Use of the TRAC PAC as a microcomputer-based laboratory (MBL) tool for addressing misconceptions in kinematics and kinematic graphs held by secondary school learners.

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DECLARATION

I, the undersigned, hereby declare that the work contained in this dissertation is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

W.J. Green
November 2004

Summary

This study investigated the impact that use of a microcomputer-based laboratory (MBL), in this case the TRAC PAC and associated software, had on student understanding in relation to common 'alternative learner ideas' and difficulties related to kinematics and kinematic graphs.

It was carried out in the South African context, and focussed on subject matter that learners are expected to work with in preparation for the Senior Certificate South African examination. Twenty Grade 12 learners from four different schools participated in the study.

Three key questions were investigated:

1. What conceptual difficulties do learners in this context experience in relation to kinematics and kinematic graphs?
2. Does use of the TRAC PAC as a microcomputer-based laboratory contribute to learner understanding of graphs of motion and related concepts?
3. If learning is enhanced using the TRAC PAC, what are some of the 'ways of learning' evident as learners participated in the MBL programme?

To answer these questions, the study employed both an empirical quantitative dimension and an ethnographic qualitative dimension.

The empirical study involved the use of pre- and post-questionnaires which were administered before and after learners participated in a TRAC PAC-based learning programme comprising of six 3-hour learning activities conducted over three days. Overall learner performance on the questionnaires, as well as responses to individual questions, were analysed statistically, as well as through use of an 'item and matrix' analysis technique described by Svec (1999). Chapter 8 of this document reports on this component of the study.

The ethnographic component of the study made use of observational data, and transcripts of video and audio recordings of learners as they participated in the learning activities. The data gathered using these techniques was analysed largely through use of a 'verbal analysis' technique described by Chi (1997). Chapter 9 of this document reports on this component of the study.

In relation to Research Question 1, the main findings of the study were:

- A literature review highlighted common 'alternative learner ideas' identified by other researchers, and these allowed me to group them into four main areas. These are described in Chapter 4 of this report.
- The analysis of the questionnaires highlighted 'alternative learner ideas' that the group of learners who participated in this project held. These are described in Chapter 8 of this report.
- The analysis of the video and audio transcripts also allowed for the identification of 'alternative learner ideas' held by this group of learners. These are described in Chapter 9 of this report.

There was a high degree of commonality between the 'alternative learner ideas' identified through use of these three different sources.

Research Question 2 was answered mainly through the empirical study described in Chapter 8 of this report. It was found that the MBL experience generally resulted in an improvement in learner understanding in this area of kinematics and kinematic graphs. More detailed statistical and 'item and matrix' analyses showed that the impact on learner understanding was better in certain areas than in others.

The ethnographic study described in Chapter 9 contributed to answering Research Question 3. Key findings in relation to this question included:

- The degree of learner involvement in learning activities seemed to impact on the effectiveness of the programme. Possible factors impacting on involvement were identified.
- 'Alternative learner ideas' were made visible in the context of 'argumentation episodes' and 'discussion and explanation episodes'. Consequently, these formed the contexts in which shifts in understanding were most likely to take place. Key learner behaviours and skills necessary for participation in these episodes are identified, and linked to success and non-success on the programme.

Recommendations arising from findings in the study are described in Chapters 8, 9 and 10 of this report.

Opsomming

Hierdie ondersoek bestudeer die uitwerking wat 'n mikro-rekenaar gebaseerde laboratorium, in hierdie geval die TRAC PAC en die gepaardgaande sagteware, op studente se begrip van kinematika en kinematikagrafieke het.

Die ondersoek is in 'n Suid-Afrikaanse konteks uitgevoer en is toegespits op die vakmateriaal wat leerders behoort te beheers ter voorbereiding vir die Suid-Afrikaanse Senior Sertifikaat. Twintig Graad 12's van vier verskillende skole het aan die ondersoek deelgeneem.

Drie sleutelvrae is ondersoek:

1. Watter begripsprobleme ondervind leerders in hierdie verband met betrekking tot kinematika en kinematikagrafieke?
2. Dra die gebruik van die TRAC PAC as 'n mikro-rekenaar gebaseerde laboratorium by tot die leerder se begrip van kinematikagrafieke en verwante begrippe?
3. Indien "leer" deur die gebruik van die TRAC PAC bevorder word, watter "vorme van leer" is waarneembaar as leerders deelneem aan die MBL-program?

Beide 'n empiries-kwantitatiewe dimensie en 'n etnografiese kwalitatiewe dimensie is in die navorsing gebruik.

Die empiriese ondersoek maak van beide 'n voortoets en 'n na-toets gebruik. Hierdie vrae is aan die leerders voorsien voordat asook nadat hulle aan die TRAC PAC gebaseerde leerprogram deelgeneem het. Die leerprogram het bestaan uit ses leeraktiwiteite, elk drie uur lank, wat oor 'n tydperk van drie dae gedoen is. Die leerders se prestasie/uitslae met betrekking tot die vrae asook hul reaksie op individuele vrae is statisties ontleed, asook met behulp

van die 'item en matriks' analitiese tegniek soos deur Svec (1999) beskryf. Hoofstuk 8 van hierdie verslag verwys na hierdie deel van die ondersoek.

Die etnografiese komponent van die die ondersoek maak gebruik van waarnemingsdata en transkripsies van band- en video-opnames van leerders verkry tydens hul deelname aan die leeraktiwiteite. Die data so verkry, is hoofsaaklik geanaliseer deur van die 'n verbale analise-tegniek gebruik te maak soos deur Chi (1999) voorgestel. Hoofstuk 9 van hierdie dokument doen verslag oor hierdie komponent van die ondersoek.

Wat Navorsingsvraag 1 betref, is die hoofbevindings van die studie die volgende:

- 'n literatuur-oorsig beklemtoon die algemene alternatiewe leerderopvattings wat deur ander navorsers geidentifiseer is. Dit het my in staat gestel om hulle in 4 hoofareas te groepeer wat ek in hoofstuk 4 van die verslag bespreek.
- Die analise van die vraelyste beklemtoon die alternatiewe leerderopvattings van die groep leerders wat aan hierdie projek deelgeneem het. Dit word in hoofstuk 8 van hierdie verslag bespreek.
- Die analise van die band- en video-opnames het ook bygedra tot die identifikasie van 'alternatiewe leerder-idees' wat by hierdie groep leerders voorkom. Dit word in hoofstuk 9 van hierdie verslag bespreek.

Daar is 'n groot mate van ooreenkoms ten opsigte van die alternatiewe leerderopvattings wat by hierdie drie verskillende groepe voorkom.

Navorsingsvraag 2 is hoofsaaklik beantwoord deur die empiriese studie wat in hoofstuk 8 van hierdie verslag bespreek word. Daar is bevind dat die MBL-ondervinding oor die algemeen 'n vebetering in die leerders se begrip ten opsigte van kinematika en kinematikagrafieke tot gevolg gehad het. 'n Meer gedetailleerde statistiese 'item en matriks'-analise het getoon dat die uitwerking op die leerders se begrip in sommige areas beter was as in ander.

Die etnografiese studie wat in hoofstuk 9 van hierdie verslag beskryf word, dra by tot die beantwoording van Navorsingsvraag 3. Sleutelbevindings met betrekking tot hierdie vraag sluit onder andere in:

- Leerderdeelname aan leeraktiwiteite hou skynbaar verband met die sukses wat hulle in die program behaal. Moontlike faktore wat 'n invloed op deelname kon hê, is geidentifiseer.
- Alternatiewe leerderopvattings is in die konteks van 'beredenerings-episodes' en 'besprekings- en verduidelikings-episodes' uitgelig.

Hierdie "episodes" het die waarskynlikste verband uitgewys waarbinne veranderings van insig/begrip kan plaasvind. Kernleerdergedrag en -vaardighede wat noodsaaklik is vir die deelname aan hierdie episodes is geidentifiseer, en is gekoppel aan 'n leerder se sukses en mislukking tydens deelname aan die program.

Aanbevelings wat voortspruit uit die bevindings van die ondersoek word in hoofstukke 8, 9 en 10 van hierdie verslag, bespreek.

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CHAPTER 1

Overview of the study

1.1 Introduction

1.1.1 Background to the study

There is no such thing as a typical South African science classroom. The experience learners have of science varies widely within particular classrooms, and across different classrooms and schools, as a result of the varying conditions under which teaching and learning takes place. Scenarios can range from 'private school' classrooms which may be well-resourced, have low teacher-learner ratios with qualified, experienced and innovative teachers, motivated learners and strong administrative support, to 'farm school' classrooms which are generally poorly-resourced, overcrowded and where teachers may be demotivated and/or unqualified to teach science. Whilst issues like resources, teacher expertise, etc. can be regarded as macro issues, micro issues like social interactions in the classroom between teacher and learner, learner and learner, and issues like cultural background, language, gender and race also impact on the experience learners have of science.

These differing conditions have, in effect, acted as selection agents for learners wishing to proceed to higher levels of science learning and thus to careers in science. A consequence of this in apartheid South Africa (and even at present) is that disadvantaged[1] sectors of society

[1] The term 'disadvantaged' is used in a broad sense and refers, for example, to groups disadvantaged by previous government policies, e.g. Blacks and groups traditionally disadvantaged by society, e.g. women.

had limited access to quality science education and thus to careers in science.

The South African government emphasizes the role that science education can play in promoting technological and economic growth. President Thabo Mbeki, in his State of the Nation Addresses during the opening of Parliament in 2001, emphasised the importance of mathematics and science in the development of the country:

> ...in this regard, Government has approved a Human Resource Development Strategy that will enable us to launch an accelerated skills development programme for those areas that are critical to a more competitive economy. Immigration laws and procedures will be reviewed urgently to enable us to attract skills into our country. Improvements in maths and science education will also be prioritised.
>
> (State of the Nation Address of the President of South Africa, Thabo Mbeki, at the National Assembly Chamber, Cape Town, 9 February 2001)

> ...the government will undertake a comprehensive review of this important sector to ensure that we correctly position and resource science and technology, research and development as a central driver of the process of the modernisation of our country and the creation of a better life for all.
>
> (Statement of the President at the conclusion of the debate on the State of the Nation Address National Assembly, 14 February 2001)

In a *White Paper on Science and Technology* (1996) it is argued that government has an obligation to promote science culture, science education and literacy amongst children and adults, in order to achieve equity and redress for disadvantaged groups:

> The most pervasive effect of the system of apartheid is the legacy of inequalities generated by decades of policy interventions specifically designed to exclude the majority of South Africans from participation in social, political and economic spheres of life. Programmes need to address the inequalities which have excluded Black women and men from the mainstream of South African society.

> An effective HRD[2] programme in science, engineering and technology is therefore vital to redress this imbalance, to improve our economic performance and to ensure the proper functioning of the NSI[3]. Such a programme will have to address the consequences of past deliberate policies and practices that promoted racial and gender discrimination in HRD. Apart from the human rights issue, there is also an imperative for South Africa to optimise its productivity and economic performance to succeed in the global marketplace. To achieve this goal, South Africa will have to maximise the utilisation of ideas, creativity, ingenuity and innovation from the entire population.
> (Department of Arts, Culture, Science and Technology, hereafter referred to as DACST, 1996).

In summary, strong opinion exists that:

- Investment in science education initiatives can contribute to social and economic growth in South Africa.
- For this to take place, these initiatives must focus on achieving equity with regard to access to quality science education for disadvantaged groups.

A direct result of this emphasis is the creation of a number of government and private initiatives aimed at improving science teaching and learning, particularly in those schools that traditionally have been denied adequate support.

Naidoo and Lewin write that:

> The major interventions to improve matters proposed to date focuses upon increasing numbers of students in science teacher preparation programs, opening new science streams in schools that currently do not teach science, upgrading science teacher qualifications, developing a new science curriculum more relevant to students' needs and increasing investment in facilities and curricular resources. (Naidoo and Lewin, 1998: 730.)

Collaboration at government level between the Department of Education (DOE), DACST and the Department of Communications has

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2 Human resource development

resulted in the development of a National Strategy for Mathematics, Science and Technology Education in General and Further Education and Training.

This strategy aims to:

- raise participation and performance by historically disadvantaged learners in Senior Certificate mathematics and physical science;
- to provide high-quality mathematics, science and technology education for all learners taking the first General Education and Training Certificate and Further Education and Training Certificate;
- to increase and enhance the human resource capacity to deliver quality mathematics, science and technology education.

Some of the initiatives being put in place to achieve this include:

- Identifying and developing dedicated mathematics and science schools – so far 100 schools have been identified nationwide for this purpose.
- Paying attention to the language of learning and teaching.
- Ensuring the development and supply of quality learning support materials (LSMs).
- Increasing participation and performance of girls in these areas.
- Providing high-quality curricula.
- Ensuring an adequate supply of qualified and competent mathematics and science educators.
- Upgrading of under-qualified and unqualified educators.
- Providing incentives to attract students to train as educators in mathematics, science and technology.

(DOE, 2001: 14-20)

3 National system of innovation.

Non-governmental organisations (NGOs) and tertiary institutions have also realised the importance of supporting development in this area and a number of initiatives and programmes have been developed. Two examples are:

- NGO initiatives like PROTEC (Programme for Technological Careers).

- Bridging programmes at tertiary institutions (e.g. The Science Foundation Programme at the University of Kwazulu-Natal, Pietermaritzburg).

The TRAC SA programme in South Africa is an example of an initiative aimed at improving access of learners to science careers, engineering in particular, by providing curricular support in science classrooms, and provides the context in which this study is carried out.

> TRAC (Transportation and Civil Engineering) is an innovative way of enhancing science and mathematics for high school pupils through the use of computer-aided technology. The idea behind the programme is to stimulate the pupils' interest in applied science, and encourage them to embark on careers in technology, more specifically in the fields of Transportation and Civil Engineering.
>
> (TRAC SA Annual Report 1998)

This is achieved mainly through the use of the 'TRAC PAC' - a set of sensory tools designed to support and enhance classroom teaching. The TRAC PAC is "a self-contained laboratory consisting of a microcomputer, software, sensor equipment, a digital interface for collecting data and other apparatus" (TRAC SA Annual Report 1998).

A novel feature of the TRAC PAC as a laboratory tool is its ability to collect data and plot graphs in real-time. For example, the motion detector component of the TRAC PAC uses sonar waves to capture the motion of a moving object. Supporting software allows the computer to plot displacement-time (s-t), velocity-time (v-t) and acceleration-time (a-t) graphs of the motion which learners can then analyze.

Brassel (1987) as well as Mokros and Tinkler (1987) have identified graphing ability as an area in which learners experience much difficulty.

The current Grade 12 syllabus for physical science in South Africa contains a substantial section that deals with motion and its representation using kinematic graphs. A recent study conducted in South African schools showed that learners:

> ...have a poor perception of the meaning of gradient in terms of rate of change. They experience difficulties with graphs of negative kinematic quantities, being generally reluctant to make use of a proper sign convention. Confusion between the meaning of velocity and acceleration often leads to incorrect v-t graphs and a-t graphs; and when transforming one graph into another related one, they tend to conserve the physical properties of the given graph.
>
> (Frauenknecht, 1998)

The ability of the TRAC PAC to address these, and other difficulties associated with kinematic graphs, as well as the mechanisms through which this might occur, will be investigated in the study.

1.1.2 Research focus

The study is carried out in three related parts:

1 A literature review of the difficulties that learners experience with graphs of motion will be conducted. The purpose of this review will be to identify areas of difficulty that could perhaps be tackled using the TRAC PAC. Findings from the review will influence the design of the teaching and learning activities used in the second part of this project.

2 A quantitative research approach involving the administering of pre-intervention and post-intervention tests, will be used to determine **what** effect (if any) use of the TRAC PAC has on learners understanding of graphs of motion and related concepts.

3 A qualitative research approach (ethnographic study) involving the experience of a group of learners in a TRAC PAC–based learning programme will attempt to explore **how** use of the TRAC PAC influences the development of learners' understanding of graphs of motion and related concepts.

1.1.3 Research questions

The following questions are related to the foci described above, and will be answered in this study:

1 What conceptual difficulties do learners experience in the area of kinematic graphs?

2 Does use of the TRAC PAC contribute to learner understanding of graphs of motion and related concepts?

3 If learning is enhanced using the TRAC PAC, how does this occur?

In particular, use of the motion sensor and graphing capability of the PAC in developing learners understanding of graphs of motion and related concepts will be investigated.

1.2 Research Methodology

A detailed discussion of theoretical underpinnings of the research methodologies that were used, as well as a discussion of additional definitions of key concepts, is conducted in Chapter 6 of this research report. The discussion here focuses mostly on practical aspects of the approach.

1.2.1 Research design

The study was conducted in four inter-related stages:

1 A content analysis of kinematics and kinematic graphs was carried out to determine key concepts that learners need to understand in this area.

2 A literature survey was conducted to explore theories of learning, to identify key misconceptions that learners experience with kinematic graphs with a view to identifying broad areas in which to ground the study, and to review other studies already carried out in this area. In essence, this survey allowed the researcher to answer Research Question 1.

3 A pre-test, post-test methodology was employed to assess the effectiveness of the TRAC PAC in addressing learner difficulties with kinematics and kinematic graphs. The design of test items was influenced in part by the literature review concerning difficulties experienced with graphs of motion. In essence, this part of the research allowed the researcher to answer Research Question 2.

4 The ethnographic study attempted to identify how use of a TRAC PAC-based learning programme influenced learning. A field

research approach was used in the ethnographic study. A large proportion of research activity involved participant observation supported by the making of field notes, video recordings and audio recordings. Focused group discussions with a selected target group were used to gain further insight of learners' experiences as they participated in the learning activities. In essence, this part of the study allowed the researcher to answer Research Question 3.

Figure 1.1 illustrates the research approach used:

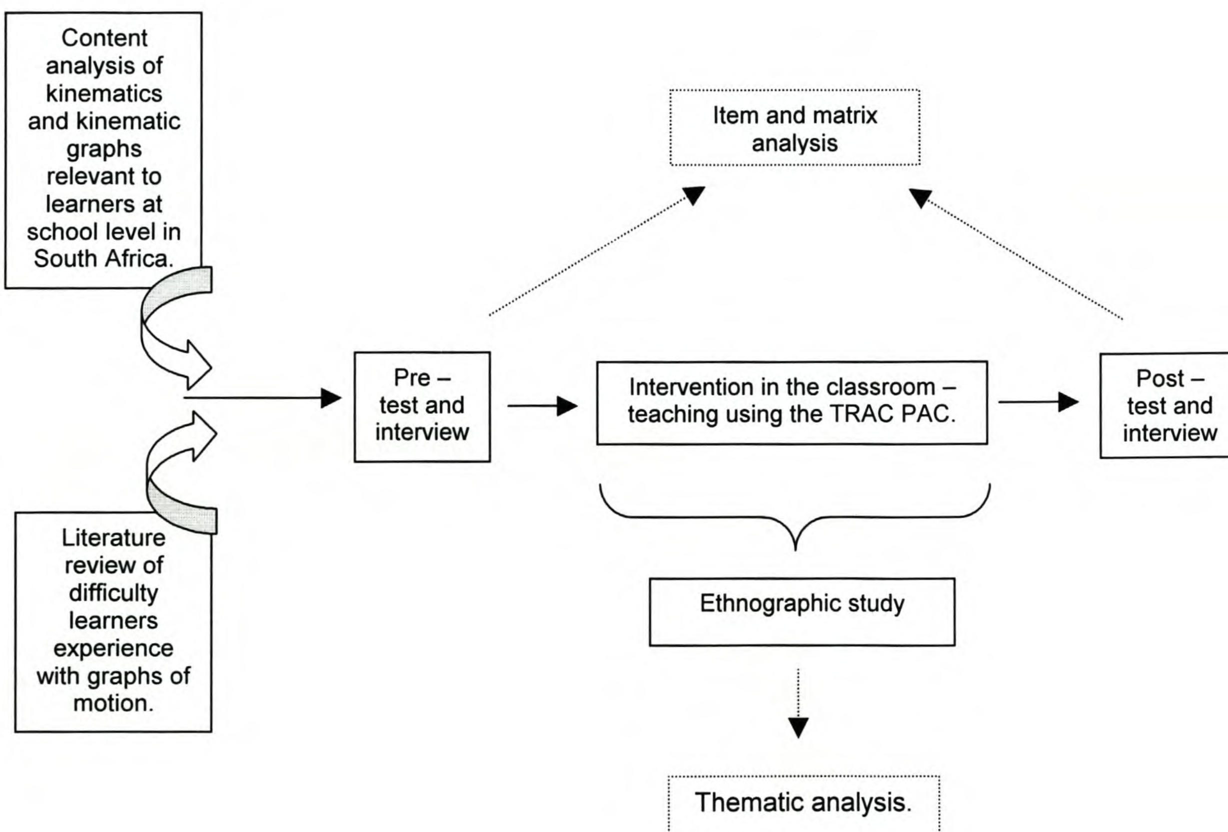


Figure 1.1: An illustration of the design of this research project. (Solid lines indicate data collection phase; dashed lines indicate analysis phase.)

1.2.2 Data analysis

Data collected in the quantitative pre-test, post-test phase of the study were analysed using a method called 'item analysis' described by Svec (1999), in order to identify the presence of common misconceptions prior to and after working through a TRAC-based learning programme.

Data collected in the ethnographic study took the form of field notes documenting observations, completed questionnaires and transcripts of interviews, video and audio recordings. This data was analysed using a technique called verbal analysis described by Chi (1999).

1.2.3 Selection of research site and sample

A workshop for twenty Grade 11 and Grade 12 learners was set up at the School of Education, University of Kwazulu-Natal, Pietermaritzburg. Learners from local schools were invited to participate on a voluntary basis. This workshop and these students served as the context in which the study was carried out. The intention was to create a situation similar to the way learners experience the TRAC Programme in South Africa, where learners visit a TRAC LAB to participate in various activities including MBL learning activities. This choice of venue and context also meant that the researcher had direct control over physical aspects such as use of computers, setting up of equipment, space and time.

It was not the intention in this study to ensure some degree of generalizability of findings, but rather to provide some insight into the effectiveness of the technology in the particular setting chosen, and more importantly, to explore learning mechanisms when learners interacted with microcomputer-based laboratory (MBL) technology like the TRAC PAC. Further studies could explore issues like the impact of language, learner background, etc. on the effectiveness of the technology being studied.

Choice of the site was thus an exercise in purposeful sampling.

Purposeful sampling is "not a probability sampling so that statistical inferences can be made" (Creswell, 1998); rather it is sampling where sites and subjects are chosen for their potential to provide additional insight into the phenomenon being studied. (Bogden and Biklen, 1992).

1.3 Motivation for the study

This study needed to be carried out for the following reasons:

- Very little research, if any, has been conducted regarding the use, feasibility and value of using computers as aids to develop concepts in science in South African schools. This study begins developing theory in this regard. The motion sensor component of the PAC and its use in developing concepts related to motion was identified as a suitable aspect for research because:

- This particular sensor works very well as part of the technology being studied.

- This topic forms a substantial part of the existing grade 11 and 12 physical science syllabus and is thus sure to be dealt with by teachers.

- Some research has been carried out in this area in developed, first world countries (For example see Broadstock and George (2001), Thornton and Sokoloff (1990), Zietsman and Hewson (1986), Brassel (1987)). Very little, if any, has been carried out in developing countries like South Africa. It would be interesting to see whether use of the TRAC PAC helps learners to overcome the problems associated with understanding of graphs of motion and related concepts in this context. Furthermore, previous studies have focused on quantifying the effects of using MBL technology. Very few studies, if any, have focused on the learning mechanisms through which the observed effects develop. This study hopes to contribute to theory in this regard.

- Kinematics and kinematics graphs form a significant component of the learning material in the Senior Certificate course for South African shools. This can be seen in section 2.4.1 where the current South African Physical Science Grade 12 syllabus is described. In addition, understanding of kinematics impacts directly on learner understanding of dynamics, another significant component of school-based physics courses. Both these areas (kinematics and dynamics) are also explored in introductory physics and engineering courses at university level. Thus, learner understanding of kinematics can have a significant influence on overall performance and success in physics and physics-related studies at school and university levels, and thus impacts on the career opportunities of learners.

- TRAC SA will receive feedback regarding the effectiveness of the TRAC PAC.

1.4 Clarification of terminology

- Various researchers and writers have used terms like 'misconceptions', 'preconceptions', 'alternative conceptions', 'immature conceptions', 'non-scientific conceptions', 'alternative ideas'. These may be used in this report, and in all cases they refer to learner understanding and articulation of concepts which are not synonymous with the expert's understanding and articulation of the concepts. See Section 3.2 for a broader discussion of this.

- The term 'learners' will be used to describe pupils, students, children, except when directly quoting from an article.

- When referring to learners and teachers, he or she, him or her, etc. is used in the report. However, each should be read to be inclusive of both genders, and use of one or the other is not meant to be discriminatory towards either gender.

- The TRAC PAC is a microcomputer-based laboratory tool consisting of a microcomputer, various sensors, and associated software. Teachers can use the TRAC PAC to support the teaching and learning of science in a practical fashion. TRAC SA, as an organization, presently operates in four provinces in South Africa (Western Province, Gauteng, Eastern Province and KwaZulu-Natal) and supplies project schools in these provinces with the TRAC PAC and the necessary technical support to utilize it effectively.

- Sensors or probes are measuring devices which can monitor and measure a physical quantity in a physical system, and transmit this data to a computer for recording, display and analysis.

- A real-time graph is a graph that is produced, for example by a computer, as an actual experiment proceeds.

- A microcomputer-based laboratory (MBL) is a combination of computer and sensors, together with the relevant software. The software typically transforms the data acquired by the sensors into real-time graphs.

1.5 Structure of this report

- Chapter 1 provides a background for the study, identifies the research questions, and elaborates on how the research is to be conducted.

- Chapter 2 is a content analysis of kinematic concepts related to the study of kinematic graphs.

- Chapters 3, 4 and 5 report on a literature survey conducted on theories about learning and teaching science, the difficulties learners experience and the misconceptions they have about graphs of motion and related kinematic concepts, and the use of computers in science teaching in this area.

- Chapter 6 describes the quantitative and qualitative research methodologies used in this research project.

