................................................................

.................................................................

.................................................................

(b) Comment about their displacements during the trips.

Motivate your answer: ....................................................

.................................................................

.................................................................

.................................................................

.................................................................

9.1 Two cars A and B move on a straight road. Use the displacement-time graph below to choose the correct answer to the question.

At the instant $t = 2 \text{ s}$, the speed of car A is
(a) greater than the speed of car B.
(b) less than the speed of car B.
(c) equal to the speed of car B.

9.2 Did the two cars start at the same place? ...........................................................

Motivate your answer: ...........................................................
10. A motorist drives along a straight, level road. His displacement from his starting point is determined every second. The following table is obtained:

<table>
<thead>
<tr>
<th>Displacement [m]</th>
<th>0</th>
<th>4</th>
<th>12</th>
<th>25</th>
<th>38</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time [s]</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

10.1 Use the data from the table to draw a displacement-time graph on the graph paper. Name the axes, choose your own scale and plot the points.

10.2 Again draw a displacement versus time graph for the motion. This time you must use the given scale.
11. Answer the following questions using the displacement time graph of the motion of an object.

(a) Where is the object furthest from its original position? .................
(b) Describe its position relative to the origin (place where it started) at point C.
.............................................................................................................
(c) Describe its position relative to the origin at point E .................
.............................................................................................................
(d) Where is it standing still? ......................................................

12. Consider the following graphs and write down the letter or letters (A, B, etc.) of those with a negative gradient ............................

A

B

C

D
13. An object can move in either direction along the + distance axis. Choose the correct velocity - time graph for each of the following questions. Which graph shows the object

13.1 moving away from the origin at a steady (constant) velocity? ...........
13.2 standing still? ............
13.3 moving toward the origin at a constant velocity? ............
13.4 reversing direction? ............
13.5 increasing its speed at a constant rate? .............
14. The motion of a girl on her bicycle is depicted by the following velocity-time graph:

Choose the correct answer:
From the graph follows that the girl
(a) rides over a hill
(b) moves faster and then slower
(c) moves slower and then faster
(d) reverses direction during the ride
QUESTIONNAIRE: Long-term effect

NAME: ....................................................................................................................
GRADE: ............... GROUP: .............. DATE: ..............................

1. Define the following concepts. Illustrate each concept by means of a sketch or example.
   (a) speed
   (b) velocity

2. Two cars A and B travel from Ventersdorp to Potchefstroom. Car A leaves before car B. Both cars reach Potchefstroom at the same time. (Answer questions 2.1 to 2.3)
   2.1 How do the distances traveled by the two cars compare?

   2.2 How do the times car A and car B have traveled compare?

   2.3 How do the average speeds of the two cars compare?
3.1 Two cars A and B move on a straight road. Use the displacement-time graph below to choose the correct answer to the question.

At the instant \( t = 2 \text{ s} \), the speed of car A is
(a) greater than the speed of car B.
(b) less than the speed of car B.
(c) equal to the speed of car B.

3.2 Did the two cars start at the same place? ......................................
Motivate your answer: ........................................................................

4. Consider the following graphs and write down the letter or letters (A, B, etc.) of those with a negative gradient ..........................
5. Answer the following questions using the displacement time graph of the motion of an object.

(a) Where is the object furthest from its original position? .................

(b) Describe its position relative to the origin (place where it started) at point C. .................................................................

(c) Describe its position relative to the origin at point E .......................
........................................................................................................

(d) Where is it standing still? ..........................................................
6. An object can move in either direction along the + distance axis. Choose the correct velocity-time graph for each of the following questions. Which graph shows the object

6.1 moving away from the origin at a steady (constant) velocity? .......... 
6.2 standing still? .......... 
6.3 moving toward the origin at a constant velocity? .......... 
6.4 reversing direction? .......... 
6.5 increasing its speed at a constant rate?  .................
APPENDIX E

NAME: ..............................................................................................................................
GRADE: ............... GROUP: ............ DATE: ............... 

1. Select the one statement that best describes your previous encounters with computers:
   (a) I often work on a computer myself.
   (b) I have worked on a computer before, but not many times.
   (c) I have never worked on a computer before.

2. Select one statement:
   (a) It was the first time that I saw work done on a computer.
   (b) I have seen a few times how work is done on a computer.
   (c) I often see work done on a computer.

3. My interest in computers is
   (a) very high
   (b) high
   (c) medium
   (d) low
   (e) very low

4. Which statement best describes how fascinated you were by the computer used during the lesson on graphs of motion?
   (a) Very fascinated
   (b) Fascinated
   (c) Somewhat fascinated.
   (d) I was not fascinated by the computer.

5. In this item you may mark any number of options. During the computer lesson my focus was mainly on the
   (a) computer itself
   (b) graphs displayed on the screen
   (c) explanation of the teacher

6. If you think back about the computer lesson, what was outstanding about the lesson? Describe in a sentence or two.

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Thank you very much for your contribution!