- Chapter 7 describes the design of a TRAC PAC-based learning programme for addressing learner misconceptions related to kinematic concepts and their representation using kinematic graphs.

- Chapter 8 is a report and analysis of the findings of the empirical investigation into the effect that use of the learning programme described in Chapter 7 has on learner understanding of kinematic concepts and their representation using kinematic graphs.

- Chapter 9 is a report and analysis of the findings of the ethnographic investigation into how learning occurs when learners participate in a TRAC PAC–based learning programme.

- Chapter 10 describes conclusions reached and identifies areas for further research.

CHAPTER 2

Content Analysis: Kinematic concepts and their representation using kinematic graphs

This chapter describes the knowledge area in which this study was carried out. The discussion focuses on the following areas:

- Descriptions of common and currently accepted understandings of concepts in the knowledge area being investigated are attempted.

- Where appropriate, learner difficulties that the researcher has noted as a result of classroom experience of teaching science in the South African context are mentioned. A later chapter (Chapter 3) explores these difficulties in more detail and reports on literature survey findings on the difficulties learners have with some of these conceptions.

- Opportunities to elaborate on use of the TRAC PAC present themselves in this discussion. These are used to provide the reader with some background about possibilities for using the TRAC PAC and the Multi-Purpose Laboratory Interface (MPLI) programme in the teaching and learning of kinematic concepts and their representation using kinematic graphs. Some of the possibilities that are identified are developed further in the learning programme which forms a major part of this study. This learning programme is described in Chapter 7.

Use is made of a method described by Treagust (1988:161) for designing and using diagnostic tests to identify learner misconceptions, that incorporates use of interviews and paper and pencil responses. (Treagust's method is employed in the empirical part of this study. See

Chapter 6 for a detailed description of the method.) The first part of his method involves **defining the content knowledge** that learners are expected to know in the area being investigated. He suggests that four steps should be followed in doing this, namely:

Step 1: Identifying propositional knowledge statements.

> This is a set of statements that describe the content knowledge learners are expected to know in the area being investigated.

Step 2: Developing a concept map.

> Related concepts in the area are built into a concept map, with lines showing links between related concepts, and short statements describing the actual relationship between them. Like the propositional knowledge statements, the concept maps allows the researcher "...to carefully consider the nature of the content which has been selected for instruction" (Treagust, 1988: 161).

Step 3: Relating propositional knowledge to the concept map.

> This allows the researcher to check that the content area chosen for investigation has been comprehensively covered. "The propositional knowledge statements are related directly to the concept map to ensure that the content being covered is internally consistent" (Treagust 1988: 162).

Step 4: Validating the content.

> The propositional statements and concept map is scrutinized, criticized and validated by educators, subject specialists and experts in the field.

Use of these steps resulted in the following set of propositional knowledge statements and concept map describing the boundaries of the knowledge area being investigated.

The following **hypothetical and idealized** scenarios are described and used in order to provide practical contexts in which the propositional statements can be elaborated upon.

Scenario 1:

In a road test, a car moves along a level track that is made up of equal lengths of 500m each. A flag indicates the end of each 500m stretch. The car accelerates from rest at flag A to flag B. A uniform velocity is maintained from flag B to flag C. Brakes are applied at flag C and the car comes to a stop at flag D. Immediately it turns around (turnaround time is 5 seconds), accelerates to flag C, where brakes are again applied. The car comes to a stop at flag B.

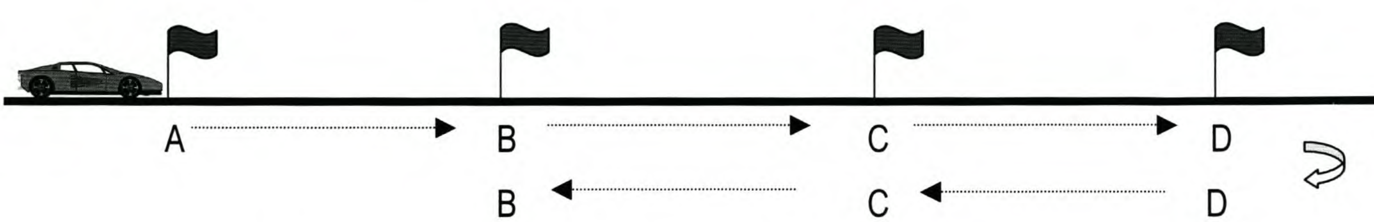


Figure 2.1 Motion of a car along a level track.

In addition to this, scenario 2, which follows, is used to provide a context through which features of the MPLI programme of the TRAC PAC can be elaborated upon. The graphs shown are actual graphs generated using the motion detector component of the TRAC PAC to collect data about the motion of the ball both up and down the slope.

Scenario 2:

A medium sized plastic ball is given a push so that it rolls up an incline. It slows down as it moves up the incline, until it stops at its highest point. Then it rolls down the slope again.

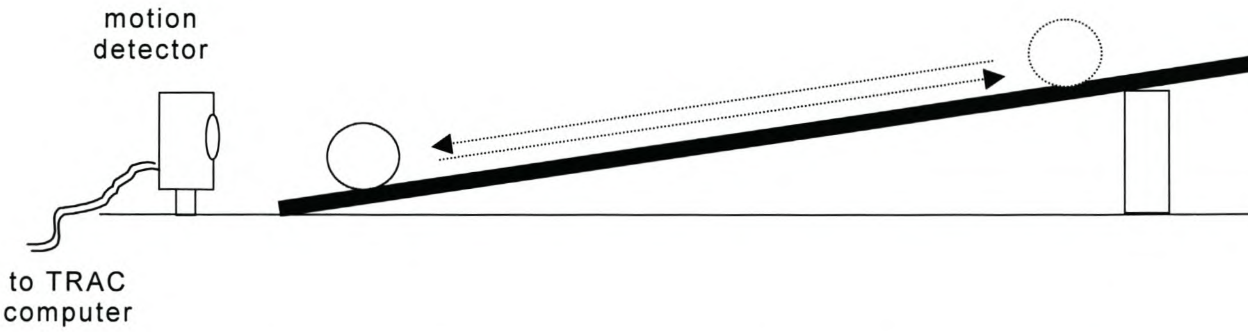


Figure 2.2 Experimental set-up for recording motion of a ball up and down an incline.

The MPLI programme component of the TRAC PAC generates displacement-time, velocity-time and acceleration-time graphs in real-time, based on data collected by a motion detector. The motion detector uses sonar waves to detect changes in displacement of an object from a previously calibrated reference point. The programme then uses this displacement data to calculate velocity and acceleration. Various programme tools allow for analysis of the graphs.

The following graph analysis tools (with the icons that represent them) can be used to analyze graphs that are generated:

The *TANGENT LINE GRADIENT* feature of the MPLI programme draws a tangent at any point on a graph and thus allows one to examine the slope at any point on the graph.

The *EXAMINE DATA* feature of the MPLI programme gives the x and y co-ordinates at any point on the graph.

The *INTEGRATION* feature allows one to determine the area under any selected region of the graph.

The *REGRESSION LINE* feature draws a 'best fit' straight line through any selected region of the graph.

The *ZOOM IN* feature allows for magnification of a particular section of the graph in order to examine it more closely, while the *ZOOM OUT* function gives a wider view of the graph.

The *AUTOSCALE* function allows the computer to select a scale that is appropriate for the range of data collected.

A typical MPLI screen with graphs generated by collecting data, as described in scenario 2 earlier in this chapter, appears as follows:

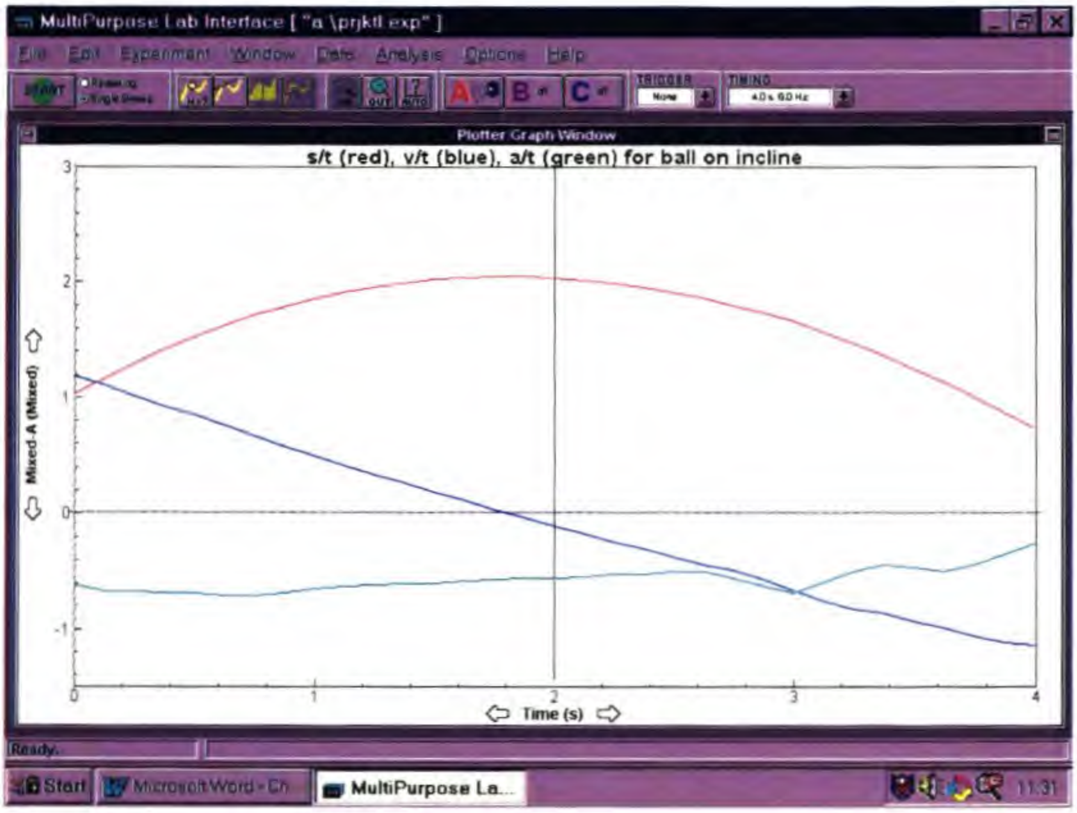
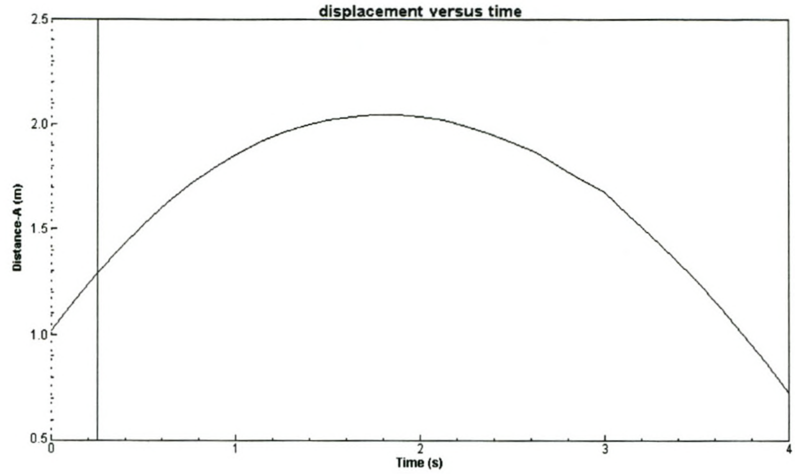


Figure 2.3: Combined kinematic graphs for ball rolling up and down an incline.

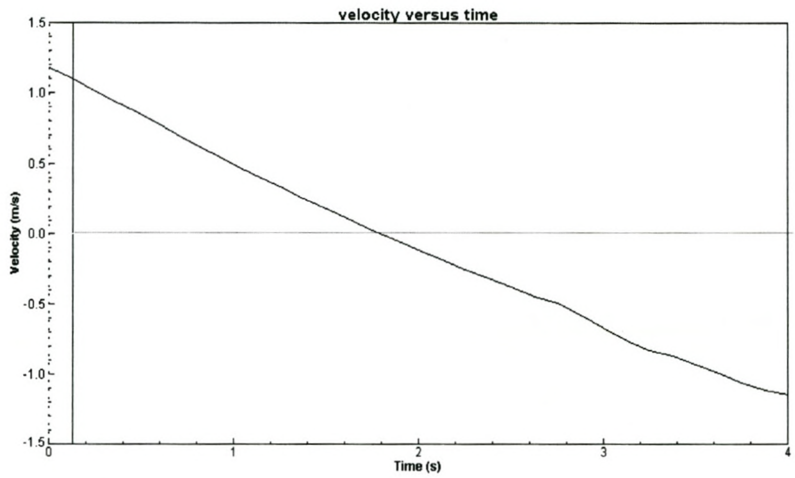
One could get all the graphs plotted on one set of axes, as in the example shown above. Alternatively, one could set up the system to plot each graph on an individual set of axes.

The following separate displacement-time, velocity-time and acceleration-time graphs were obtained for the ball's motion in Scenario 2 (upward movement is designated as being positive and downward motion is designated as being negative).

A



B



C

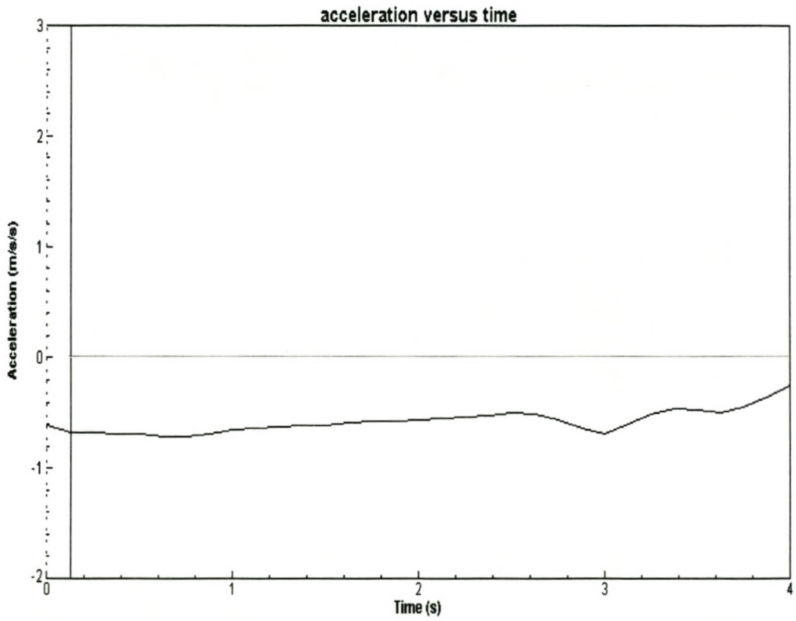


Figure 2.4: Displacement-time (A), velocity-time (B) and acceleration-time (C) graphs for the motion of a ball up and down an incline.

2.1 Propositional knowledge statements

Essentially, the propositional statements are descriptions of the various concepts and relationships being investigated (as 'experts' in the field would describe them).

The following propositional statements can be made about concepts and relationships in the area of kinematics and kinematic graphs.

2.1.1 Kinematics

Propositional statement 1:

Kinematics is a study of the branch of mechanics concerned with the motion of objects without reference to the forces that may be influencing the motion. It has also been described as an area of study concerned with a mathematical description of motion.

In scenario 1 described above, the car experiences different types of motion as a result of the forces acting on it on the parts of the track. In kinematics, we are concerned with a verbal, mathematical or graphical description of the types of motion that the car experiences, rather than a description of the forces that may be causing these differences. This study focuses on the graphical description of motion.

2.1.2 Motion

Propositional statement 2:

Motion can be described as a continuous change in position of an object in space.

It may be useful to distinguish between motion and states of motion. As described above, the term motion refers to a constant change in position. However, an object at rest (zero change in position) is not **in motion**, but can be described as being **in a state of motion**. At school level, three states of motion are usually considered, viz. zero velocity, constant velocity and constant acceleration.

In Scenario 1 above, we can say that the car is in motion as it moves between flag A and flag D, and again as it moves between flag D and flag B.

The states of motion that the car experiences include:

- Zero velocity (when it is at rest before it begins moving at flag A, and again when it stops at flag D).
- Constant velocity (when it is moving from flag B to flag C).
- Constant acceleration (when it is moving from flag A to flag B, from flag C to flag D, from flag D to flag C and from flag C to flag B).

2.1.3 Rectilinear motion

Propositional statement 3:

Rectilinear motion is motion along a straight line. It can also be described as motion in which only one component of the displacement is non-zero (Sears, Zemansky and Young, 1985: 40).

The racing car's motion in the scenario above can be described as rectilinear motion. It has only one non-zero displacement component for any part of its motion.

At school level in South Africa, discussion of motion is limited to a consideration of rectilinear motion only.

2.1.4 Position

Propositional Statement 4:
An object's position is the point it occupies in space relative to a specified reference point.

From this statement it becomes clear that in order to describe the position of an object, one needs to refer to an arbitrarily chosen but explicitly stated reference point.

Propositional statement 5:
A reference point is an arbitrarily chosen point from which the position or displacement of the object can be described.

In the scenario above, if we choose the position of flag B as the reference point for the car's motion, then we can describe its position anywhere else on the track by referring to this reference point.

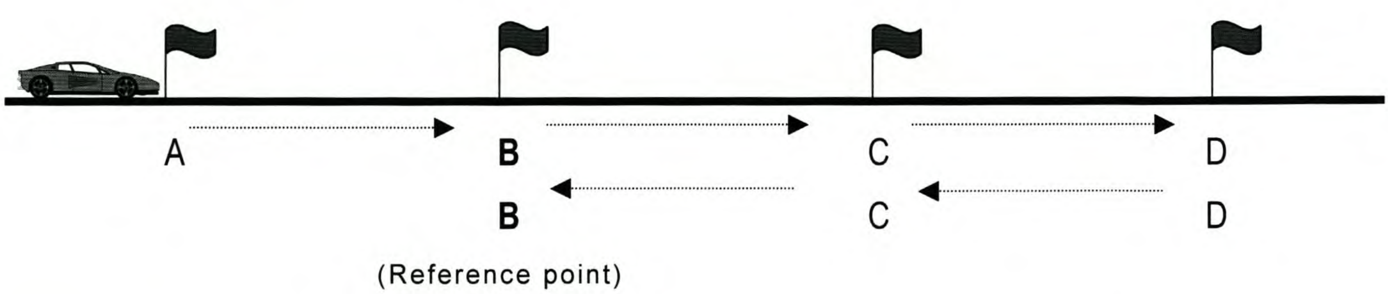


Figure. 2.5: In order to describe an object's position, an arbitrarily chosen reference point should be specified.

If point B is chosen as the reference point, then we can describe the position of the car as being 500m away from point B when the car is still at flag A. Note that this could be 500m to the left of the reference point (flag B) or to the right of it. Thus, in order to describe the displacement of the car (which is a description of the car's position with respect to the reference point in a particular direction, we also need to specify a reference direction. Therefore, in order to describe displacement of the car, a reference point and a reference direction needs to be specified (see the discussion of displacement in 2.1.7 below).

The MPLI programme allows the user to specify the reference point from which the motion will be represented. For example, in Scenario 2, one could programme the motion sensor to take any point in a straight line along the ball's path as the reference point. Exercises like this can possibly contribute to learner understanding of how choice of reference point affects the description of an object's motion and will be one of the facets explored in this study. See the discussion on displacement-time graphs below (2.1.12) for examples of graphs of the motion in Scenario 2 where different reference points are specified.

2.1.5 Reference direction

Once an object moves its position changes. If we limit our discussion to rectilinear motion, then we need to indicate how the object has moved in the straight line of which the reference point is part. This is done by arbitrarily assigning reference directions.

Propositional Statement 6:

Reference directions are arbitrarily assigned directions on the straight line along which movement is taking place and of which the reference point is a part.

One way of assigning directions is to use a sign convention (positive and negative signs to indicate opposite directions). Other ways of describing direction in one dimension include use of the terms “to the left”, “to the right”, “up” or “down”.

If we look at the case of the car on the track, we can arbitrarily assign reference directions using sign convention as shown:

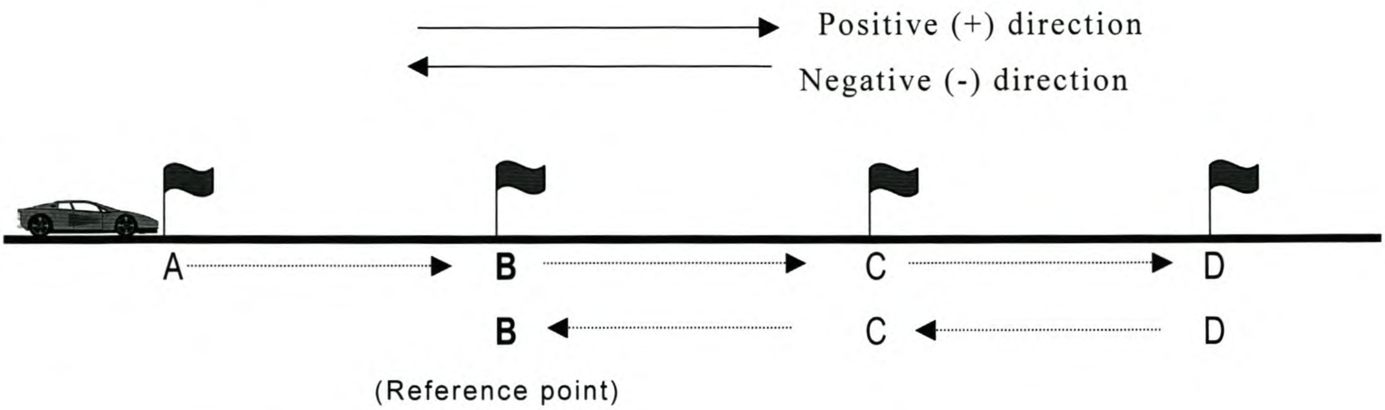


Figure 2.6: Arbitrarily assigned reference directions for the motion of the car on the track.

Movement of the car from flag B to flag C will be movement in the positive direction. Movement of the car from flag C to flag B will be movement in the negative direction.

The choice of reference direction affects the sign used to describe the velocity and acceleration of the motion being considered. For any motion in the positive direction, the sign of the velocity will be positive. Likewise, for any motion in the negative direction, the sign of the velocity will be negative. A resultant force produces acceleration. If the resultant force is in the positive direction, the resulting acceleration will be positive. If the resultant force is in the direction chosen as negative, the object's acceleration will be described as negative.

2.1.6 Distance

Propositional Statement 7:

Distance represents a measure of space in one dimension.

Thus, a description of the distance that a moving object undergoing rectilinear motion covers, is a description of the total amount of space in straight lines that the object covers while moving.

Considering the motion of the racing car described above, when it reaches flag B the first time, it has covered a distance of 500m. When it reaches flag B for the second time, it has covered a distance of 500m (A→B) + 500m (B → C) + 500m (C →D) + 500m (D → C) + 500m (C →B) = 2 500m.

2.1.7 Displacement

Propositional statement 8:

Displacement is the straight-line distance from the chosen reference point to the end of a motion for the time interval being considered.

An object will have a positive displacement when it is in the positive area with reference to the chosen reference point, and a negative displacement when it is in the negative area with reference to the chosen reference point.

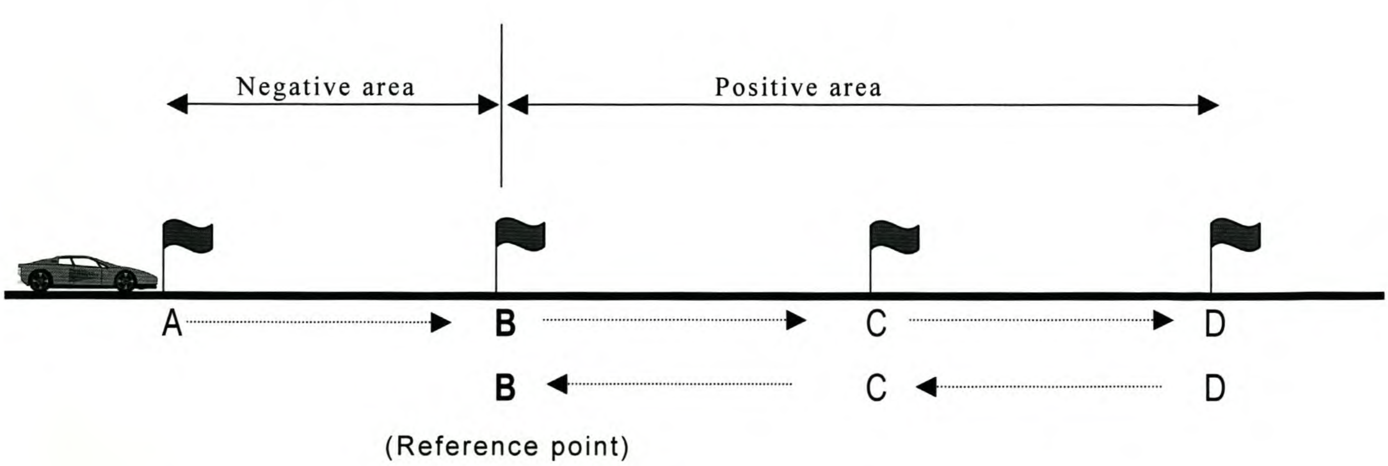


Figure 2.7: The sign of an object's displacement depends on its position with regard to the chosen reference point.

In the car scenario above where flag B has been chosen as the reference point, the displacement of the car relative to the chosen reference point (point B) when it is anywhere between B and D will be positive, and when it is anywhere between B and A it will have a negative displacement. For example:

- When the car is at flag C for the first time, it has a displacement of + 500m.
- When it is at flag C for the second time its displacement is still + 500m, even though it is now moving in the negative (opposite) direction.
- When it is at its starting point (flag A), its displacement is – 500m.

Thus, the sign of a displacement is an indication of the position of the object at the instant being considered with reference to the chosen reference point, rather than an indication of the direction in which it may be moving.

Again, it is possible to set up exercises using the TRAC PAC and the MPLI programme, where the learner is able to recalibrate the motion sensor to assign different reference directions for the same motion being observed and captured. For example, the sets of graphs in Figure 2.8 below were produced using the motion of the ball up and down the incline in Scenario 2 described earlier in this chapter. In the first set, the motion up the slope was chosen to be in the positive direction. In the second set of graphs, the motion up the slope was stipulated as being negative.

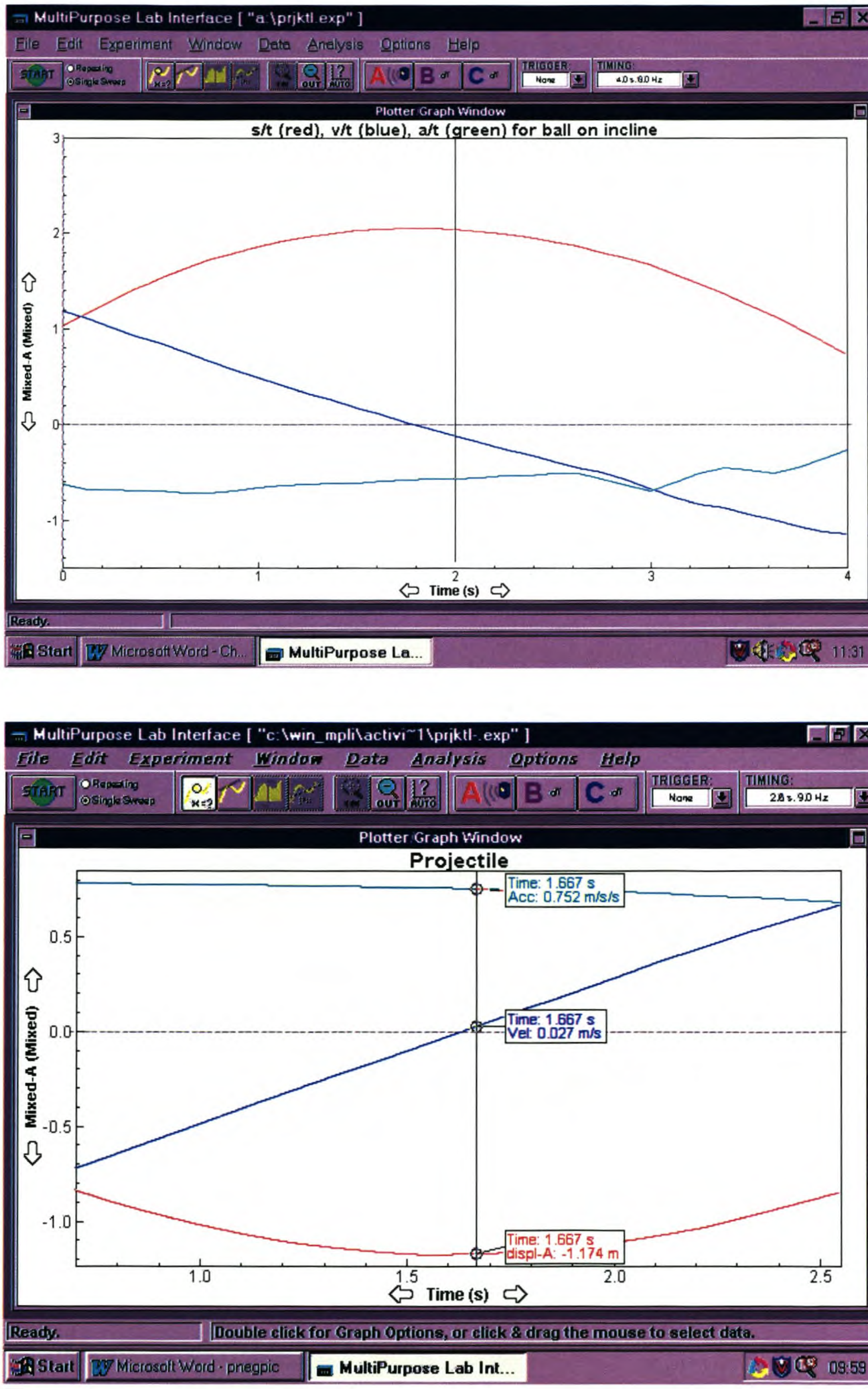


Figure 2.8: The effect that choice of reference direction has on the representation of kinematic graphs.

Exercises like this can possibly contribute to learners understanding the need to assign reference directions and how this affects representation and description of the motion of objects, and is therefore one of the elements that is investigated in this study.

2.1.8 Speed

Propositional statement 9:
Average speed is the rate of change of distance from a reference point for the time interval being considered.

Average speed therefore, is a measure of the amount of distance covered in a certain time, and can be computed using the relationship:

$$\textit{Average speed} = \frac{\textit{distance traversed}}{\textit{time elapsed}}$$

or, using symbols:

$$v = \frac{\Delta s}{\Delta t}$$

where v represents average speed, Δs represents the distance covered in the interval being considered, and Δt represents the time that elapses while this distance is being covered.

For the car scenario described above, the average speed of the car for the entire trip can be calculated provided the time that the car takes for the trip is known.

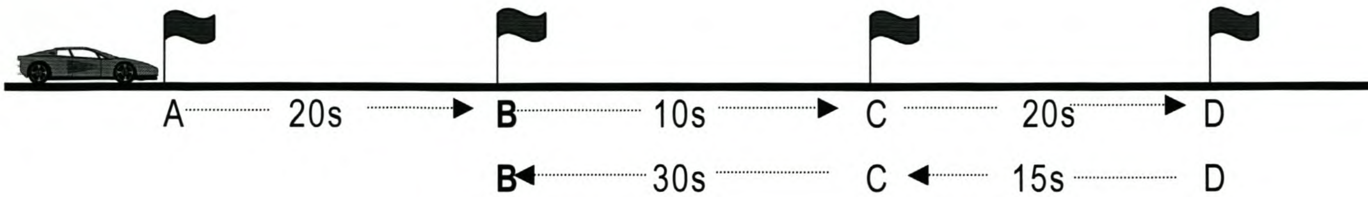


Figure 2.9: Elapsed times for different parts of the racing car's motion.

$$v_{A\to B} = \frac{s_{A\to B}}{t_{A\to B}}$$

$$= \frac{500m + 500m + 500m + 500m + 500m}{20s + 10s + 20s + 5s + 15s + 30s}$$

$$= 25m.s^{-1}$$

Note that this is the average for the speeds of the car over the entire trip. The distances covered in the different intervals indicate that the car has different speeds over different parts of its motion. The value calculated above is an average of all the different speeds.

There are sections of the car's motion (e.g. from flag B to flag C) where its speed does not change.

This speed can be calculated as follows:

$$v_{BC} = \frac{s_{BC}}{t_{BC}}$$

$$= \frac{500m}{10s}$$

$$= 50m.s^{-1}$$

This means that during this period of the car's motion, it consistently covers 50m for every second that it is moving.

This speed is referred to as a uniform speed.

Propositional statement 10:

An object has a uniform speed when it covers equal distances in equal time periods.

Moving objects in real life seldom move at a consistently uniform speed, and the term average speed is used as a representation of the various different speeds of the object over a significant time period of its motion. When an object has a varying speed it is possible to define its speed at a particular point of its path or at a particular instant of time. This speed is known as the instantaneous speed at that particular point.

Propositional statement 11:

When a very small (infinitesimal) time interval (Δt) is used to calculate the speed of an object, the speed calculated is referred to as an instantaneous speed.

At school level, learners demonstrate much confusion in the meanings they assign to these different terms. They have difficulty distinguishing between average speed, uniform speed and instantaneous speed. For example, if asked to determine the average speed of the car between flags A and B, they usually interpret this figure as being the speed of the car at any point between A and B (a uniform speed). They have a problem visualizing that the speed of the car is constantly changing between these two points and that the speed at any point between A and B (the instantaneous speed) could be different from any other point between A and B. These difficulties have been reported in studies by Peters (1982), Halloun and Hestenes (1985), Trowbridge and McDermott (1980), and are described in more detail in Chapter 4.

2.1.9 Velocity

Speed is an indication of the rate at which a moving object changes its position, with no consideration being given to the direction of movement. Velocity however, is concerned with the direction of movement as well. When a particular direction is associated with the distance that an object covers, the object's displacement is being described. Velocity therefore can be thought of as the speed of an object in a particular direction, or in more technical terms:

<u>*Propositional statement 12:*</u>
Average velocity is a quantitative measure of the rate of change of displacement.

Average velocity can be calculated using the relationship:

$$\textit{Average velocity} = \frac{\textit{change in displacement}}{\textit{Elapsed time}}$$

or, using symbols:

$$\vec{v} = \frac{\Delta \vec{s}}{\Delta t}$$

where $\vec{v}$ represents velocity, $\Delta \vec{s}$ represents the change in displacement of the object, and Δt represents the elapsed time during which the change in displacement takes place.

Note that the arrows above the symbols allow us to differentiate between distance and displacement, speed and velocity. These indicate that displacement and velocity are vector quantities. They have a definite direction associated with them.

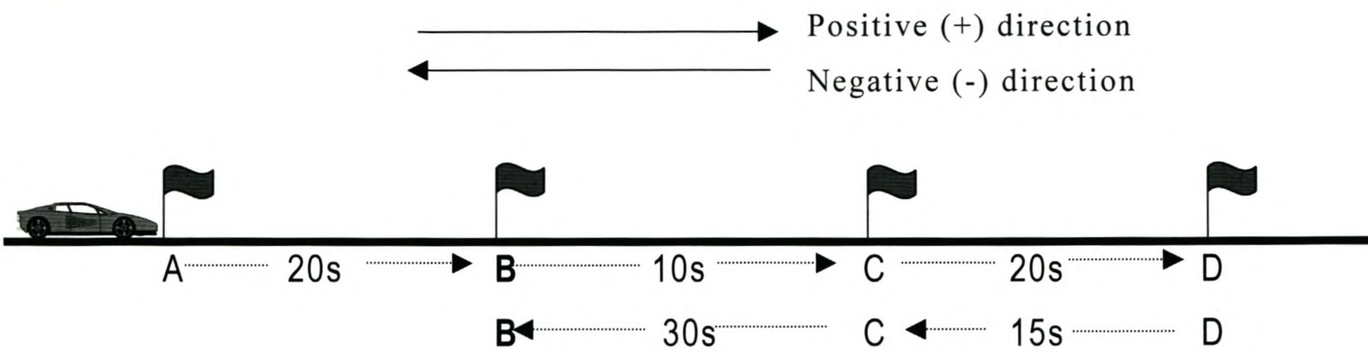


Figure 2.10: A description of an object's velocity is a description of its speed in a particular direction.

The average velocity of the racing car for the motion between flag A and flag B, where flag B represents the reference point, can be calculated as follows:

$$\vec{v}_{AB} = \frac{\Delta \vec{s}}{\Delta t}$$

$$= \frac{\vec{s}_B - \vec{s}_A}{\Delta t}$$

$$= \frac{0 - (-500)\text{m}}{20\text{s}}$$

$$= \frac{500\text{m}}{20\text{s}}$$

$$= +\,25\text{m.s}^{-1}$$

The velocity is positive because the car is moving in the direction chosen as positive.

Following from this, and similar to the arguments made for speed above, we can define uniform velocity and instantaneous velocity as follows:

Propositional statement 13:

An object moves with a uniform velocity when it experiences the same change in displacement in equal time intervals.

Propositional statement 14:

Instantaneous velocity is the velocity calculated over an infinitesimally small period of time of the object's motion. It is the velocity at a specific point of the object's motion.

In South African schools, learners are typically taught to approximate the instantaneous velocity of an object at the middle of a time interval as being equal to the average velocity over the whole interval. For example in the racing car scenario above, learners would need to calculate the average velocity over interval AB to find the instantaneous velocity at the middle of that particular time interval.

Similar to the confusion learners exhibit in the meaning they assign to the terms average speed, uniform speed and instantaneous speed, they also exhibit confusion in the meanings they assign to the concepts average velocity, uniform velocity and instantaneous velocity. An example of this confusion is demonstrated when learners are requested to calculate the final velocity of an accelerating object. They use the mathematical representation of average velocity ($v = \Delta s/\Delta t$) to do this, rather than recognizing that the velocity of the object is constantly changing and thus using an equation of motion appropriate to rectilinear accelerated motion to determine the final velocity. The study by Trowbridge and McDermott (1981), which is described in Chapter 4 of this report, describes these difficulties in more detail.

2.1.10 Acceleration

An object accelerates when its velocity changes with time. Thus we can define acceleration as follows:

Propositional statement 15:

Average acceleration is a quantitative measure of the rate of change of velocity.

Since velocity (and therefore acceleration) is a vector quantity, changes in velocity can be caused in the following ways:

- By changing the direction of the velocity while keeping its magnitude (speed) constant.
- By changing the magnitude of the velocity while keeping its direction constant.
- By changing both the magnitude and direction of the velocity.

For an object undergoing rectilinear motion, it accelerates when the magnitude of its velocity changes. The average acceleration of the object can be calculated using the relationship:

$$\textit{Average acceleration} = \frac{\textit{change in velocity}}{\textit{elapsed time}}$$

or, using symbols:

$$a = \frac{\Delta \vec{v}}{\Delta t}$$

where a represents acceleration, $\vec{v}$ represents velocity and Δt represents the time during which the change in velocity takes place.

For example, in the car road test scenario above, the acceleration of the car between flag A and flag B can be calculated as follows:

$$a_{BC} = \frac{\Delta \vec{v}}{\Delta t}$$

$$= \frac{\vec{v}_B - \vec{v}_A}{t_{AB}}$$

Thus to calculate the acceleration of an object over a certain time interval, one needs to know the initial velocity at the beginning of the interval (the instantaneous velocity at flag A) and its final velocity at the end of the interval (the instantaneous velocity at flag B).

In South African schools, the discussion of acceleration in physical science classrooms is limited to a discussion of uniform or constant acceleration in a straight line only.

Propositional statement 16:
An object has a constant acceleration when its velocity changes at a constant rate.

Thus for the car in the road test above, if it experiences a constant acceleration between flag A and flag B of $2.5m.s^{-2}$, it means that its velocity increases by $2.5m.s^{-1}$ every second. After the first second of its motion, its velocity will be $2.5m.s^{-1}$ (since it starts from rest), after the second second it will be $5m.s^{-1}$, after the third second $7.5m.s^{-1}$ and so on.

Acceleration is a vector and like displacement or velocity, a sign convention can be used to describe its direction. The direction of the acceleration is the same as the direction in which the resultant force producing it acts.

<u>*Propositional statement 17:*</u>

An object will have a positive acceleration when the resultant force producing the acceleration acts in the direction specified as being positive. A negative acceleration is produced when the resultant force producing the acceleration acts in the direction specified as being negative.

For the car road test scenario above, the car accelerates uniformly from flag A to flag B, from flag C to flag D, from flag D to flag C and from flag C to flag B.

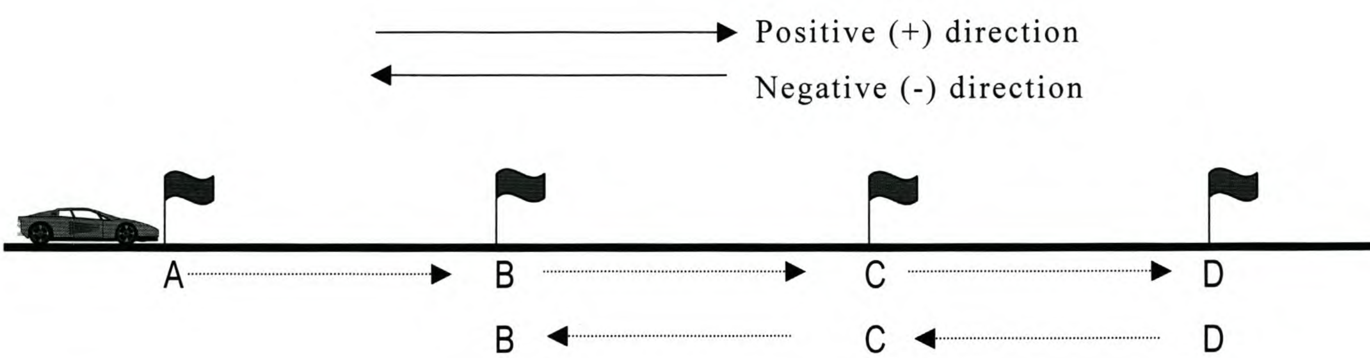


Figure 2.11: Arbitrarily assigned reference directions can be used to describe the direction of the resultant force and thus the direction of the acceleration.

The direction of the acceleration of the car for the intervals where it accelerates between flags can be described as follows:

Interval being considered	**Sign representing the direction of the velocity**	**Sign representing the direction of the resultant force**	**Sign representing the direction of the acceleration**
A → B	+	+	+
C → D	+	-	-
D → C	-	-	-
C → B	-	+	+

Another common problem is that learners often relate the direction that the object is moving with the direction of the acceleration of the object. For example in the car scenario above, some learners would describe acceleration when the car is moving in the positive direction (to the right) as being positive, and acceleration when the car is moving in the negative direction (to the left) as being negative. This is particularly evident in the special case of vertical projectile motion when an object, e.g. a ball, is thrown upwards and then caught again, or in the case of Scenario 2, where a type of motion very similar to projectile motion occurs. If motion in the upward direction is specified as being positive, then typically learners describe the acceleration of the ball in the upward direction as being positive and acceleration of the ball as being negative while it is moving downwards. Learners also describe the acceleration of the ball at its peak as being zero because the ball is not moving. When using an acceleration-time graph to describe the acceleration of the ball during its motion, they draw graphs similar to Figure 2.12 (a) or Figure 2.12 (b).

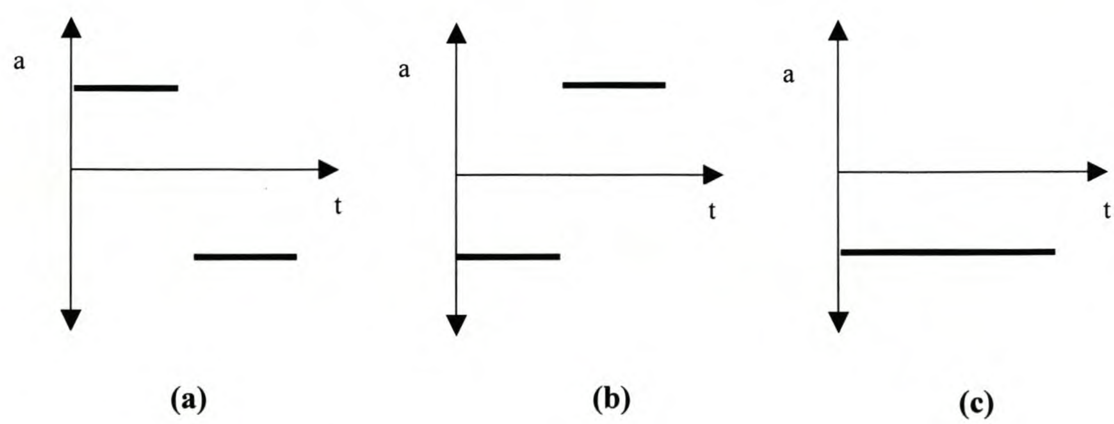


Figure 2.12: (a) Typical incorrect acceleration versus time graph learners draw when the upward direction is specified as being positive.
(b) Typical incorrect acceleration versus time graph learners draw when the upward direction is specified as being negative.
(c) Correct acceleration versus time graph when the upward direction is specified as being positive. (As shown in the actual graph obtained using the MPLI programme in Figure 2.12 above.)

Learners may also automatically describe the upward acceleration as being negative because the ball is slowing down or decelerating, and the acceleration while the ball is moving downward as being positive because the ball is increasing speed. Here, a negative sign is used to indicate deceleration (the ball's velocity is steadily decreasing) and a positive sign to indicate that the ball's velocity is steadily increasing. A popular textbook used in South African schools supports this interpretation when it proposes:

"Suppose a car slows down uniformly. We sometimes call such a motion a **deceleration**. In scientific language we say such an object undergoes a **negative acceleration**." (Pienaar, Walters, Schreuder and de Jager, 1997: 38, emphasis in original.)

These difficulties have been observed and reported in the Trowbridge and McDermott (1981) study, which is described in Chapter 4 of this report.

2.1.11 Graphical representation of kinematic concepts

Graphs are a useful tool for developing and/or demonstrating quantitative and qualitative understanding of relationships between physical quantities. In South African school level physics courses, learners are generally expected to be able to:

- Draw accurate graphs which display the relationship between physical quantities which entails a quantitative representation of relationships.
- Draw sketch graphs which display the relationship between physical quantities, which entails a qualitative representation of relationships. This may include translational tasks (converting between different ways of representing relationships, e.g. verbal

representation to graphical representation) or transformational tasks (converting one graphical representation into another).

- Interpret given graphs in order to demonstrate understanding of relationships between physical quantities, which entails a demonstration of qualitative understanding of the concepts being represented.

Propositional statement 18:
Kinematic graphs are graphs that display relationships between kinematic quantities.

In school level physics kinematic courses, learners are expected to use kinematic graphs to represent relationships between:

- Distance and time (s / t graphs)
- Displacement and time ($\vec{s}$ / t graphs)
- Speed and time (v / t graphs)
- Velocity and time ($\vec{v}$ / t graphs)
- Uniform acceleration and time ($\vec{a}$ / t graphs)

Further discussion about this can be found later (Section 2.4.1) when the South African school syllabus is looked at in more detail.

2.1.12 Distance-time and displacement-time graphs

Propositional statement 19:
A distance-time graph is a graphical representation of the relationship between distance and time for a moving object,

A sketch graph of distance-time for the car in the scenario described above could be drawn as follows:

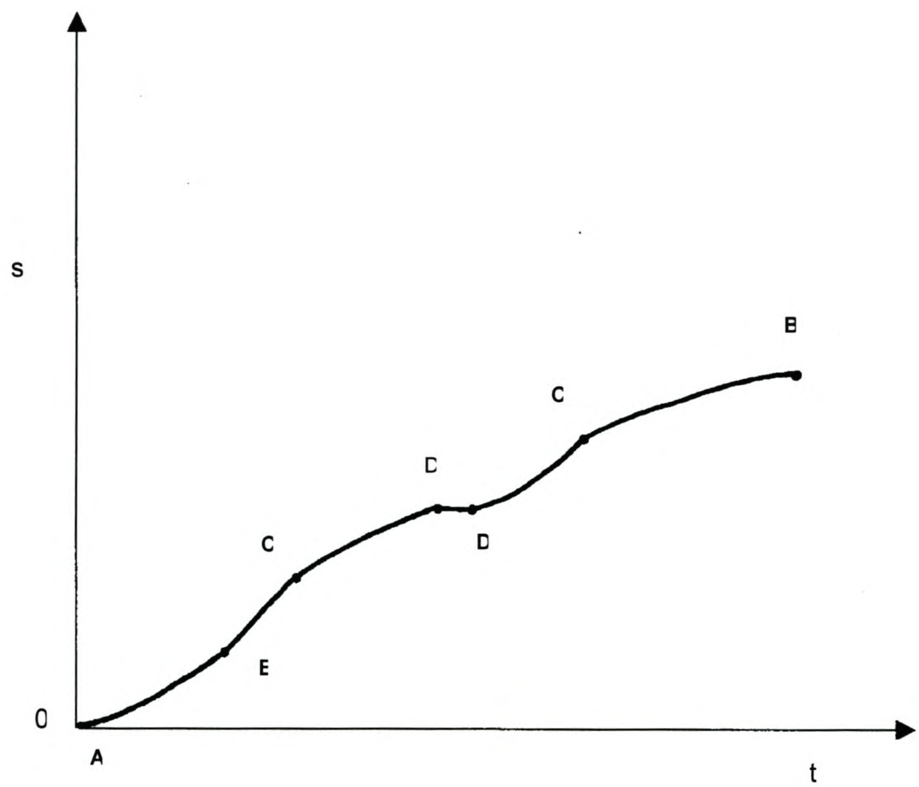


Figure 2.13: Distance-time sketch-graph for the motion of the car in the road test scenario.

Not much emphasis is placed on distance-time representations at school level. This may be an underlying cause of the problem learners have with the representation and interpretation of negative and positive displacement. If learners were given tasks where they had to represent changes in distance over time and changes in displacement over time, perhaps on the same set of axes, they could possibly build up an understanding of the need to use sign convention to indicate the directional aspect of the displacement and thus build up an understanding of what is meant by a positive and negative displacement.

<u>*Propositional statement 20:*</u>

A displacement-time graph is a graphical representation of the relationship between displacement and time for a moving object.

A sketch-graph of displacement versus time for the motion of the car in the road test scenario can be drawn as follows:

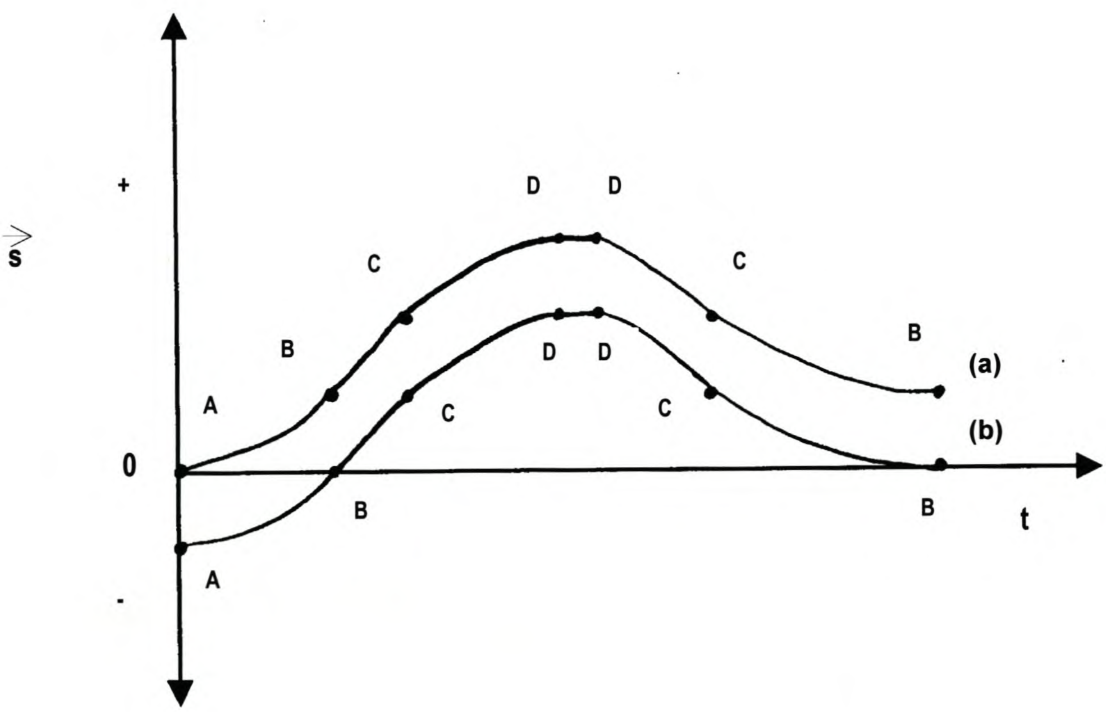


Figure 2.14: (a) Displacement-time graph where the chosen reference point is flag B.
(b) Displacement-time graph when the chosen reference point is flag A.

Learners display a number of problems with this type of graphical representation. They have difficulty drawing the curved sections of the graph and/or interpreting what they mean. They also do not demonstrate a good understanding of the necessity of specifying a reference point and how this affects the displacement-time representation. For example, in Figure 2.14 above, many learners would not recognize that it is the same motion being represented in both graphs, the only difference being that a different reference point was chosen in each case. They have difficulty seeing that the choice of reference point only affects the position of the graph on the set of axes, and that the shape of the graph remains the same.

Another difficulty is the meaning learners give to the situation where the graph crosses the x-axis. It is not unusual to hear learners say that the object is stationary at this point, rather than identifying this as representing a point during the object's motion when it is at the reference point.

These difficulties have been identified and reported in studies by McDermott, Rosenquist, Mark and van Zee (1987) and Goldberg and Anderson (1989). These studies are described in Chapter 4 of this report.

As mentioned above, the specified reference point and the reference direction can easily be changed when monitoring an object's motion using the motion sensor component of the TRAC PAC in association with the MPLI programme.

It may be possible that exercises like these, where learners are given opportunities to specify the reference point and then collect motion data using the reference point they have specified, may allow them to develop a better understanding of how choice of reference point affects representation of motion. The potential of the TRAC PAC to contribute to such understanding is investigated in this study.

Analysis of different features of accurately drawn kinematic graphs can give a quantitative indication of other features of the motion. For example:

2.1.12.1 Coordinates of a kinematic graph

Propositional statement 21:

The y-coordinate at a point on a kinematic quantity versus time graph corresponds to the height of the graph at that point and gives the value of the kinematic quantity while the x-coordinate at the same point gives the time corresponding to that particular value.

The MPLI programme, which the TRAC PAC uses, has a feature called the EXAMINE function which, when switched on, provides the x and y coordinates at any point on the graph. Figure 2.15 below provides an example of how this can be done for the motion of the ball in Scenario 2 which was described earlier in this chapter.

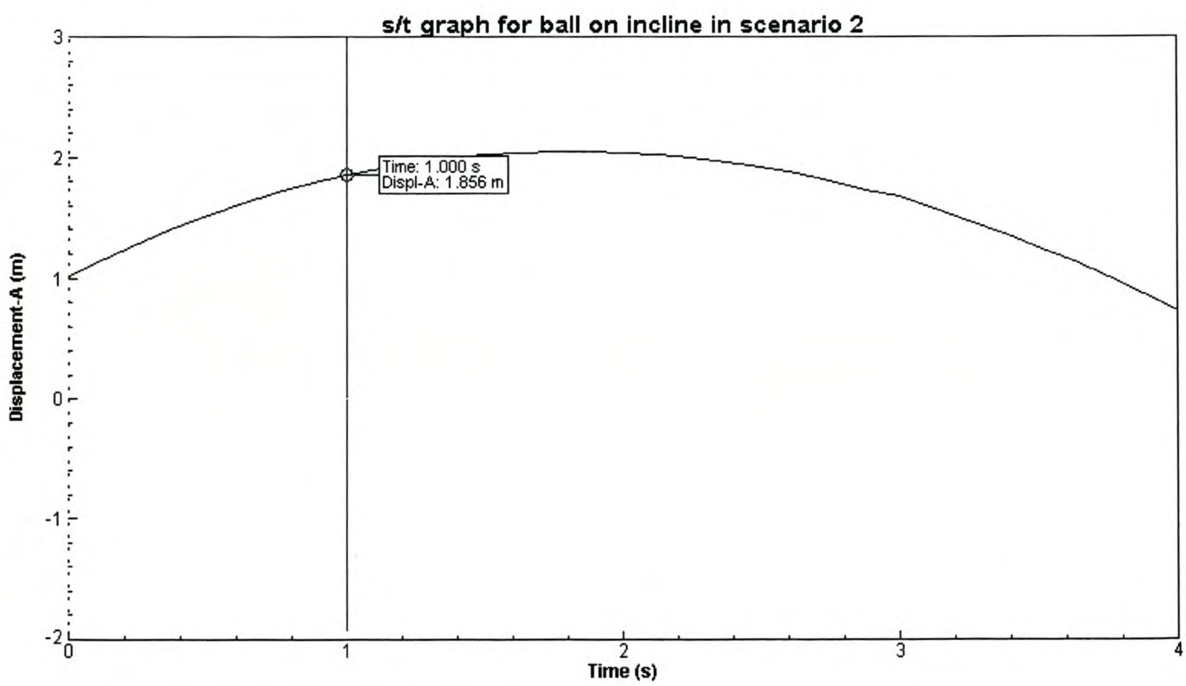


Figure 2.15: Using the *EXAMINE* function to show the x and y coordinates at a specific point during the ball's motion.

2.1.12.2 The slope of a kinematic graph

Propositional statement 22:

The slope of a kinematic-time graph gives the rate-of-change of that particular kinematic quantity.

Thus, for a displacement-time graph, the slope gives the rate-of-change of displacement, which is the velocity of the object:

- A zero slope (graph parallel to the x-axis) indicates a zero velocity. The object is stationary (e.g. interval DD on the graphs in Figure 2.14). A constant slope indicates that the object has a uniform velocity (e.g. interval BC on the graphs in Figure 2.14).
- A changing slope (curved portion of the displacement-time graph) indicates that the velocity is changing and consequently that the object is accelerating (e.g. intervals AB, BC, CD, DC and CB on the graphs in Figure 2.14).
- A positive slope indicates that the object is moving in the direction chosen as positive (e.g. intervals AB, BC and CD on the graphs in Figure 2.14), and a negative slope indicates that the object is moving in the direction chosen as negative (e.g. intervals DC and CB on the graphs in Figure 2.14).
    - The steepness of the slope is an indication of the magnitude of the velocity and in the case of a curved graph, the rate at which the steepness changes gives an indication of how quickly the velocity is changing (an indication of the magnitude of acceleration of the object).

The MPLI programme has a useful feature called the *TANGENT LINE* function. It draws a tangent at any point on a graph and allows users to examine the slope of the graph at that point. Using the *EXAMINE* function in conjunction with the *TANGENT* function allows one to explore relationships between the various quantities.

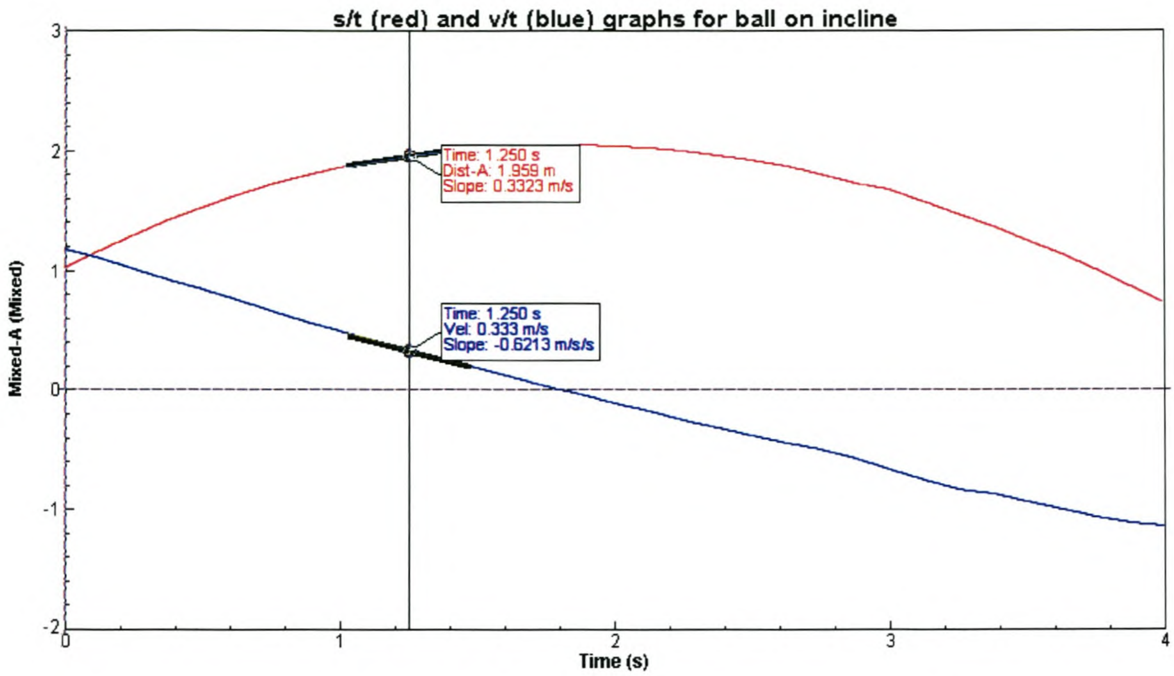


Figure 2.16: The *EXAMINE* function and the *TANGENT* function can be used to explore relationships between kinematic quantities.

It can thus clearly be seen that the slope of the displacement-time graph at a specific point is equal to the velocity at that point. Examining different points on the graph may allow learners to build up an understanding of how the slope changes over the motion, and how this relates to the velocity of the object.

These features of the MPLI programme can possibly contribute to learner understanding of information that can be generated from the slope of a graph and are part of the elements being investigated in this study.

2.1.13 Speed-time and velocity-time graphs

Propositional statement 23:
A speed-time graph is a graphical representation of variation of an object's speed with time.

Propositional statement 24:
A velocity-time graph is a graphical representation of variation of an object's velocity with time.

A sketch graph of speed versus time (v-t) for the car in the road test scenario above can be drawn as follows:

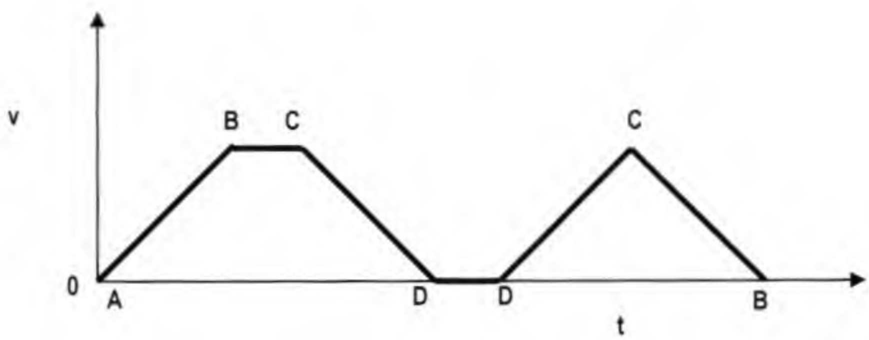


Figure 2.17: Speed-time sketch graph for the motion of the car in the road test scenario.

The graph indicates that the speed of the car increases uniformly between flag A and B. It then moves at a uniform speed between flag B and C. Its speed decreases uniformly from C until it comes to a stop at flag D (where it spends 5s turning around). Its speed then increases uniformly until it reaches flag C where its speed again begins to decrease uniformly until it comes to rest at flag B.

In South African schools, learners are very seldom exposed to, or required to work with speed-time graphs. If they do, it is usually only the Higher-Grade learners who get this opportunity. Again this, in the researcher's opinion, may be one of the underlying reasons why learners experience difficulty differentiating between the concepts of speed and velocity, and the difficulty they have working with negative quantities and areas of graphs under the x-axis. It may be that when learners have the opportunity to work simultaneously with speed-time and velocity-time graphs, this may contribute to them developing a qualitative understanding of the difference between the two concepts and thus allow them to assign a correct interpretation to what is meant by a negative velocity and to portions of velocity-time graphs which appear below the x-axis.

A sketch graph of velocity versus time for the motion of the car in the road test described can be drawn as follows:

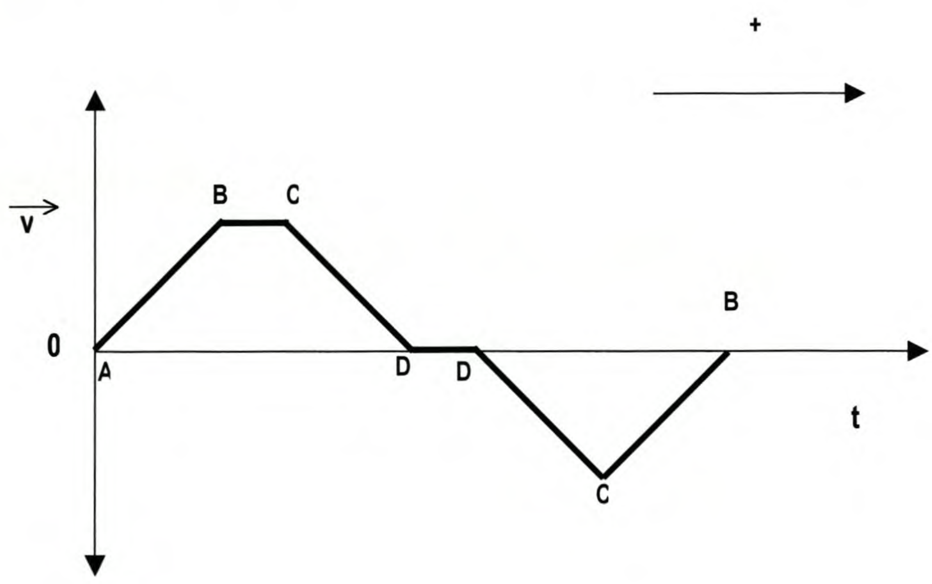


Figure 2.18: Velocity-time sketch graph for the motion of the car in the road test scenario.

The graph indicates that the velocity of the car increases uniformly between flags A and B. It then moves at a uniform velocity between flag B and C. It's velocity decreases uniformly from C until it comes to a stop at flag D (where it spends 5s turning around). The magnitude of its velocity then increases uniformly until it reaches flag C where the magnitude of its velocity again begins to decrease uniformly until it comes to rest at flag B.

Note that regardless of whether the reference point is chosen to be flag A or flag B, the shape of the graph and its position on the axes will be the same. Thus, choice of reference point only affects the displacement-time representation.

However, any portions of the graph that are above the x-axis are an indication that the object is moving in the direction chosen as positive. Similarly, any portions of the graph below the x-axis indicate that the object is moving in the direction stipulated as negative.

When a velocity-time graph crosses the x-axis, this is an indication that the object has stopped (indicated by the point on the x-axis) and then continued moving in the opposite direction (indicated by the portion of the graph continuing on the opposite side of the axes).

The study by Goldberg and Anderson (1989) identified several difficulties that learners experience when working with negative quantities on a kinematic-time graph, including difficulty with interpreting what crossing the x-axis actually means and with working with portions of the graph which lie in the negative area below the x-axis. This study, and these difficulties are discussed in greater depth in Chapter 4 of this report.

The slope of a velocity-time graph is a representation of the rate of change of velocity and is thus a representation of the acceleration of the object.

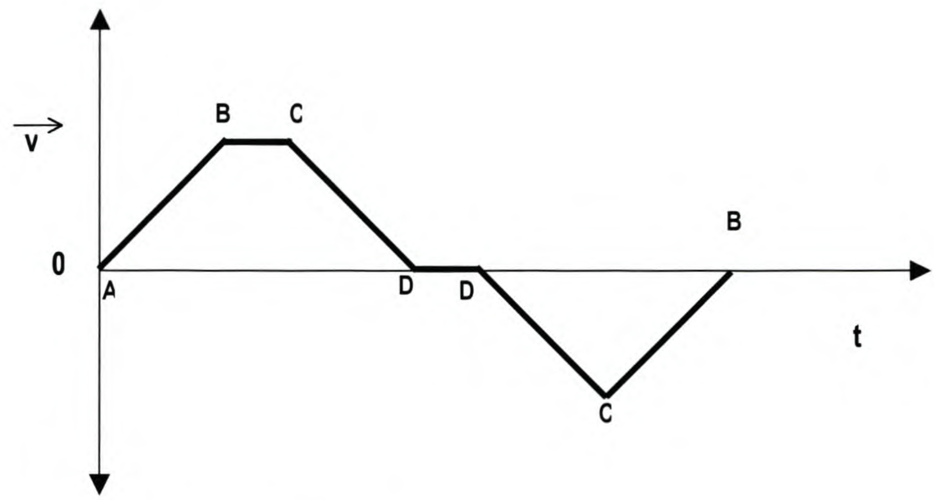


Figure 2.19: The slope of a velocity–time graph is an indication of the acceleration of the object.

In the velocity-time graph for the car scenario above, slope AB indicates that the car is accelerating uniformly in the direction chosen as positive. The level portion of the graph (B-C) indicates that the car is moving at a uniform velocity (zero acceleration) in the positive direction. The slope CD indicates that the car is slowing down uniformly while still moving in the positive direction until it comes to a position of rest at flag D where it spends 5s turning around. Slope DC under the x-axis indicates that the car is speeding up, but now in the opposite direction (the negative direction). Slope CB indicates that the car is slowing down while still moving in the negative direction, until it comes to a position of rest at flag B.

An upward slope (left to right) above the x-axis indicates a positive acceleration (the resultant force causing the acceleration is acting in the direction chosen as positive). This causes the car to speed up uniformly while moving in the positive direction (e.g. slope AB above the x-axis).

An upward slope (left to right) below the x-axis indicates that the object has a positive acceleration (the resultant force producing the acceleration is acting in the direction chosen as positive. Since the car is moving in the negative direction at this time, this causes the car to slow down uniformly (e.g. slope CB under the x-axis).

A downward slope (left to right) above the x-axis indicates a negative acceleration (the resultant force causing the acceleration is in the direction chosen as negative). Since the car is moving in the positive direction at this time, this causes the car to slow down uniformly (e.g. slope CD above the x-axis).

A downward slope (left to right) under the x-axis represents a negative acceleration while the car is moving in the negative direction. This causes the car to speed up uniformly in this direction (e.g. slope DC below the x-axis).

This can be summarized as follows:

Table 2.1: Interpreting the meaning of the slope of velocity-time graphs for uniform accelerated motion in a straight line.

Type of slope	Direction of movement	Direction of resultant force	Direction of acceleration	Interpretation
Upward slope above x-axis	positive	positive	positive	Object is speeding up while moving in the positive direction.
Upward slope below x-axis	negative	positive	positive	Object is slowing down while moving in the negative direction.
Downward slope above x-axis	positive	negative	negative	Object is slowing down while moving in the positive direction.
Downward slope below x-axis	negative	negative	negative	Object is speeding up while moving in the negative direction.

The MPLI programme provides the facility of being able to collect motion data and then immediately display (on the same screen) displacement-time, velocity-time and acceleration-time representations of the motion which the learner can then compare. This may contribute to overcoming these problems.

In addition, the *TANGENT LINE* function can be used to examine the slopes of all the graphs at the time instant during the motion. Using the *EXAMINE* function in conjunction with the *TANGENT* function allows the user to compare slope values on one graph with co-ordinate values on another graph. For example, the *TANGENT* function can be used to give the slope of a velocity-time graph at a specific point while the *EXAMINE* function can be used to display the acceleration value at the same time on the acceleration-time graph.

Figure 2.20 below provides an example of how this can be done for the ball rolling up and down the slope in Scenario 2 which was described earlier in this chapter.

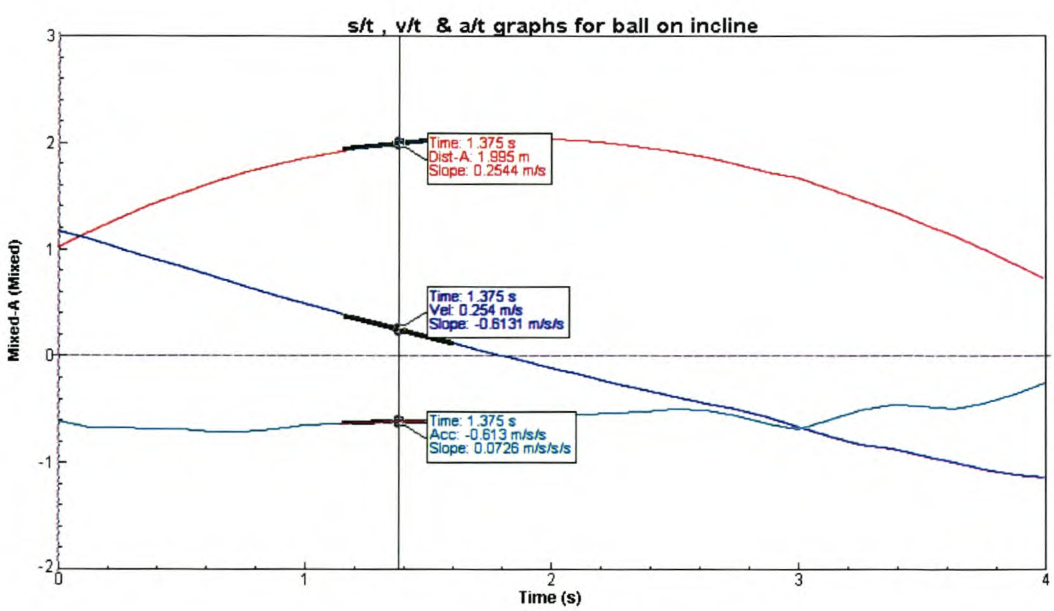


Figure 2.20: s/t (red), v/t (blue) and a/t (green) graphs for the ball rolling up and down an incline in Scenario 2.

The TANGENT function and EXAMINE function have been used to analyse the graphs after 1s has elapsed. One can easily identify the slope of the velocity time graph ($-0,6507 m.s^{-2}$) and the acceleration at that point ($-0.652 m.s^{-2}$), and this demonstrates quite vividly the relationship between slope of a velocity-time graph and acceleration.

The studies conducted by Goldberg and Anderson (1989) and McDermott *et al.* (1987) have highlighted difficulties that learners experience with interpreting the meaning of different slopes on kinetic-time graphs. These studies and the specific difficulties they identified are described in Chapter 4 of this report.

MBL exercises involving working with the slopes of kinematic-time graphs like the ones described in the discussion above may help overcome learner difficulties and enhance understanding of concepts in this area. Their potential to do this is part of the focus of this study.

Propositional statement 25:
The area under a velocity time graph is a measure of the change in displacement of the object.

The overall displacement of the car in the road test scenario can be determined by adding areas 1, 2, 3 and 4 as shown below.

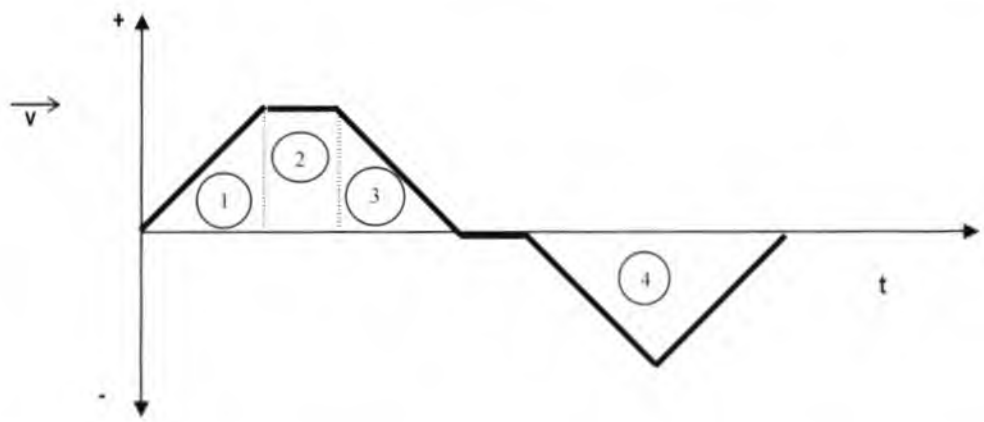


Figure 2.21: The area under a velocity–time graph is an indication of the displacement of the object.

A typical error learners make here is the failure to allocate areas under the x-axis negative signs because they represent negative displacements. Again, this error may be caused by the difficulty learners experience with negative quantities and interpreting portions of the graph under the x-axis.

The *INTEGRAL* function of the MPLI programme allows the area under a graph to be calculated. Learners can then compare this figure with the associated displacement on the displacement-time graph, and thus develop an understanding about the relationship between displacement and area under a velocity-time graph.

Figure 2.22 below provides an example of how this can be done using the experimental set-up described in Scenario 2 earlier in this chapter.

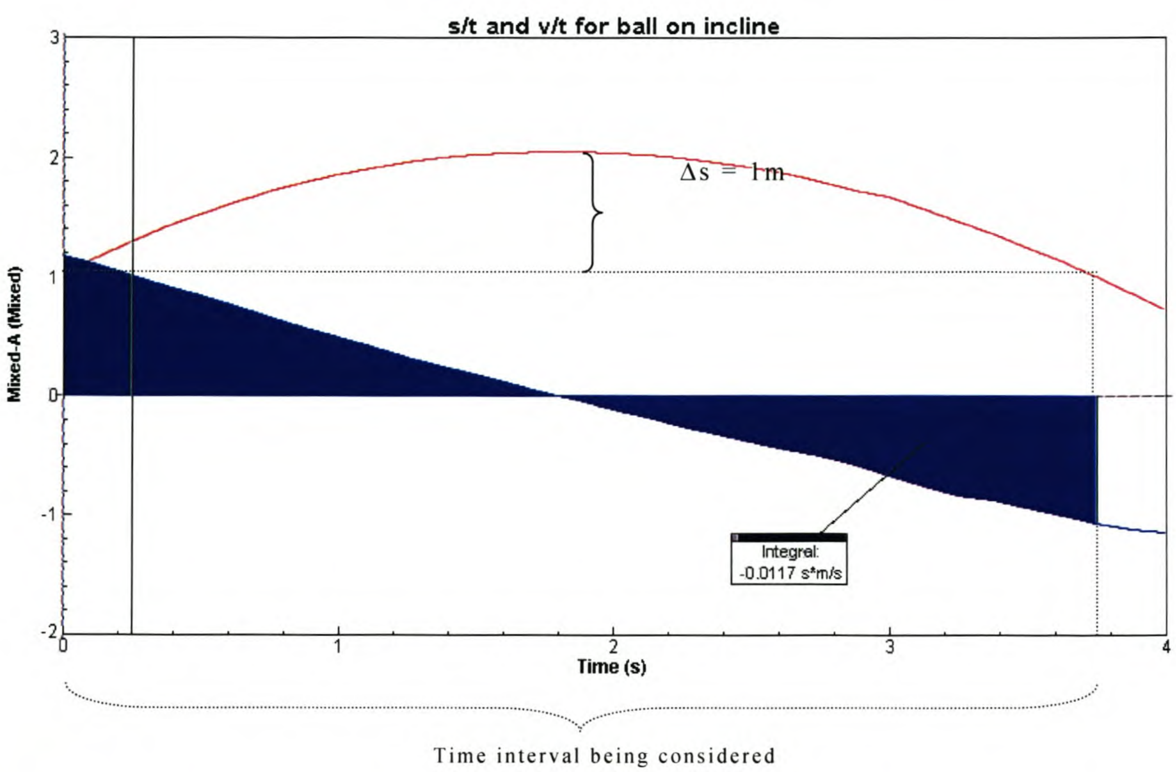


Figure 2.22: s/t (red) and v/t (blue) for a ball rolling up and down an incline.

The s/t graph illustrates that, for the time interval being considered the ball has a displacement of zero (it moves 1 metre up the slope and 1 metre down, and is therefore back at its original position). Using the *INTERGRAL* function to obtain the area under the v/t graph, a value very close to zero (0.0117) is obtained.

MBL exercises can be developed where learners analyze the displacement-time graph to determine the displacement over a particular time interval, and then work out the area under the velocity-time graph for the corresponding time interval. Exercises like this may contribute to learners' understanding about relationships between displacement and velocity and will thus be one of the areas investigated in this study.

2.1.14 Acceleration-time graph

Propositional statement 26:

An acceleration-time graph is a graphical representation of variation of an object's acceleration with time.

As mentioned before, discussion of motion at school level in South Africa is limited to rectilinear motion where objects are moving with a uniform velocity or with a uniform acceleration. Thus, learners only have to work with acceleration-time graphs which are straight lines parallel to, or on the x-axis. Even with this simplification, learners still experience problems using acceleration-time graphs to represent motion, or interpreting acceleration-time graphs of different motions.

A sketch graph of acceleration-time for the car road test in Scenario 1 above could be drawn as follows:

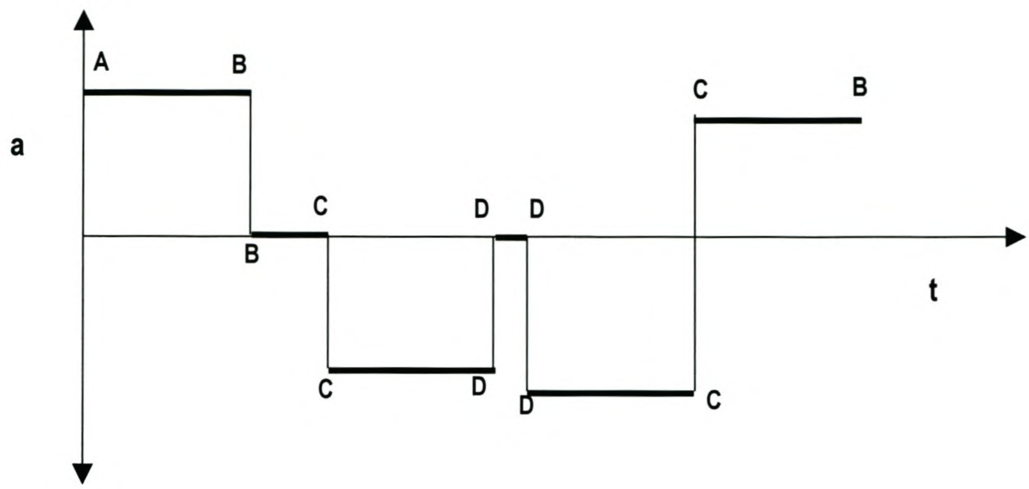


Figure 2.23: Sketch graph of acceleration versus time for the car in the road test scenario.

Learners experience difficulty deciding whether to represent the different accelerations with horizontal lines above or below the t-axis. They may represent all accelerations where the speed of the car is increasing as positive above the t-axis and all accelerations where the speed of the car is decreasing as negative, below the t-axis. Thus they may not recognize how the direction of the force causing the acceleration influences the direction (and hence the sign) of the acceleration.

A typical graph illustrating this error is drawn below:

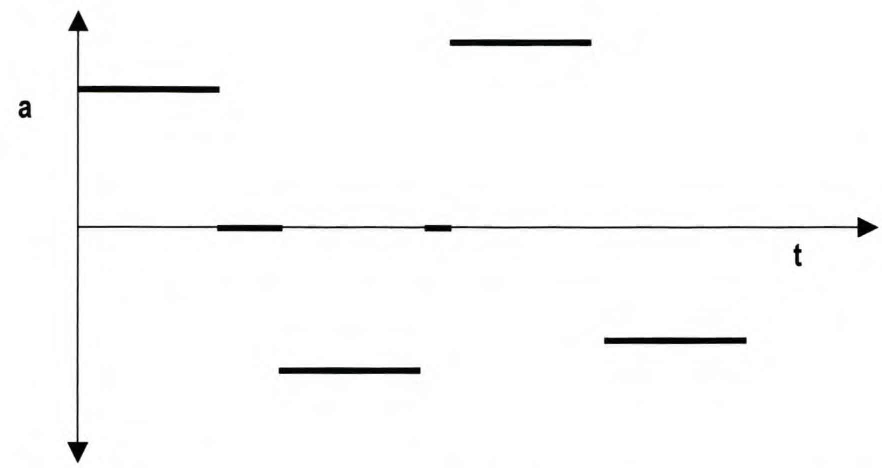


Figure 2.24: Incorrect sketch graph of acceleration versus time for the car in the road test scenario, exhibiting student difficulty with representing direction of acceleration.

These difficulties that learners experience with the graphical representation of acceleration have been identified and described in study conducted by McDermott *et al.* (1987), which are discussed in greater depth in Chapter 4 of this report.

In the acceleration-time graph obtained by collecting motion data using the TRAC PAC as described in Scenario 2 where the ball rolls up and then down an incline, the acceleration is consistently represented as being negative (a roughly parallel line below the t-axis). In this case the direction up the incline was specified as being positive. Thus the resultant force producing the acceleration as the ball rolled up the slope, and the acceleration as the ball rolled down the slope acted in the negative direction, resulting in a negative acceleration for the whole motion (see Figure 2.25).

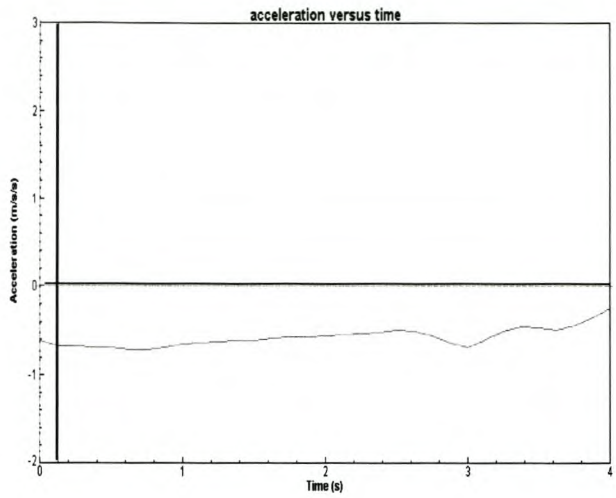


Figure 2.25: Acceleration-time graph obtained using the TRAC PAC in Scenario 2 described earlier in this chapter.

It is a simple exercise, when using the TRAC PAC, to specify the upward direction as being negative and then to observe the effect this will have on the representation of the acceleration on the acceleration-time graph. Thus, practical and visual exercises like this may contribute to learners developing a clearer understanding of what is meant by negative and positive acceleration and their representation in acceleration-time graphs. Again, this is one of the areas that will be explored in this study.

2.2 Applicability of the TRAC PAC to the teaching of kinematics

The TRAC PAC is a microcomputer-based laboratory tool. The motion sensor component of the PAC can be used to generate real-time s/t, v/t and a/t kinematic graphs for an object's motion. Since the equipment itself generates the graph, aspects like ability to draw accurate graphs - which incorporates skills like the learner's ability to draw a set of axes, choose an appropriate scale, plot points on the graph, connect points, use the graph to generate additional accurate quantitative information about the object's motion, etc. – may need to be developed in other ways. A common method in South African classrooms involves the use of a ticker timer to generate a ticker tape representation of the object's motion and analysis of the tape to determine relationships between quantities, which are then represented graphically.

It is proposed that the TRAC PAC's major strength is its potential to contribute towards and even assess learners' qualitative understanding of kinematics. As pointed out at various points in this chapter, it is a relatively simple matter to create activities that develop learners' ability to generate real-time graphs of a variety of motions, to focus on specific aspects of the motion using the associated programme analysis tools, to compare representations for different motions, to interpret graphical representations, to translate graphical representations into other representation forms and to transform from one type of graphical representation to another.

The main focus of this research project is thus to assess the TRAC PAC's potential to contribute towards a qualitative understanding of kinematics and more specifically, graphs of motion.

2.3 Diagram of a concept map relating to the propositional knowledge statements

Step 2 of Treagust's (1988:161) method for designing diagnostic tests involves the development of a concept map showing the relationships between propositional knowledge statements in the content area. The concept map which follows (Figure 2.26) illustrates the relationships between the main concepts being explored in this area.

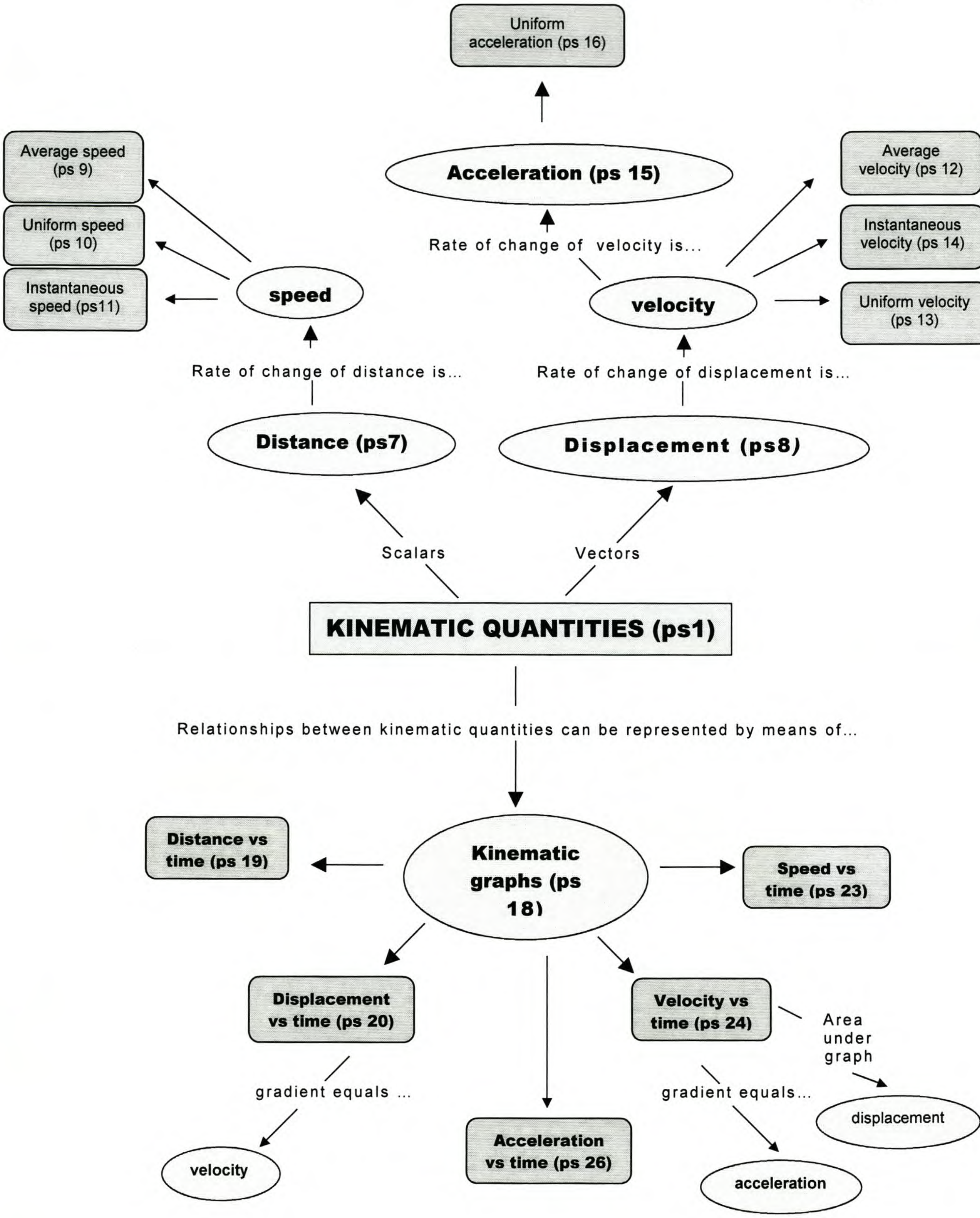


Figure 2.26: Concept map showing the main concepts explored in this study (ps = propositional statement).

2.4 The teaching and learning of kinematic graphs in South African schools

Learners' understanding of kinematic graphs is directly dependent on the experience they have of this knowledge area in school. Some of the factors that influence how teachers approach the topic and consequently how learners experience it, include the official syllabus, the treatment that the topic gets in officially recognized school textbooks and the nature of assessment. These are explored in more detail in the discussion below.

2.4.1 Kinematics and kinematic graphs in the Interim South African school syllabus

The following is an extract from the present Physical Science (HG) interim[1] syllabus in KwaZulu-Natal, one of the 9 provinces of South Africa. Syllabi in other provinces will be similar to this.

CONTENT	PRACTICAL WORK	OBJECTIVES
8. Kinematics 8.1 Basic kinematic concepts The concepts distance, displacement, speed, velocity and acceleration. Distinction between: distance and displacement speed and velocity average speed and average velocity Velocity defined as rate of change of displacement. The meaning of uniform	8.1 [T] Use a ticker- timer to investigate (a) constant velocity (b) uniform acceleration	Pupils should be able to (i) define: average acceleration and instantaneous acceleration (ii) interpret: the graphs of s/t, v/t and a/t for both constant velocity and constant acceleration. (iii) perform calculations using the equations

[1] After the first democratic elections took place in South Africa in 1994, a curriculum review process was instituted which had the goal of adapting the apartheid-era syllabi to create a uniform syllabus for all South African learners. This led to the creation of Interim Syllabi for the various school subjects, which were to be used until a comprehensive curriculum review process could be undertaken. This has been undertaken, a new National Curriculum Statement has been developed and is due for implementation at Grade 10 level in 2006.

velocity (constant velocity). The equation s = vt for zero acceleration. 8.2 <u>Graphs of motion and equations of motion</u> 8.2.1 Graphs of : displacement-time, velocity-time and acceleration-time (limited to graphs of linear motion with uniform acceleration. Information obtained from gradients of graphs and the 'area' under graphs. 8.2.2 Equations of motion: From the definition $a = \frac{v - u}{t}$ average velocity $v_{av} = \Delta s / \Delta t$ show that $v = u + at$ and $s = \frac{(u + v)}{2} . t$ Hence $s = ut + ½ at^2$ and $v^2 = u^2 + 2as$ (Graphically and algebraically) Emphasise that these equations apply in cases of uniform acceleration only. Candidates will **<u>not</u>** be expected to derive these equations in the final examination.		$s = vt$ $v_{av} = \frac{\Delta s}{\Delta t}$ $a_{av} = \frac{\Delta v}{\Delta t}$ $v = u + at$ $s = \frac{(u + v)}{2} . t$ $s = ut + ½ at^2$ $v^2 = u^2 + 2as$ (iv) c<u>ontrast</u>: scalar and vector quantities, distance and displacement, average speed and average velocity, ***instantaneous speed and instantaneous velocity, average acceleration and instantaneous acceleration.*** <u>Higher abilities</u> Pupils should be able to apply some of the above in unfamiliar situations.

8.2.3 Calculations using the equations of uniformly accelerated motion. Include free fall and objects projected vertically. (Take the value of 'g' as $10 m.s^{-2}$).		

(Kwazulu-Natal Department of Education and Culture: Syllabus for Physical Science (Higher and Standard Grade) Grades 11 and 12: 1995)

Note that:

- Italic bold face type in extract indicates Higher Grade requirements only.
- Practical work (experiments) marked [T] are intended for the teacher to carry out as a demonstration.

Some issues that arise from a perusal of this syllabus document in relation to graphs of motion include:

- Learners are not required to engage with distance–time and speed-time graphs.

- Learner investigative activity is limited to observation of demonstrations carried out by the teacher of uniform velocity and uniform acceleration. Learners may be requested to analyse ticker tapes generated in the investigations and to generate graphs from these. The experiments are often limited to motion in one direction, and thus learners have little opportunity to explore how direction of motion impacts on graphical representation of the motion. In addition, the fact that no reference is being made to reference point of the motion means that learners do not explore how changing a reference point impacts on graphical representation.

- Learners are not required to draw accurate graphs to represent relationships between kinematic quantities quantitatively, nor to sketch graphs to represent relationships between kinematic quantities qualitatively. This means that learners do not have sufficient opportunities to develop the skills of transformation (transforming one graphical representation into another, e.g. an s/t graph to a v/t graph) or translation (translating one type of representation into another, e.g. verbal or physical representation into a graphical representation).

In most cases in the South African context, teachers adhere rigidly to the syllabus in planning their lessons and teaching this section. This means that the detail included in the syllabus, the detail omitted and the lack of prescribed practical work largely determine what is taught and how it is taught. This may be one of the factors contributing to learners developing difficulties in this area.

2.4.2 Kinematic graphs in the South African National Curriculum Statement for Physical Sciences

The curriculum reconstruction process in South Africa has resulted in the creation of a National Curriculum Statement for various subjects, including the Physical Sciences, which is characterized by the adoption of outcomes-based and learner-centred approaches. This curriculum is due for implementation in Grade 10 in 2006, Grade 11 in 2007, and Grade 12 in 2008.

An extract from this statement of the section which has some description of content relating to kinematics and kinematic graphs is shown below:

MECHANICS

Grade 10 – 12.5%

- **<u>Motion In one dimension</u>:**
  - position, displacement, distance;
  - speed, average velocity, instantaneous velocity;
  - acceleration;
  - description of motion in words, diagrams, graphs and equations;
  - frames of reference.

- **<u>Gravity and mechanical energy</u>:**
  - weight (force exerted by the earth on an object);
  - acceleration due to gravity (acceleration resulting from the force exerted by the earth);
  - gravitational potential energy;
  - kinetic energy;
  - mechanical energy (sum of gravitational potential energy and kinetic energy);
  - conservation of mechanical energy (in the absence of dissipative forces).

Grade 11- 12.5%

- **<u>Force, momentum and impulse</u>:**
  - pairs of interacting objects exert equal forces on each other (Newton's Third Law);
  - momentum;
  - a net force on an object causes a change in momentum — if there is no net force on an object/system its momentum will not change (momentum will be conserved);
  - impulse (product of net force and time for which it acts on an object, momentum change);
  - a net force causes an object to accelerate (Newton's Second Law);
  - objects in contact exert forces on each other (e.g. normal force, frictional force);
  - masses can exert forces on each other (gravitational attraction) without being in contact, fields;
  - force between two masses (Newton's Law of Universal Gravitation);
  - moment of force, mechanical advantage.

Grade 12 – 12.5%

- **<u>Motion In two dimensions</u>:**
  - projectile motion represented in words, diagrams, equations and graphs;
  - conservation of momentum in 2D;
  - frames of reference.

- **<u>Work, power and energy</u>:**
  - when a force exerted on an object causes it to move, work is done on the object (except if the force and displacement are at right angles to each other);
  - the work done by an external force on an object/system equals the change in mechanical energy of the object/system;
  - power (rate at which work is done).

(Department of Education , 2003: 38-39)

Some comparisons that stand out in relation to the interim syllabus for Physical Science:

- Kinematics is not afforded a separate section, but is included in a broader framework of an exploration of Mechanics. It is intended that Mechanics as a whole, constitutes a substantial amount (12.5%) of the teaching/learning time at each grade level.
- In keeping with an outcomes-based approach, the detail of content that learners should explore is not described in as much detail, and in as prescriptive a fashion as in the previous syllabus.
- Practical work is not prescribed, with the intention being that this is left up to participants in the actual context to incorporate as required and/or needed as outcomes are being developed. However, the curriculum emphasises an investigative approach, with investigative ability being one of the three learning outcomes for the subject.
- Components of kinematics content in the previous syllabus, located largely at Grade 11 level, have been spread through Grades 10 to 12 in the new Curriculum Statement, taking into account issues of development and progression.

It will be interesting to observe how teachers interpret this new document in application in their classrooms. Of even more interest will be the interpretations made by text-book developers, as these often largely determine what happens in the classroom.

2.4.3 Kinematics and kinematic graphs in South African school text books

Prescribed textbooks have traditionally become a central factor in the South African school system – to the extent that many teachers seldom refer to the official syllabus but rather teach according to what is in the textbook. Thus, the choice of content and the manner it is presented in prescribed textbooks exert a powerful influence on the experience learners have of science.

Frauenknecht (1998: 101–114) provides a comprehensive description of the treatment this area of knowledge gets in some popular South African school textbooks and should be consulted for an in-depth discussion of all the textbooks. As an example, a discussion of the treatment that kinematic graphs get in one of these textbooks is conducted below.

2.4.3.1 Senior Basic Physical Science (Pienaar, Walters, Schreuder and de Jager, 1987)

Kinematic graphs are discussed in a chapter titled 'Uniform and Accelerated Motion' in this book.

- The authors begin with a discussion of a practical demonstration involving a ball rolling down an inclined portion of a model railway track onto an extended level portion. This is done to illustrate the concepts of uniform velocity and uniform acceleration in a practical situation.

- They then move on to a practical investigation of rectilinear motion with constant velocity using a dynamics-trolley attached to ticker tape, which passes through a ticker timer. The trolley is allowed to roll down an appropriately inclined smooth runway. Learners are expected to carry out the investigation, take appropriate measurements from the ticker tape and record these in a table. The measurements are used to calculate kinematic quantities that could not be directly measured e.g. velocity, which are also then included in the table. Learners are expected to use the data in the table they have constructed to generate kinematic graphs. They are required to draw a displacement-time graph and a velocity-time graph. A series of questions leads them through an analysis of these graphs. The questions are designed to allow learners to make links between features of the graphs and kinematic quantities. Presenting a hypothetical situation of a moving car on a road concludes the discussion of uniform velocity. Idealized displacement-time and velocity-time graphs of the motion of the car are used to consolidate the relationships and links learners should have 'discovered' in the practical investigation.

- An exploration of uniform accelerated motion is conducted in much the same way, except that in the hypothetical situation they present, the motion of a falling body is used to generate an idealized displacement-time graph and the motion of a 'moving body' is used to generate an idealized velocity-time graph.

- A summary of results from the practical investigation and discussion based on idealized scenarios follows. The summary shows ideal shapes of kinematic graphs for motion with a uniform velocity and motion with a uniform acceleration. It is interesting to note that in the summary, acceleration-time graphs are also presented, although these are not actually explored in the preceding investigations and discussions. The shapes of kinematic graphs of motion with a uniform negative acceleration are also presented (without any supporting discussion). The summary concludes with a statement of information that can be derived from kinematic graphs.

- A discussion of sketch graphs is carried out next. Readers are told what sketch graphs are. Distance-time, displacement-time, speed-time and velocity time sketch graphs for the motion of a ball which is thrown upwards and then caught again are presented.

- The chapter is concluded with a discussion of equations of motion, and how these can be used to calculate kinematic quantities associated with rectilinear, uniformly accelerated motion.

The approaches used by other popular textbooks do not differ significantly from this.

Specific learner difficulties that learners experience with kinematics and kinematic graphs are described in Chapter 4. Also in that chapter, possible links between learner difficulties in this area, and the treatment of the area in popular textbooks are reflected upon.

2.4.4 Kinematics and kinematic graphs in the Senior Certificate Examinations

It can be argued that the nature of assessment of a subject strongly influences the manner in which that subject is taught and learned. The predominant form of assessment of learners of physical science at senior certificate level in South African schools is through the use of formal examinations. Questions requiring learner understanding of kinematic concepts and their representation using kinematic graphs make up a significant part of final Senior Certificate physical science examinations in the South African school system. The integrated nature of the questions asked makes it difficult to separate this area of knowledge and expertise from other areas in the syllabus. However, a simple addition of the marks allocated to all questions in which understanding of kinematic graphs is directly examined, gives us a quantitative picture of the importance of understanding of this area of knowledge for learners.

The 1999 physical science papers from the following provinces or institutions illustrate this:

Table 2.2: Distributions of questions on kinematic graphs in the 1999 South African matriculation physical science examinations.

Province / Institution	Question and mark allocation	% of total mark
Western Cape Province	Question 1.2: 4 marks Question 1.5: 4 marks Question 2.3: 19 marks	13.5%
Eastern Cape Province	Question 8: 4 marks Question 1.1: 6 marks	5%
Northern Cape Province	Question 2.2.4: 4 marks	2%
Gauteng Province	Question 1.3: 3 marks Question 1.4: 3 marks Question 4: 25 marks	15.5%
Free State Province	Question 1.3: 3 marks Question 2.2: 4 marks	3.5%
Mpumalanga Province	-	-
North West Province	Question 1.4: 3 marks Question 2.2: 31 marks	17%
Northern Province	Question 1.4: 3 marks Question 3: 19 marks	11%
KwaZulu Natal	Question 1.2: 4 marks Question 1.4: 4 marks Question 2.6.4: 5 marks	6%
Independent Examinations Board	Question 1.6: 4 marks Question 2.2: 6 marks	5%

Thus one can see that learner understanding of kinematic graphs can have a significant effect on learner success rates in these examinations.

The specific difficulties that learners may have with kinematics and kinematic graphs, will impact on their ability to deal with examination-type questions in this area. Specific difficulties that learners may have are described in Chapter 4, and, in that chapter as well, some representative examination-type questions are discussed. The impact that specific difficulties may have on succesful solution to the problems is discussed.

CHAPTER 3

A survey of the literature: Theories of learning, conceptual change and understanding

This literature review provides a context in which the research is being undertaken, and explores various theoretical areas that may offer help in analysis of the data collected during the research. It covers three important areas related to this research study. Each area is dealt with in a separate chapter.

The literature survey begins in this chapter with an exploration of philosophical perspectives of science and goes on to demonstrate how these perspectives have influenced theories about science teaching and learning. Examples of some important learning theories are described, and these are used as a base to explore the origin of leaner misconceptions. Common misconceptions identified in the literature about kinematic graphs and related kinematic concepts are described in Chapter 4. Chapter 5 concludes the literature survey with an exploration of the use of computers in science education, particularly in the teaching of kinematic graphs.

3.1 Perspectives of Science

This discussion attempts to build up a description of the different perspectives that people have of science. The inclusion of this discussion in this literature review is important because these perspectives provide the platform from which different learning theories have developed.

All science activities, e.g. investigating, experimenting, teaching science, learning science, researching, etc. are at least partly grounded in views or philosophical perspectives of science, and making one's views or perspectives of science explicit, provides a framework and rationale for the manner in which one engages in these activities.

Nussbaum (1989:531) provides a useful representation of three well-known philosophical perspectives of science, and identifies key contributors to each perspective:

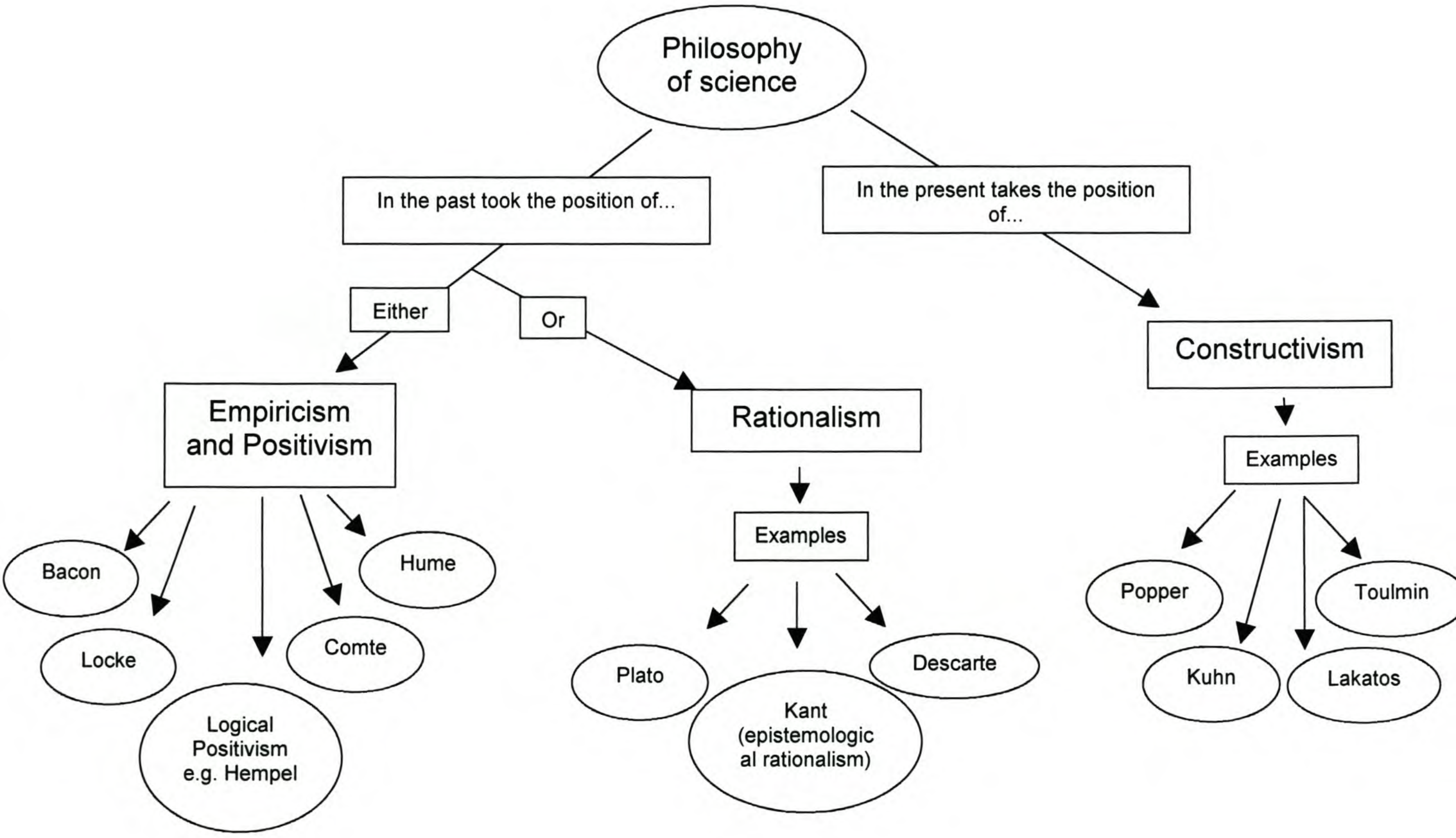


Figure 3.1: Perspectives of science (Adapted from Nussbaum, 1989).

These perspectives differ in the response they provide to several key questions, including:

- What is the nature of scientific knowledge?

- How does scientific knowledge grow?

- What are the applications of these philosophical perspectives in education?

These questions are used as a framework to elaborate on the various perspectives in the discussion that follows. In the conclusion to this discussion, principles and theoretical positions which the researcher identifies with most strongly and which have influenced the design and the direction of this study, are identified.

It is important to note that even within the different perspectives themselves, different theorists may provide different interpretations or explanations of phenomena. However, an in-depth examination of the different thinkers, and the differences between them, lie beyond the scope of this project. This review provides an overview of the different philosophical approaches, with an emphasis on educational (psychological) implications of the different perspectives.

3.1.1 The nature of science knowledge

Both positivists and rationalists view knowledge as that which "can be described in absolutist terms such as 'true', 'proven', 'confirmed', 'right' and 'correct'". (Nussbaum, 1989: 531). Knowledge is seen as being objective - existing outside of human influence - and as something "waiting out there to be discovered".

Constructivists however, hold the view that knowledge can never be proven or confirmed, but results from an individual's construction of meaning as he/she makes sense of the world. "Our own constructed theories determine how we perceive the world" (Nussbaum, 1989:531).

From this perspective then, knowledge is seen as being subjective and dependent on the world-view of the person who makes meaning of the knowledge.

3.1.2 The development of knowledge

In the positivist framework, knowledge is "discovered" through empirical endeavor using the scientific method and it is "accumulated inductively" (Nussbaum, 1989:535).

Rationalists view knowledge growth taking place through the application of logical processes (the scientific method) using existing or available "a priori mental structures" (Nussbaum, 1989: 535).

Theorists in the constructivist paradigm differ on how conceptual growth and change takes place. For example, Kelly (1997: 356) argues "constructivism straddles an epistemological divide". He suggests that the adherents of the radical and social varieties of constructivism show the largest separation. Constructivists who adhere to the conceptual change view of science "explicitly seeks to understand the cultural transmit of scientific practice and tends to favor a social view of knowledge construction". Adherents of the radical constructivist view focus on the "personal constructs of individuals" in the construction of knowledge.

In a similar description about differences within the constructivist perspective, Nussbaum (1989: 532) writes about those who see the use of "**inner** disciplinary criteria (e.g. rational-logical, empirical)" as being vital in the selection of knowledge (e.g. Popper), while others who "argue that the selection occurs under the influence of **outer** disciplinary factors (e.g., the personality of the scientist, socio-psychological processes in the scientific community, prevailing societal conceptions, institutional conditions and political pressures) as well as **inner** disciplinary factors" (e.g. Kuhn).

Different theorists also use different mechanisms to describe how conceptual change and the growth of knowledge takes place. For Popper, the logic of experimentation and the falsification of hypothesis through testing, was the main mechanism for achieving this. For Lakatos, progress occurred when a "rival research programme" was shown to be more "fruitful". For Toulmin, "conceptual systems change as individual concepts change their meaning in socio-historical process and by rational acts". For Kuhn, "theory-choice is a community decision, influenced by **shared** professional, social and psychological **values**, rather than by rules of choice" (in Nussbaum, 1989: 534).

While differing on **how** the shift from one conception to another takes place, theorists in the constructivist paradigm also differ on the **nature** of the shift. For constructivists like Popper, Lakatos and Toulmin, the growth of knowledge or a shift from one conception to another, is a gradual evolutionary process. For constructivists like Kuhn, conceptual change is revolutionary and occurs in moments of crisis (Nussbaum, 1989: 534).

3.1.3 Some applications in education

The philosophical views discussed above have been carried forward into the psychological/educational arena and articulated in a number of well-known and influential theoretical frameworks.

3.1.3.1 Behaviourism

The behaviorist tradition in education has its roots in the empiricist/positivist tradition. Skinner's "programmed learning" and Gagne's instructional design based on a "hierarchy of competencies" are good examples of learning models located in this framework. Nussbaum (1989:535) writes "both psychologists assumed that careful and systematic inductive teaching would **guarantee** correct learning".

3.1.3.2 Rationalism

For Piaget and his followers, conceptual development is dependent on the existence of "a priori mental structures" which include categories like "formal logic". The development of concepts in learners is dependant on whether they have developed the required "logical operations", and whether they can apply them (Nussbaum, 1989:535). From this perspective, Piagetian theory can be viewed as an expression of Kantian "epistemological rationalism" in the field of education. However, and perhaps more importantly, Piaget also elaborates on the role of the social context in the development of cognition for individual learners. From this perspective, Piagetian theory can be viewed as having constructivist roots as well. Piagetian theory is explored further in Section 3.3.1 of this chapter.

3.1.3.3 The constructivist approach

The constructivist approach is the application of constructivism in education. For constructivists, learners actively construct their own meaning as they participate in a learning situation, and elements of the learning situation, including socio-cultural elements, have an influence on learner ability to construct meaning.

"All versions of the constructivist approach in teaching require that both the teacher and the curricular activities help the students to actively construct their own meaning of the material under study" (Nussbaum, 1989:537).

The learning theories proposed by Piaget and Vygotsky can be viewed as a constructivist theories, and if there is a significant difference between the theories of Piaget and Vygotsky, it probably lies in the location of cognitive structure and the domain in which it is modified.

For Vygotsky, cognitive structure is publicly and socially determined, and so is located in the social domain. Social understanding is modified primarily through interaction with others in the social setting.

For Piaget, cognitive structure is located with the individual and is modified through interaction between the individual (subject) and objects in the environment, including people.

These two important theories are explored in greater detail in Section 3.3.1 and Section 3.3.2 of this chapter.

3.2 Concept learning and conceptual change

> Concept learning and conceptual change lie at the heart of science learning, since concepts provide the organizing element and the guiding principles for all lessons, as well as for all laboratory or fieldwork. (Nussbaum, 1989: 530.)

Klausmeier (1992: 268) describes a concept as being a mental construct consisting of an individual's organized information about the item, and that these mental constructs form the building blocks of a person's cognitive structure.

Hewson and Hewson (1984:4) describe a conception as a "functional unit of thought which has both propositional (knowing-that) and procedural (knowing-how or knowledge-in-action aspects)".

As a result of past experiences in a social environment, it is likely that most learners will enter a learning situation with some understanding of the subject matter being dealt with. Various terms are used to describe the prior understandings learners have, including "misconception", "mixconception" (Nussbaum, 1989), "preconception", "alternative conception" (Hewson and Hewson, 1984), "students' alternative framework" (Driver and Eastley, 1978), "children's science" (Gilbert, Osborne and Fensham, 1982) and "spontaneous or everyday concepts" (Vygotsky, 1987). Each term has a slight variation in meaning which places emphasis on the way the particular writer or theorist views the issue. The terms will be used interchangeably in this report, with the understanding that all, in some way, refer to the pre-conceived notions that learners bring into a learning situation.

Rather than developing a completely new understanding or conception of something, most classroom learning involves building on or changing existing ideas that learners have, i.e. developing a new understanding of existing concepts. This can be referred to as conceptual change. This view has been developed into a model of learning as conceptual change by theorists such as Posner, Strike and Hewson (1982) and Hewson and Thorley (1989). (See 3.3.4 below.)

Researchers, educationists and curriculum developers have focussed much attention on the area of learner preconceptions and conceptual change in the past two decades. Driver (1989: 481) suggests that two reasons for the growth of interest in the area could be that:

- "...findings addressed the concerns of science educators and teachers directly, illuminating problems of communication and understanding that exists at the heart of teaching."

- Studies in this area have made important contributions to an emerging new perspective on learning, known broadly now as the 'constructivist perspective'. "Central to this perspective is the historically important view that learning comes about through the learner's active involvement in knowledge construction."

Typical studies in this field have focussed on:

- In-depth investigations into learner conceptions in specific domains.

- Cross-age studies that have documented the "progressive evolution of children's conceptions within specific domains." (Driver, 1989:483.)

- Studies aimed at developing and/or contributing towards a theory of conceptual change.

- "Classroom studies designed to promote conceptual change in a specific domain..." (Driver, 1989: 485.)

- A recent area of interest for investigation has been the relationship between metacognition and conceptual change.

This particular research project is an integration of the last three focuses above.

If it is agreed that learning is an "adaptive process, one in which the learners' conceptual schemes are progressively reconstructed", then some important questions that need to be considered regarding concept learning and conceptual change include:

- What is the source of the 'ideas' that learners bring into a learning situation? (Section 3.2.1.)

- What is the nature of these 'ideas'? (Section 3.2.2.)

- How does concept learning and conceptual change take place? (Section 3.3.)

- How can learner conceptions be identified? (Section 3.4.)

- What effects can teaching have on learner conceptions? (Section 3.5.)

- When will teaching bring about effective conceptual change? (Section 3.6.)

These questions are examined in the discussion that follows.

3.2.1 The source of learners 'ideas'

For behaviorists:

> Any conception that is at odds with that of the accepted scientific community is simply wrong, and it deserves the label '*misconception*'. The sources for misconceptions are always faulty observations or *mis*applications of logic. (Nussbaum, 1989:535.)

For Piagetian theorists, misconceptions arise because the learners are at a stage where they do not have access to the necessary operations, or because they simply misuse them:

> The reasons for differences between student's conceptions and scientific ones are that they are at a developmental stage during which the required logical operations have not yet been developed, or that they simply misapply logical operations. (Nussbaum, 1989:535.)

Klausmeier (1992:274) differentiates between developmental inability and misapplication when he describes an "immature concept" and a "misconception". He suggests that an immature concept arises when a learner is at a developmental stage below that which is required for complete development of the concept. This learner:

> ...makes errors in identifying difficult examples and non-examples, cannot use the concept adequately, has a meaning that differs from that of the experts, draws incorrect inferences or demonstrates some combination of these. (Klausmeier, 1992:274.)

He describes a misconception as being formed when a learner has access to the necessary structures and processes but uses the concept in question at a much lower level.

These theorists seem to suggest that the learner characteristics, such as the inability to observe correctly, not having reached the necessary developmental stage, incorrect application of the concept by the learner, etc., are the reasons behind the development of misconceptions. Other theorists look beyond the individual to the social situation in which the individual is operating in order to identify sources of misconceptions.

For example, Driver, Guesne and Tiberghien (1985:2) use a constructivist framework to describe some of the sources of learners' 'ideas' when they write that:

> Children come to science classes with ideas and interpretations concerning the phenomena that they are studying even when they have received no systematic instruction in these subjects whatsoever. Children form these ideas and interpretations as a result of everyday experiences in all aspects of their lives: through practical physical activities, talking with other people around them and through the media. (Driver, Guesne and Tiberghien, 1985:2.)

Bodner (in Marais, 1997) also holds this view when he writes:

> In an attempt to create order from the chaos of information with which they are constantly bombarded, they subconsciously construct knowledge that fits their experience, that is, they adapt the information to make sense in terms of their intuitive knowledge of a topic. (Bodner in Marais, 1997)

Misconceptions can also have their source in the formal teaching and learning situation. Various studies (see for example Ivowi and Oludotun 1986, Helm 1978) have demonstrated that science teachers themselves can hold misconceptions. It is likely that these misconceptions will be passed on to their learners during teaching.

Writers like Helm (1978) and Warren (1965) have suggested that textbooks are another potential source of misconceptions, and errors have been identified in a number of science textbooks that can give rise to misconceptions.

3.2.2 The nature of learners' 'ideas'

Driver *et al.* (1985:2) describes three characteristics of these ideas:

- "These ideas are personal."

Learners make sense of an experience in their own individual way, and while they may build up an understanding that is shared with other people, it is unlikely that one learner will develop an understanding which is exactly the same as another learner's.

> " Individuals internalize their experience in a way which is at least partially their own; they construct their own meanings. These personal 'ideas' influence the manner in which information is acquired." (Driver *et al.*, 1985: 2.)

- "A child's individual ideas may seem incoherent."

Learners may offer contradicting explanations for the same phenomena, and see no problem in doing this. For example, in a structured learning situation, e.g. the classroom, a learner may attempt to offer an academic explanation, while in an everyday situation he may rely on a 'common-sense' explanation. Driver *et al.* (1985:3) writes that:

> The same child may have different conceptions of a particular type of phenomenon, sometimes using different arguments leading to opposite predictions in situations which are equivalent from a scientist's point of view, and even switching from one sort of explanation to another for the same phenomenon." (Driver *et al.*, 1985:3.)

- "These ideas are stable."

It can be very difficult to change learners' conceptions and the tenacity or stability of these is well documented in the literature.

> It is often noted that even after being taught, students have not modified their ideas in spite of attempts by a teacher to

> challenge them by offering counter-evidence. (Driver *et al.*, 1985:3.)

Treagust (1988:16) also holds this view when he writes that:

> It is however, well documented that the task of changing misconceptions is extremely difficult, as they have often been incorporated securely into cognitive structures. (Treagust, 1988:16.)

In an introduction to their model on conceptual change, Hewson and Thorley (1989: 541) describe learner' ideas as being "rich, pervasive, contrary and stubborn".

Panse, Ramadas and Kumar (1994: 64) write that:

> Investigations have revealed that student's conceptions have a marked degree of universality that cuts across different cultures, that they have a measure of internal consistency and, what is more important from the point of view of pedagogy, the alternative conceptions are fairly robust and resistant to formal training. (Panse, Ramadas and Kumar, 1994: 64)

3.3 Theories and models of learning and conceptual change

3.3.1 Piaget's theory

The discussion which follows explores Piaget's theory of cognitive development. The theory is a comprehensive and detailed one, and the discussion here highlights elements of it that may be pertinent to this study. Piaget's theory, as it is understood today, evolved as a result of his work, research and writing over time (1920s – 1980s). The discussion here draws strongly on a summary by De Lisi and Goldbeck (1999).

De Lisi and Goldbeck (1999: 5) describe constructivism as "a process in which the individual reflects on and organizes experiences to create order in and adapt to the environment". They suggest that Piaget's theory of cognition incorporates two related meanings for the term:

- They suggest that one interpretation of constructivism in the theory is that is refers to the refinement of existing cognitive systems over time, an aspect which Piaget labeled as **development.**
- Secondly, it refers to the **application** of existing cognitive systems to present circumstances in order to make meaning of those circumstances.

These two meanings can be seen in the diagram which follows and which outlines Piaget's theory of cognition. The right hand side of the diagram reflects the **development** aspect, while the left hand side reflects the **application** aspect.

In the discussion that follows, the various facets of the theory captured in the diagram are discussed. The discussion will clarify what they mean, and how they fit together.

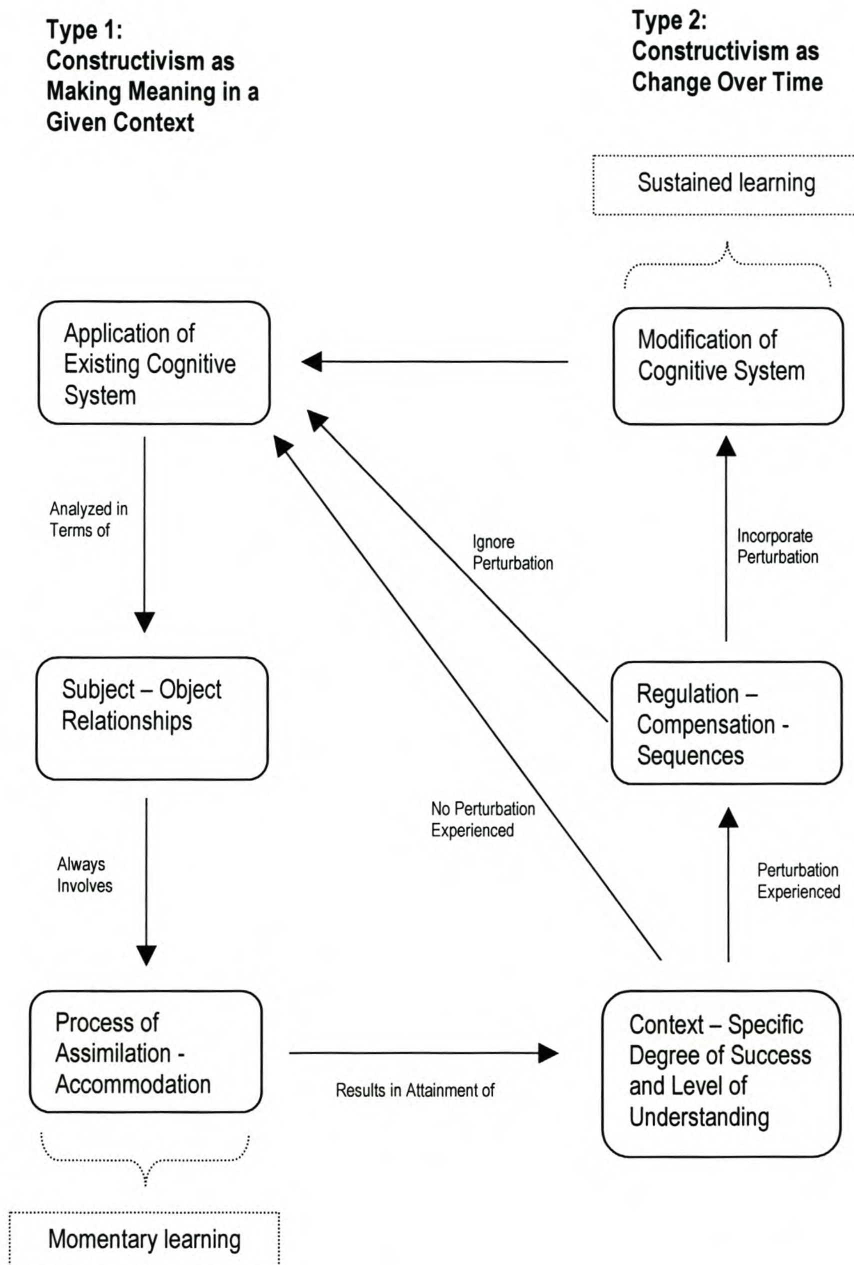


Figure 3.2: **Summarizing Piaget's Theory (slightly adapted from De Lisi and Goldbeck, 1999: 6). The entire diagram is reflective of the process of equilibration.**

3.3.1.1 Cognitive Systems

Piaget describes two major cognitive systems a person may possess and which they bring to bear on experiences they have in any given context, and which impact on their level of success or understanding attained in the context. They are the **sensory-motor** and **operational** systems. De Lisi and Golbeck (1999: 6) write that both systems involve internal coordinations by the person, but that the sensory-motor system coordinates overt action (means-ends behaviors) in order to attain success in an immediate environment, while the operations system coordinates thinking actions to attain understanding in both immediate and anticipated contexts.

Piaget divided the cognitive systems into stages of development:

> We have seen that there exists structures which belong only to the subject, that they are built, and that this is a step-by-step process. We must therefore conclude that there exist stages of development. (Piaget, 1983: 109.)

Piaget argued that these stages were invariant, and that successful development of a previous stage was a prerequisite for development of the next stage. The four stages are summarized by Meadows (1993) as follows:

- **Sensori-motor stage**: Initially the child is dependant on a number of reflex responses which, over time, develop into organized behavior patterns or schemes which can be used intentionally. The child is profoundly egocentric.

- **Pre-operational stage**: The child begins to use semiotic systems such as language and imagery. The child lacks operational thought, i.e. flexible, reversible reasoning which allows it to conserve, classify, seriate, co-ordinate perspectives and to overcome misleading perceptual impressions.

- **Concrete-operational stage**: The child is capable of systematic and quantitative thinking. Thinking is described in terms of formalized logical structures relating to classification and relations in quantity and in space.

- **Formal operational stage**: Thinking at this stage is more abstract and less tied to content. Individuals in this stage are capable of dealing with hypothetical material.

De Lisi and Goldbeck (1999: 6) write that "Successive substages reveal a greater deal of internal consistency and applicability across contexts".

Piaget also describes the cognitive system of a person as being made up of "schemes". A scheme can be thought of as an elaborate network of related concepts. A stage can be thought of as an extended period of equilibrium during which the schemes are relatively stable. Successive stages differ from one another in the quantity and quality of schemes that are available to the person at that stage, with the schemes becoming more in number, richer and more complex as the individual moves toward the formal operational stage.

For Piaget, progression through the stages is driven by the individual's need to make sense of, and to adapt to the environment in which he finds himself.

> At the core of Piaget's model is the idea that cognition is one form of adaptation between organism and environment, which is seen through all the living world. The child, or indeed the adult, is all its life actively trying to make sense of the world, just as any organism must try to adapt to its environment. (Meadows, 1993:198.)

3.3.1.2 Subject-Object Relations

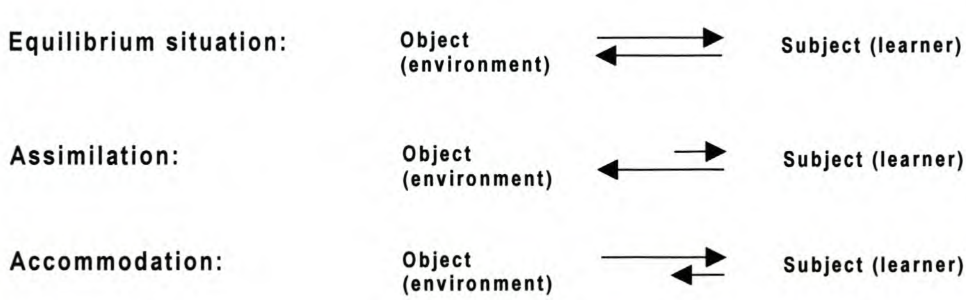
Piaget's theory also has a relational perspective, in that cognitive functioning is described in terms of subject-object relations. Cognitive functioning and the development of understanding occurs as a result of the actions that the subject (learner) performs with and on objects (other people, ideas, physical materials) in the environment. The relationship is seen as a two-way, reciprocative process where the subject (learner) performs actions on the environment, and the environment influences actions of the individual.

This seems to counter perceptions that Piaget's theory of cognition is an individualistic one, as he clearly incorporates relationships of the learner with his/her environment (social and physical) into the theory and sees them as making vital contributions to cognitive functioning.

3.3.1.3 Assimilation, Accommodation and Equilibrium – momentary learning

It's important to note that the process of cognitive functioning is always a two-way process between the subject and object, but the question can be raised: Are the contributions to cognitive functioning made equally by subject (individual learner) and object (social and physical environment) in the subject-object relationship in any given situation?

Three possibilities exist. The perspective of the subject (learner) exerts a greater influence, the perspective of the object (social and physical environment) exerts a greater influence, or these perspectives are balanced. This question can be addressed using Piaget's concepts of assimilation, accommodation and equilibrium. The theory does not predict which will dominate in a given situation, but does suggest that when cognitive systems are not in equilibrium, one of accommodation or assimilation processes will dominate. Note that it's never an either-or process. Both processes happen simultaneously, but one may be favoured over the other, resulting in an 'unbalanced' equilibrium. This may be depicted as follows:



Assimilation is an inward-directed process in which "the object or event is brought into one or more cognitive system components in order to confer meaning". (De Lisi and Goldbeck, 1999: 8.)

Accommodation occurs when one or more components of the cognitive system take account of what is being assimilated and this may result in momentary modification of the cognitive system, which in turn may lead to success and understanding in the immediate context.

3.3.1.4 Equilibration – sustained learning

Can momentary modifications resulting from the equilibrium processes of assimilation and accommodation lead to a permanent modification of the cognitive system, and if so, how does this occur? Piaget's construct of *equilibration* describes how this may occur.

> Equilibration is clearly a force for stability, via a self-regulation that balances external and internal changes. In some cases it works by restoring the previous stable state, in the cases which are more interesting for development, successful adaption calls for a more radical and pervasive shift if balance is to be regained. (Meadows, 1993: 202.)

> Equilibration is a dynamic process in which the tendency to be closed or retain previously developed ways of interacting and understanding is counteracted by the opposite tendency towards openness, such that the present cognitive system is modified to capitalize on newly discovered means and insights. This dynamic tension between openness and closure is the motivational force for cognitive development. (Paiget, 1971, 1978a, 1990, described in De Lisi and Golbeck, 1999: 12.)

Three forms of equilibration are described in the theory:

- Equilibration though assimilation-accommodation involving individual schemes in the cognitive system, and pertaining to present, ongoing cognitive restructuring.
- Equilibration involving restructuring the relations in individual schemes or between schemes at the same level of complexity – a

horizontal restructuring. This pertains to present, ongoing cognitive restructuring as well as to restructuring over time.

- Equilibration involving restructuring of sets of schemes and the total cognitive system of which they are a part - a vertical restructuring which happens over time.

Again, all of these are occurring at the same time. Present cognitive restructuring at the first level impacts on the second and hence on the third and so in combination with other restructuring in other contexts, leads to broader cognitive changes over time.

Piaget uses the constructs of **Perturbation-Regulation-Compensation Sequences** to describe a mechanism through which more permanent cognitive restructuring can take place.

3.3.1.5 Perturbations

Assimilation-accommodation of experiences and thus momentary learning in the context results in the learner experiencing a degree of success/failure and/or demonstrating a level of understanding in the context. This, in turn, may or may not lead to the learner experiencing perturbations. Three possible scenarios arise:

- No perturbations are experienced, and the cognitive structure of the learner remains unchanged.
- Perturbations are experienced but the cognitive system of the learner remains intact because the perturbations are ignored, not recognized, the learner cannot make sense of them, the perturbations lead the learner in a different direction, the learner does not have the capacity to explore them further, etc.
- Perturbations are experienced and they are dealt with seriously by the learner leading to cognitive restructuring.

In relation to the third possibility, De Lisi and Golbeck (1999: 14) write that:

> Here, cognitive failures and gaps in understanding are acknowledged and dealt with seriously. The child attempts to establish a new relation between his cognitive system and what he observes. (De Lisi and Golbeck, 1999: 14)

Piaget identifies two types of perturbations that can be experienced:

- **Obstacles,** which are experienced as errors or failures to arrive at the goals set for a particular task. These are regulated through negative feedback.
- **Lacunae** (gaps) – The learner may experience a sense of incompleteness and needs that are unsatisfied. These are regulated by positive feedback that prolongs the assimilation situation.

3.3.1.6 Regulations and Compensations

Perturbations lead to regulatory behavior which may or may not lead to a change in cognitive structure. Regulatory behaviors are described as **Regulations** in the theory, and they lead to one of three types of **Compensations:**

- The cognitive system remains unchanged after the regulation. A perturbation is experienced by the learner but compensatory behaviour in order to establish equilibration involves the perturbation being ignored, avoided or cancelled out. This is called an **alpha-compensation.**
- The perturbation is eliminated through its incorporation or addition into the cognitive system as an internal variation of the system. This is called a **beta compensation.**
- The perturbation is recognized as a consistent, highly developed and intact cognitive system in its own right and is incorporated as such into the cognitive structure of the learner. This is called a **gamma compensation.**

So, from the perspective of this theory, learning involves the restructuring of cognitive systems which occurs through the process of equilibration, and which is dependant on the subject (learner) experiencing perturbations as a result of the relations between the subject (learner) and object (elements in the learner's environment including other people).

3.3.2 Vygotsky's social learning theory

This theory emphasizes the role of the social environment and social interaction in learning. For Vygotsky and other theorists who subscribe to his views, experience and interaction with others in a social environment are the driving forces behind the development of cognition and conceptual development.

Elements of the theory which may be pertinent to this study are explored below.

3.3.2.1 The Zone of Proximal Development

An important component of Vygotsky's theory of learning, is what he calls the zone of proximal development (ZPD). Underlying this concept is the notion that development must take into account at least two developmental levels, viz. the level of understanding the learner currently is at (where the learner can operate independently), and a higher level (the level of understanding the learner is able to reach when assisted). Vygotsky describes the ZPD as:

> The distance between the actual developmental level as determined by individual problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers. (Vygotsky, 1978, quoted in Tharp and Gallimore, 1988:30.)

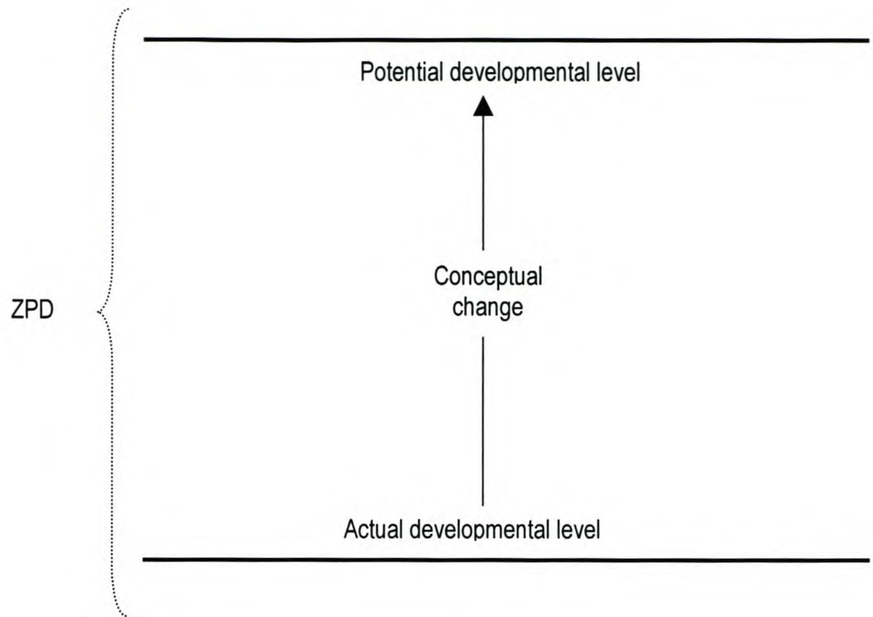


Figure 3.3: The Zone of Proximal Development.

Learning is deemed to have taken place when the responsibility for task performance shifts from the more capable adult or peer to the learner. Task performance now becomes 'automised' or 'internalised'.

For Vygotsky, therefore, a very close developmental relationship exists between the external world and the internal world of the learner. Through internalisation, external social processes are adopted by a learner as internal psychological processes. Internalisation occurs through 'guided reinvention' as a result of social interaction with others in the social environment.

> Through guided reinvention, higher mental functions that are part of the social and cultural heritage of the child will move from the social plane to the psychological plane, from the intermental to the intramental, from the socially regulated to the self regulated. (Tharp and Gallimore, 1988: 30.)

The description of cognitive development occurring as a result of a learner's reinvention of prior learning in a social context is concurrent with the central theme in socio-cultural constructivist theory.

3.3.2.2 'Everyday concepts' and 'scientific concepts'

Vygotsky makes a distinction between what he calls "spontaneous or everyday concepts" and 'scientific concepts". In Vygotsky's view, formal learning (e.g. at school) was responsible for the development of scientific concepts, while everyday concepts developed as a result of a person's everyday social experiences.

A learner's 'everyday concepts' develop from concrete experiences in the social environment while 'scientific concepts' develop from "analytic procedures rather than concrete experiences". (Panofsky *et al.*, 1991:251.)

3.3.3 Concept Learning and Development Theory (Klausmeier, 1992)

Klausmeier's Concept Learning and Development Theory (1992) is an example of a theory of concept learning in the Piagetian framework. He argues that learners attain understanding of concepts at successively higher levels.

> A concept as a mental construct, or representation, consists of a person's organized information about an item or class of items...An individual's mental construct changes as he or she attains a given concept at successively higher levels of understanding. (Klausmeier, 1992:268.)

He suggests that concepts can be formed at four different levels:

- **The concrete level:**
  The learner is able to identify an item as being identical to one encountered in an identical previous situation.

- **The identity level:**
  The learner is able to recognize an item as being the same as one encountered in a different spacio-temporal perspective.

- **The classificatory level:**
  The learner can recognize two items as being equivalent or not, but cannot explain the basis for this classification.

- **The formal level:**
  In addition to the abilities outlined in the descriptions above, the learner is able to carry out "either a set of inductive processes that include hypothesizing, evaluating and inferring, or a set of meaningful reception operations that includes processing and correctly using the given information" (Klausmeier, 1992: 268).

Thus, for Klausmeier, conceptual change happens when learners develop understanding of conceptions at higher levels.

3.3.4 Conceptual change Theory (Posner, Strike, Hewson and Gertzog, 1982; Hewson and Thorley, 1989)

Much of what is described in this theory of conceptual change, can be attributed to work done by Posner *et al.* (1982), who suggested that there is a need for a "well-articulated theory explaining or describing the substantive dimensions of the processes by which people's central, organizing concepts change from one set of concepts to another set, incompatible with the first" (Posner *et al.*, 1982: 211). The theory they describe has its roots in work done in the philosophy of science, particularly in work done by Kuhn (1970) and Lakatos (1970).

> We believe that a major source of hypotheses concerning this issue is contemporary philosophy of science, since a central question of recent philosophy of science is how concepts change under the impact of new ideas or new information (Posner *et al.*, 1982: 11.)

Hewson and Thorley (1989:543) identify two things that can happen when a learner is confronted by a new conception. They suggest that:

- The new conception can be incorporated with existing conceptions if the learner is able to find the new conception to be intelligible, plausible and fruitful. They term this process **conceptual capture**. Posner *et al.* (1980) use the term **assimilation** to describe this process.

- The new conception may be intelligible to the learner but is not plausible since it contradicts and clashes with existing conceptions. The status of the existing conceptions therefore have to be lowered before the new conception can replace them. They term this process **conceptual exchange**. Posner et al (1980) use the term **accommodation** to describe this process.

Another possibility can arise when the new conception is unintelligible to the learner, and is simply rejected.

The theory focuses on the more radical 'accommodation' change and is framed by the following questions that impact on whether accommodation takes place and how it takes place. Posner *et al.* (1982: 213) articulate these questions as follows:

1 Under what conditions does one central concept come to be replaced by another?

2 What are the features of a learner's conceptual ecology, which governs the selection of new concepts?

3 How does accommodation take place?

3.3.4.1 The conditions of conceptual change

These conditions "apply to conceptions that the learner either holds or is considering. A critical point is that it is the **learner** who needs to decide, implicitly or explicitly, whether they are met" (Hewson & Thorley, 1989:542).

The following conditions are identified:

- **Intelligibility** - Does the learner know what it means? Do the pieces of the conception fit together for the learner? Is the learner able to find a way of representing the conception? Can the learner begin to explore possibilities inherent in it?

- **Plausibility** - If a conception is intelligible to the learner, does the learner also believe that it is true? Is it consistent with and able to be reconciled with other conceptions accepted by the learner? Does the new conception make sense to the learner?

- **Fruitfulness** – If a conception is intelligible to the learner, does the learner also find that it achieves something of value for him or her? Does it solve otherwise insoluble problems for him or her? Does it suggest new possibilities, directions, ideas?

- **Dissatisfaction** – For a learner to consider adopting a new conception or adapting an existing conception, he or she should be dissatisfied with the existing conception. This may be because it may no longer seem plausible or fruitful.

When a conception is viewed as being no longer plausible or fruitful, its status is lowered. Thus conceptual change, in this model, is viewed in terms of "lowering the status (in terms of intelligibility, plausibility, and fruitfulness) of alternative conceptions and raising that of the target scientific conceptions" (Hewson & Thorley, 1989: 543).

3.3.4.2 Features of conceptual ecology

Posner *et al.* (1982: 214) suggest that the following features of a learner's conceptual ecology may influence if and how accommodation takes place:

- **Anomalies:**

New observations or information can give rise to anomalies for which existing ideas cannot provide suitable explanations.

- **Analogies and metaphors:**

The existence of these in a learner's conceptual structure can serve to suggest new ideas and make them intelligible.

- **Epistemological commitments:**
    - Explanatory ideals: Subject matter-specific views in a field can determine what counts as an acceptable explanation in that field.
    - General views about the character of knowledge: Some characteristics of knowledge, e.g. elegance, parsimony, are not field or subject specific.

- **Metaphysical beliefs and concepts:**
    - Metaphysical beliefs about science: Learners may subscribe to metaphysical beliefs about the nature of science, which can influence whether new ideas are accepted or rejected.
    - Metaphysical concepts of science: "Specific scientific concepts often have a metaphysical quality in that they are beliefs about the ultimate nature of the universe and are immune from direct empirical refutation" (Posner *et al.* 1982:215).

- **Other knowledge:**
    - Knowledge in other fields;
    - Competing concepts.

    A learner's knowledge in another field or the existence of competing concepts may act as a barrier to the adoption of new ideas. "One condition for selection of a new concept is that it should appear to have more promise than its competitors" (Posner *et al.*, 1982: 215).

3.3.4.3 The nature of accommodation

While Posner *et al.* (1982) describe accommodation as being a radical change in a person's conceptual structure, they also suggest that rather than being an abrupt or sudden change, it may occur in a gradual and piece-meal fashion.

> Accommodation, particularly for the novice, is best thought of as a gradual adjustment in one's conception, each new adjustment laying the groundwork for further adjustments, but where the end result is a substantial reorganization or change in one's central concepts (Posner *et al.,* 1982: 223.)

Typically, learners will attempt to assimilate new information into existing structures before they attempt to change their existing structures. Thus, "much fumbling about, many false starts and mistakes, and frequent reversals of direction" may precede accommodation (Posner *et al.*, 1982: 223).

3.3.5 Scheme theory (Driver, Guesne and Tiberghien, 1985)

Driver *et al.* (1985:4) describe a learning model which takes as it's starting point the assumption that learners come into a classroom situation with pre-constructed ideas of the material being dealt with.

> Students' minds are not blank slates able to receive instruction in a neutral way; on the contrary, students approach experiences presented in science classes with previously acquired notions and these influence what is learnt from new experiences in a number of ways. (Driver *et al.*, 1985:4.)

The model is based on the hypothesis that information is stored in memory, in groups of elements called 'schemes'.

> Thus, the term 'scheme' denotes the diverse things that are stored and interrelated in memory. These 'schemes' also influence the way a person may behave and interact with the

> environment, and in turn may be influenced by feedback from the environment (Driver *et al.*, 1895:4.)

They use this model of the organization of schemes integrated into structures to describe learning or the acquisition of a new piece of knowledge. They suggest that "the way a new piece of information is assimilated depends both on the nature of the information and the structure of the learners 'schemes'" (Driver *et al.*, 1985:5).

They use an analogy of how personal and group relationships in a class can change when a new person is introduced to the class to describe what can happen when a learner encounters new information. They suggest the following:

- The new learner might not relate with other learners at all and will remain isolated. (The new information might not relate at all to existing schemes and structures and thus remain isolated or is rejected.)

- The new learner can join an existing group. (The new information might be assimilated into existing schemes and structures. This is similar to what Piagetian theorists describe as assimilation.)

- The new learner can cause a reorganization of the friendship groups in the class. (Existing schemes and structures will be altered through exposure to the new information. This is similar to what Piagetian theorists describe as accommodation.)

- They extend the analogy by suggesting that the experience a new learner has when introduced into one class might be very different to the experience another new learner will have when introduced to the same class. (Different learners will respond in different ways when exposed to the same experience.)

They use this model to explain the personal, contradictory and stable nature of learners' ideas.

> These images of the organization of schemes and the acquisition of new schemes may account for the existence of these personal, contradictory and stable ideas. Each one of us has a characteristic organization of schemes. Acquired information is linked to other information and even if this new information is the same for several people, the link established between this acquired information and the already stored information has little chance of being the same from one person to the next. When a person states several contradictory ideas, different schemes are brought into play; these ideas may all be stable in so far as the schemes leading to them are integrated into structures, and to change any one of them may require the modification of a structure, not merely an element of that structure. (Driver *et al.*, 1985:5.)

Their approach therefore seems to integrate elements of the information-processing approach described by cognitive scientists, contructivist theory and the Piagetian approach. Driver (1989:482) however, points out how this perspective of learning differs from the traditional Piagetian approach:

> It differs from it, however, in two significant ways. Instead of focussing on the development of general logic capabilities, the new perspective emphasizes the development of domain specific knowledge structures. In addition, whereas the emphasis in the Piagetian research programme has been on the personal construction of knowledge through an individual's interaction with the physical environment, the new perspective also acknowledges to a great extent the social processes in knowledge construction both at the level of the individual and within the community of scientists. (Driver, 1989: 482.)

From the point of view of this model then, conceptual change involves a reorganization of an individual's schemes. "Such reorganization takes time and favorable circumstances" one of these being the role that teachers play in reorganization and restructuring when teaching science (Driver *et al.*, 1985:6).

3.4 Understanding

Writers like Nickerson (1985), Trowbridge and McDermott (1980) have emphasized that because children pass tests and complete other similar assessment tasks successfully, this does not mean that they understand the subject matter. This may be because:

- The tasks they are required to do are of a simple nature and they can respond successfully to them using their simple understanding.
- The tasks they are required to do have been encountered many times over in the same context and learners have developed strategies to deal with them through drill and practice.
- They have 'learnt' how to respond in an acceptable and expected way in the classroom, but will revert to common-sense understandings in other real-life settings.

Indeed, if learners purport to 'understand' a particular concept, issue or process, etc., what do they actually mean, and how can we determine if this is in fact the case? What does it actually mean to 'understand'?

> We find it quite easy to use the term 'I understand' or 'I do not understand', but when pressed for an explanation of what we mean by this, we may find it difficult to do so. (Nickerson, 1985: 215.)

Sierpinska, quoted in Pire and Kieran (1990:243) poses similar questions when asking:

> Is understanding an act, an emotional experience, an intellectual process or a way of knowing? Are there levels, degrees or rather kinds of understanding? What are conditions for understanding to occur? How do we come to understand?" (Sierpinska in Pire and Kieran, 1990:243.)

This section aims to problematise the issue of understanding by using the following organising questions:

- What is 'understanding'? (Section 3.4.1.)

- How does understanding develop? (Section 3.4.2.)
- How can we look for/identify evidence of understanding (what must a student be able to do to demonstrate understanding)? (Section 3.4.3.)
- Drawing from the discussions in the focus questions above, what does it mean to understand kinematic graphs? (Section 3.4.4.)

3.4.1 What is understanding?

Instead of trying to propose a concise definition of what it means to understand, a task that he suggests will be very difficult to do, Nickerson (1985: 215-235) explores characteristics and constructs which may be related to understanding:

- He points out that understanding is context-dependent, and that understanding a concept in one context does not necessarily mean understanding it in another. This could explain why an everyday understanding of a concept would suffice as an organising and explaining tool in everyday life, whereas its use would be restricted in a more technical context like the science classroom, or the laboratory.

- He refers to the non-binary nature of understanding and suggests that the situation is not as simple as understanding or not understanding something. Concepts, processes, principles, etc. can be understood to greater or lesser degrees. If we agree with this proposition, then it means that learners will always have some degree of understanding prior to our intervention as teachers, and teaching thus involves promoting the growth of understanding.

- He links the issue of understanding to that of expertise. "One understands a concept (principle, process or whatever) to the degree that what is in one's head regarding the concept corresponds to what is in the head of an expert in the relevant field." (Nickerson, 1985:272.) From this perspective, growth of understanding would entail, in part, development from what we have termed misconceptions, everyday science, children's science, etc. to that of an expert's understanding of the concept.

- Understanding a problem means being able to represent it. Representation can take place at increasingly complex levels. Larkin (1980), described in Nickerson (1985), identifies three levels of representation, all of which are semantic in nature.

> In all three cases, the representations are though of as semantic networks, the differences between them being the nature of the concept nodes and the ways in which they are interconnected. (Nickerson, 1985:224).

The three ways of representing are:

➢ **Naive representations**

The person bases his or her representation of the problem on everyday understanding of the English words and prose in the problem statement. Components of the problem situation are likely to be related only through relationships described in the problem statement, or even treated as separate entities.

➢ **Scientific representations**

Scientific representations contain entities that represent principles, operations or relationships that define the discipline or area of knowledge in which the problem is being posed. They require knowledge not only of English prose, but also of the entities typically found in problems in that discipline and of the relationships between the entities. These representations are more abstract in nature so that a scientific representation can accommodate several naive representations.

➢ **Mathematical representations**

Mathematical equations are used to represent principles, operations, relationships or processes. They are more abstract in nature in that a mathematical representation can characterize several scientific representations.

Larkin suggests that a key difference between novice and expert problem solvers in the physical sciences lies in the ability of an expert to construct and use scientific rather than naive representations to make sense of and solve problems. (Nickerson, 1985: 225.)

- Finally, Nickerson suggests that understanding a system involves being able to create a qualitative mental simulation of that system in the mind's eye and being able to use this representation to answer unanticipated questions about the system under 'novel' or 'faulty' conditions. This ability to deal with a system qualitatively has been identified by a number of researchers exploring the differences in understanding between novices and experts.

> Indeed, several investigators of the differences between expert and novice problem solvers have noted the greater tendency of experts to analyze a problem qualitatively before attempting a quantitative representation. (Nickerson, 1985: 225.)

3.4.2 How does understanding develop?

Growth of understanding can be thought of as developing an increasingly complex, broad and deep knowledge base from which to operate (Nickerson, 1985), developing an increasingly complex means of representation (Larkin, 1980; described in Nickerson, 1985), or being able to make meaning of concepts, processes and relationships at successively higher levels of functioning. (Klausmeier, 1992).

Klausmeier's (1992) Concept Learning and Development (CLD) Theory (1992) (See Section 3.3.3 earlier in this chapter) describes how understanding can be developed at increasingly complex levels.

Klausmeier describes four possible levels of development:

- At the **concrete level** the learner is capable of recognizing an item as being identical to one encountered earlier in an identical setting. Processes that the learner can carry out at this stage include 'attending to an item', 'discriminating the item as entity different from its surroundings', 'representing the item in long-term memory' and 'retrieving the image in order to recognize an item as being the same as that discriminated earlier'.

- At the **identity level** the learner is able to recognize an item as being the same as one previously encountered in a different spacio-temporal perspective. Additional processes that the person can carry out at this stage include 'generalizing' that the item is the same as one experienced earlier, even though it is experienced differently.

- At the **classificatory level** the person can recognise that even though two items appear to be different, they are in fact equivalent. The person can identify nearly all examples and non-examples of the item, but cannot really explain the basis for this classification.

- At the **formal level** the person is able to identify any and all examples and non-examples. He is able to name the concept, give its defining attributes, give the expert's definition and specify the critical attributes that differentiate the concept from other closely related concepts. In addition to processes identified in the previous levels, he is able to carry out "either a set of inductive processes that includes hypothesizing, evaluating and inferring or a set of meaningful reception operations that includes processing and correctly using the given information".

Klausmeier uses this model to differentiate between what he terms an 'immature concept' and a misconception. He suggests that a person has an immature understanding when she has not developed the concept to its maximum level because she lacks the necessary level of development in terms of cognitive structure and processes.

> This learner makes errors in identifying difficult examples and non-examples, cannot use the concept adequately, has a meaning that differs from that of the experts, draws incorrect inferences or demonstrates some combination of these. Klausmeier, 1992: 274.)

A misconception arises when the person has access to the necessary cognitive structures and processes, but uses the concept in question at a much lower level. He may then demonstrate any or all of the deficiencies described above.

3.4.3 Evidence of understanding

Drawing from Nickerson (1985) and Klausmeier (1992), some of the things we could look for to make a judgment about understanding, and which will be used for this purpose in the qualitative phase of this study (particularly in the construction of the questionnaires which attempt to identify levels of understanding that learners reach in relation to particular concepts and ideas:

- The degree of abstractness with which the person is able to engage.
- The richness of the knowledge base from which the understanding derives.
- The extent to which one can apply the concept in non-typical situations or ways (novel situations).
- The level of representation (naive, scientific or mathematical, qualitative or quantitative) the person uses to make sense of and tackle a problem.
- The degree to which the person's description of a concept, process, relationship, etc. matches that of an expert in the field.
- The observed level that the person has reached in respect of the Klausmeier's (1992) CLD model.
- The arguments that the person makes in support of choices.

3.4.4 What does it mean to understand kinematic graphs?

Frauenknecht (1998:181) proposes a list of broad questions which can be used to determine whether learners have a qualitative understanding of kinematic graphs. A selection of these questions which I think will be useful for this study, as well as some of my own, drawing from the discussion of understanding the above, are listed below:

- Can the learner construct sketch graphs representing a motion from other representations e.g. verbal descriptions of a motion, physically observing a motion, diagram of a physical situation, etc? That is, can he translate between different representations of motion?

- Can the learner make proper connections between various graphical representations of the motion, i.e. can he successfully carry out graphical transformations, e.g. a displacement-time graph to the corresponding velocity-time graph and correctly describe how kinematic quantities are represented on the different graphs?

- Does the learner consistently obtain correct answers from a wide variety of questions set on various translations and transformations between representations of a motion?

- Can the learner draw appropriate analogies between aspects such as the area under a *v vs t* graph giving the change in displacement or the area under an *a vs t* graph, giving the change in velocity?

- Can the learner interpret a given graph correctly so that every feature is given the correct physical interpretation?

These questions will be used as a guide for constructing learning activities that make up the TRAC PAC-based learning programme, and for developing research tools, particularly the pre- and post-tests, which will have the aim of assessing if learner understanding has increased as a result of participation in the learning programme.

3.5 Possible consequences of the interaction between learner conceptions and science teaching

Gilbert, Osborne and Fensham (1982: 628) propose five possible outcomes of the interaction between science teaching and the preconceived ideas (which they call children's science), which learners bring to the classroom.

3.5.1 The Undisturbed Children's Science Outcome

The views that the learner held prior to instruction (children's science or S_{ch}) are not modified by science teaching (S_T). The learner's conceptual structure remains unchanged. This can be represented graphically as follows:

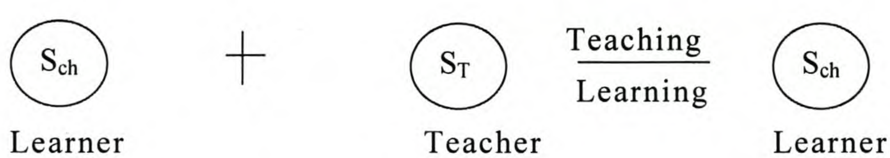


Figure 3.4: "A prelearning children's view of science can persist unchanged by science teaching" (Gilbert *et al.*, 1982: 628).

3.5.2 The Two Perspective Outcome

The learner basically rejects what is being taught but realizes that it might be required in the formal school situation, e.g. for examination purposes. The learner can thus hold two views, one which will be used in everyday experiences, the other will be used in formal learning situations.

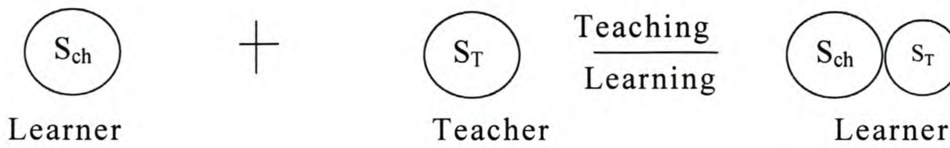


Figure 3.5: "Science teaching can result in a second view being acquired for use in school but the original children's views persist elsewhere" (Gilbert *et al.*, 1982: 629.)

3.5.3 The Reinforced Outcome

The learner's prior ideas and understandings are so dominant that teaching actually causes them to be reinforced. The learner uses the new material presented during teaching to support his initial conceptions.

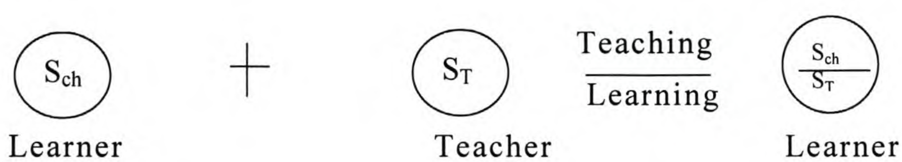


Figure 3.6 "The original children's view is strengthened by science teaching which now is misapplied to support it" (Gilbert *et al.*, 1982: 628).

For example consider this response of a learner who was asked to explain where the droplets of water on the outside of a cold glass container came from:

> Through the glass...like diffusion through air and that...well it hasn't got there any other way (a lot of people I have talked to have been worried about this water...it troubles them) yes, because they haven't studied the things like we have studied (what have you studied which helps?) things that pass through air, and concentrations, and how things diffuse. (Gilbert *et al.*, 1982: 630.)

The learner is using what he has learned about the diffusion of substances to reinforce his view that the water moves from inside the glass container to the outside.

3.5.4 The Mixed Outcome

In this outcome of teaching and learning, science ideas are learned and understood to a certain extent, but not fully, because of the complexity and inter-relatedness of these concepts. This results in learners holding views that are a mixture between children's science views and teacher's views.

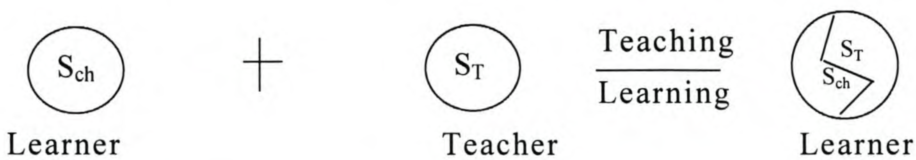


Figure 3.7 "Science teaching resulting in a mixed outcome where children's science and teacher's science now co-exist together" (Gilbert *et al.*, 1982: 630).

This mixture of ideas is evident when learners provide explanations that combine elements of children's science ideas and teacher's science ideas. The description below of a learner describing the structure of water in the solid phase and liquid phase illustrates this:

> I think it is the same atoms in the ice before and now they are unfrozen in the water (what else is in there besides that atoms? the stuff that freezes?) no... I don't know...yes...no...it's all atoms but the atoms are just frozen. (Gilbert *et al.*, 1982: 631.)

The learner demonstrates an understanding of the conservation of matter between different phases, but attributes microscopic changes in structure to general changes in the properties of the microscopic components (which he is calling "atoms").

3.5.5 The Unified Scientific Outcome

Gilbert *et al.* (1982: 630) suggest that this is the outcome that all teaching and learning should be aiming to achieve. Here learners develop an understanding of the science concepts that may even move beyond the teacher's representation of it, to how a scientist may represent it.

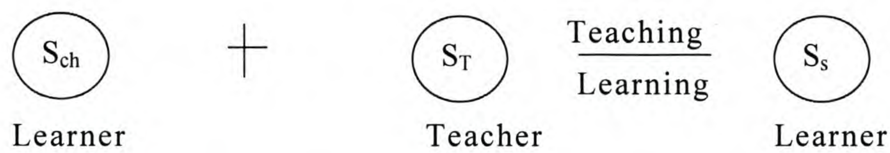


Figure 3.8 "Science teaching which extends children's science and teacher's science to a more unified science view" (Gilbert *et al.*, 1982: 630).

Consider this learner's explanation about the condensation of water on the outside of a cold jar:

> It is wet on the outside...'cos the jar's cold...'cos the ice is inside it and therefore the water molecules that are in the air moving around...although we can't see them...when they hit the cold jar...that makes them cold...and therefore they group together again in their groups of molecules and they become water again because they've been cooled down. (Gilbert *et al.*, 1982: 631.)

The learner demonstrates an understanding of the difference in arrangement and behavior of molecules of water in the gaseous and liquid phase and also provides a coherent explanation of how a decrease in temperature results in the condensation of water.

Gilbert *et al.* (1982: 631) therefore see teaching as a process of developing "children's science" to "scientist's science" and conclude by suggesting that although the ultimate goal of science teaching should be for learners to achieve an understanding which closely approaches a scientist's view, this may be a very difficult task to achieve. They suggest that the development of understanding can be started by making learners explicitly aware of the existence of the two different views and demonstrating to learners that the scientist's view may at least be as "logical, coherent, useful and versatile" a way of viewing the world as their present view.

3.6 Teaching for conceptual development and change

If we agree with Gilbert *et al.* (1982:630) that the preferred outcome of science teaching and learning is "that a learner should obtain a coherent scientific perspective (Ss) which he understands, appreciates and can relate to the environment in which he lives and works" then we need to think about teaching strategies which can promote this.

Driver *et al.* (1985: 6) suggest that: "Taking account of students' prior ideas is one of the strategies, though certainly not the only one, which enables teaching to be better adapted to students". They suggest that this can occur in a number of ways:

3.6.1 The choice of concepts to teach

Curriculum planners and teachers can make the mistake of taking some concepts for granted, and not give them the attention they deserve. Students, on the other hand, may experience difficulty with these apparently simple concepts and this then leads to "further and more serious learning problems".

3.6.2 The choice of learning experiences

Learning experiences that conflict directly with learner expectations can cause them to reconsider their ideas, especially if alternative ideas which learners see as necessary, reasonable and plausible are also presented. This requires knowledge of learners existing ideas.

3.6.3 The presentation of the purpose of proposed activities

As a result of their own initial understandings, learners may have an entirely different interpretation of the teacher's intention for the lesson. It is important to attempt to generate a common understanding of the intention or purpose of particular activities.

Klausmeier (1992: 280) suggests that concept learning and concept development can be greatly enhanced by using a teaching strategy that he calls 'focussed instruction'. He describes this as teaching which adopts and applies the following principles:

- Concepts should be taught in groups of two or more related concepts. This allows learners to identify any relationships between them and to use them as non-examples of each other.

- Orienting instruction.
  "Creating student intention to learn merits a special note. An intention is the motivational component for a strategy for attaining a goal. As long as the intention remains, activity continues towards goal attainment" (Klausmeier, 1992:280).

- Provide opportunities for recall early in the instructional sequence so that the learner is able to reinstate in working memory all prior knowledge related to the concept being examined, and to allow the teacher to identify common misconceptions held by the learner.
  "Eliminating the misconception is a prerequisite for attaining the target concepts" (Klausmeier, 1992: 280).

- Use as many examples and non-examples as possible.
  "Presenting the examples in a most-typical to least-typical sequence produces desired results. The typical examples aid the learner in forming an initial prototype. Least-typical examples that are very much like non-examples prevent under-generalization (not correctly identifying an item as an example), whereas non-examples, very

much like examples, prevent over-generalization (incorrectly identifying a non-example as an example)" (Klausmeier, 1992:280).

- Represent the concept in a variety of ways, e.g. verbal, diagrammatic, visual models, samples, etc.

- Eliciting and/or providing definitions that include the essential attributes of the concept.

- Provide affirmative feedback to indicate to the learner whether he/she has an acceptable understanding of the concept being learned. This will prevent the formation of misconceptions.

Meadows (1993), also uses a Piagetian framework to describe how learners can develop increased understanding when she writes:

> In order to resolve disequilibrium in the direction of cognitive growth, you must be able to recognize (not necessarily consciously) that there is a disequilibrium...you must similarly recognize at least what approximately has caused it, you must want to resolve it, rather than deciding to live with the contradiction. (Meadows, 1993:204.)

Teaching strategies for addressing misconceptions that can be drawn out of this description include:

- Learners should be made aware that they have an inadequate understanding of the concept being developed. The difference between the learner's understanding and the 'scientific' understanding should be intentionally investigated.

- The causes or reasons for learners holding this understanding should be investigated. Learners should be encouraged to provide arguments in support of their understanding of the concept.

- Learners should see a need to change their understanding of the concept. Klausmeier (1992:280) describes this as creating intention to learn.

Postner *et al.* (1982: 223) describes implications of conceptual change theory for curricular objectives, content, teaching strategies and the teacher's role. The last two are pertinent to this study and are elaborated on here.

Regarding teaching strategies, the theory implies that:

- Lesson programmes should be developed which promote 'cognitive conflict' in learners. These lessons should challenge learners' existing conceptions and give them opportunity to question the plausibility and fruitfulness of existing conceptions.

- Teaching should be organized to allow teachers substantial amounts of time for diagnosing learner preconceptions and identifying methods and reasons learners use to resist adopting a new conception.

- Teachers should develop and use strategies which allow them to identify learner preconceptions and to identify methods and reasons learners use to resist adopting a new conception.

- Learners should be helped to make sense of science content by presenting the content in a number of ways (e.g. verbal, mathematical, concrete-practical, pictorial) and by helping them to translate from one representation to another.

- Evaluation techniques should be developed which allow teachers to monitor conceptual change in learners.

Regarding the teacher's role, Posner *et al.* (1982: 226) suggest that, "The teacher as a clarifier of ideas and presenter of information is clearly not adequate for helping students accommodate new conceptions" and that teachers will have to develop two further roles in order to develop student accommodation, including:

- An adversarial role in the sense that the teacher should constantly confront the student with problems associated with attempts to assimilate new conceptions into existing frameworks with which they are in conflict.

- Becoming a role model for scientific thinking.

> Aspects of such a model might include a ruthless demand for consistency among beliefs and between theory and empirical evidence, a pursuit of parsimony among beliefs, a skepticism for excessive "*ad hoc*-ness" in theories and a critical appreciation of whether discrepancies between results may be in "reasonable agreement" with theory. (Posner *et al.*, 1982: 226.)

3.7 How these teaching and learning theories affect this study

Chapter 7 of this work describes the design of a learning programme used to address learner misconceptions in kinematics and kinematics graphs. This learning programme is made up of a series of activities that target various difficulties learners may have in this area of knowledge. A specific teaching and learning approach is used to design the activities. This teaching and learning approach is informed by my own views of teaching and learning, which in turn, are informed by the ideas and writings of the various theorists described above. Central principles that are drawn from the preceding discussion, which guide design of the learning programme, teaching and learning through the classroom intervention phase, and which illustrate my own beliefs about teaching and learning, include:

3.7.1 Knowledge is actively constructed

Learners interact with the physical and social environment to create their own understanding of the world and how it operates. Thus, learners will always come into a formal teaching and learning situation with pre-constructed knowledge. These pre-constructed ideas can exert a powerful influence on any new learning that needs to take place and the teacher needs to be aware of and take them into account when planning learning activities.

3.7.2 Knowledge is constructed through social interaction with others

This social interaction allows a learner to present his ideas for scrutiny, assessment and refinement. Thus, learning activities that allow for social interaction are essential. Cooperative learning strategies, e.g. group-work, are important strategies in this regard.

3.7.3 Learners' existing ideas need to be challenged and tested

Learner conceptions need to be intentionally explored and compared with accepted scientific conceptions through use of techniques like practical investigation, debate and dialogue.

3.7.4 Learning programmes need to be activity-based

Effective learning takes place when learners are engaged in different activities that allow them to construct their own understanding.

3.7.5 Learning activities and teaching strategies need to be varied

People have different strengths and learn in different ways. For example, when presenting material, use of verbal, graphical, visual, and written presentation techniques will cater for the needs of a wider range of learners than use of verbal presentation alone.

3.7.6 Clarity

Outcomes of learning, e.g. the target conceptions, should be made explicit and all participants should be aware of these from the outset. Ways of measuring whether these outcomes have been achieved (assessment) needs to be built into the learning experience.

3.7.7 Learners need to be able to appreciate the relevance of the learning material being explored

Learners are motivated when new learning material is linked to everyday life experiences, and its usability is clearly evident. This, in turn contributes to the creation of student 'intention' to learn.

3.7.8 Suitability of learning material

Piagetain theory suggests that learners progress through successively complex developmental stages. Thus we need to ensure that learners possess the ability to engage with the learning material we present. Material which is too complex will demotivate learners and conversely, material which is too simplistic will lead to boredom.

3.7.9 Clear organization of knowledge

If we agree that learner's incorporate new knowledge into existing 'schemes', then we need to present new knowledge in ways that facilitate this process. For example, the order in which new material is explored should be such that, where possible, simpler concepts are explored first and then used as a base for development of more complex concepts. The links between different concepts should be made explicit, and techniques like mind mapping and use of flow charts should be used to help learners organize information.

3.7.10 The teacher is the designer, creator and facilitator of learning experiences

As such, the teacher is an essential component of the teaching and learning environment, and his role extends beyond mere facilitation. The designing of learning activities demands teacher competency with regard to knowledge of learners' needs, choice of outcomes, choice and construction of learning and means of assessing whether outcomes have been achieved. In Vygotskian terms, the teacher serves as one of the "more capable" others who aid the learner to achieve a higher level of development.

3.7.11 Learner- centredness

All these principles embody what one could describe as learner centredness – ensuring that the learner's needs are the focal point of the teaching and learning experience.

Besides informing the design and implementation of the teaching and learning programme, these theories and models of learning and teaching are used as a theoretical framework in the construction of data collection tools, and in the analysis of findings, both in the empirical study phase (chapter 8 of this work) and in the ethnographic phase of this study (chapter 9 of this work). For example, the discussion of learner understanding in section 3.2.4 indicates some of the elements that needed to be built into the data collection tools and some of the evidence that the researcher needed to look for when determining whether learner understanding of kinematic graphs has improved as a result of them participating in the TRAC PAC- based learning programme.

CHAPTER 4

A survey of the literature: Learner difficulties with graphs of motion

A number of studies have been conducted in this area of learner conceptions e.g. Panse (1994), Goldberg & Anderson (1989), Frauenknecht (1998), McDermott, Rosenquist and van Zee (1987), and a number of common misconceptions and/or difficulties that learners have in this area have been identified. While this particular study focuses on misconceptions related to kinematic graphs, it is virtually impossible to separate this area from the broader study of kinematics. Misconceptions and/or difficulties that learners experience with graphs of motion may have their roots in weak conceptual understanding of kinematic concepts like displacement, velocity and acceleration.

Goldberg and Anderson (1989:254) outline some underlying causes of difficulties learners' experience with kinematic graphs including:

> ... a lack of understanding of kinematic concepts, confusion between the concepts, an inability to extract appropriate information from the slope or ordinate of a graph, and a tendency to draw a curve which looks like a picture of the motion of the object. (Goldberg and Anderson, 1989: 254)

A study conducted by Clement, Mokros and Schultz (1985) identified the following misconceptions, namely, "graph as picture, slope/height confusion, centering on one variable only, linearity of scale, initial positioning at the zero point on the axis, and a static (rather than dynamic) conception of graphs" (Clement *et al.*, 1985: 2).

Frauenknecht (1998: 328) identifies five broad categories of potential problem areas including "a poor perception of reference point and sign convention", "not differentiating adequately between certain kinematic quantities", "an unwillingness to use gradients and areas to interpret graphs", "a tendency to conserve the features of a given graph when having to construct a related graph" and "viewing graphs as pictures of the problem scene".

The misconceptions and/or difficulties that learners experience are categorized into groups purely to allow a systematic exploration of the misconceptions associated with kinematics and kinematic graphs. While it may be useful to categorize learner difficulties into various groups, it must be emphasized that these difficulties cannot be viewed separately. For example, problems with basic understanding of kinematic concepts will manifest themselves in learner inability to interpret graphs. For the sake of this study, the following categories are identified:

Category A

Problems related to conceptual understanding of kinematic quantities.

Category B

Problems associated with reference points, sign convention difficulties and difficulties dealing with negative kinematic quantities.

Category C

Graph translation and transformation difficulties.

Category D

Graph interpretation difficulties.

Each of these categories is explored in greater detail in the discussion that follows. Studies that identified difficulties in each area are described.

4.1 Category A - Problems related to conceptual understanding of kinematic quantities

The level of conceptual understanding that learners have of basic kinematic quantities like position, distance, displacement, velocity and acceleration has been shown to impact on their ability to work with graphical representations of motion.

In my experience, science teaching in our schools, and presentation of these concepts in commonly used textbooks, fails to distinguish adequately between these concepts. For example, the concept of position is largely ignored in our coverage of kinematics.

In a study into the conceptual difficulties that physics honors students have with kinematic concepts, Peters (1982:502) found that:

- Students are confused about the meanings of position and velocity, and are often unable to distinguish between the two.

- Students have difficulty with representing features of motion like speeding up and slowing down.

- They do not see the relationship between the position-time graph and the velocity-time graph. For example, they do not recognize that the velocity-time graph should be a plot of the slope of the position-time graph.

- They have difficulty with the concept of objects having a negative velocity and are often unable to represent this on a graph.

Halloun and Hestenes (1985:1063) found that:

- Learners do not differentiate between a "time interval" and an "instant of time". They interpret an instant to mean a very short time interval.

- Velocity is defined as distance divided by time. Thus learners do not differentiate between instantaneous velocity and average velocity.

- Concepts of distance, velocity and acceleration are not well differentiated.

Studies by Trowbridge and McDermott into student understanding of the concept of velocity in one dimension (Trowbridge and McDermott, 1980), and acceleration in one dimension (TrowBridge and McDermott, 1981), explored the difficulties learners experience with these concepts.

4.1.1 Difficulties with learner understanding of the concept of velocity

In a study of "student understanding of the concept of velocity in one dimension", Trowbridge and McDermott (1981) explored the difficulties that students have with the concept of velocity. Students who were enrolled in a variety of university level introductory physics courses were required to respond to the two speed comparison tasks described below in individual demonstration clinical-type interviews. In the tasks the students were required to compare the motions of two identical balls rolling on parallel aluminium u-channels.

In Speed Comparison Task 1:

> ...ball A travels with uniform motion from left to right while ball B travels in the same direction, starting with an initial velocity greater than that of ball A. As ball B travels up a gentle incline, it slows down and eventually comes to rest. Ball B first passes ball A, but later, ball A passes ball B. The students observe the motions of the balls, first separately and then together, several times. (Trowbridge and McDermott, 1981, 1022.)

Figure 4.1(a) below represents the physical motions of the ball, and Figure 4.1(b) represents a position time graph for the motion. The graph was not used in the interviews.

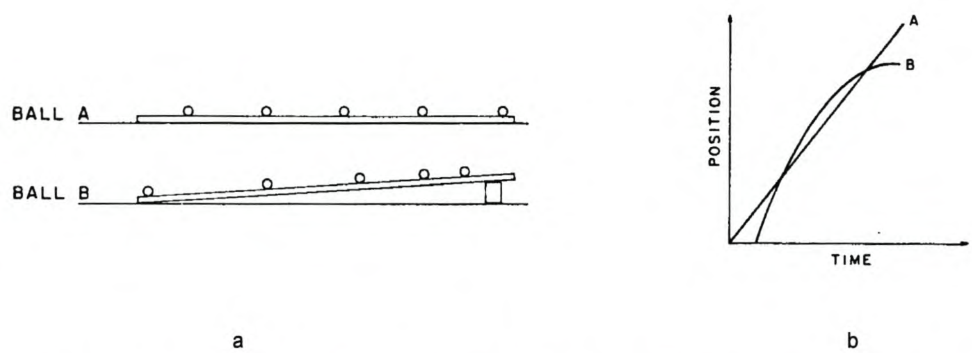


Figure 4.1: (a) Speed Comparison Task 1. Motion is from left to right. (b) Position-time graph for motion in (a).

In Speed Comparison Task 2:

> ...ball B has the same motion as before. It starts with some high initial velocity, slows down, and comes to rest. Another ball, ball C, starts from rest at a point ahead of ball B. It accelerates uniformly down a gentle incline. Ball B never overtakes ball C. (Trowbridge and McDermott, 1981, 1023.)

Figure 4.2(a) below represents the physical motions of the ball, and Figure 4.2(b) represents a position time graph for the motion. The graph was not used in the interviews.

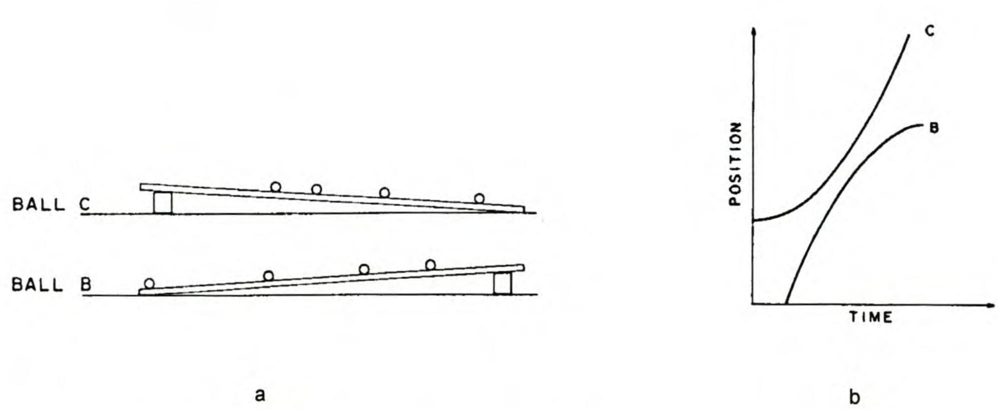


Figure 4.2: (a) Speed Comparison Task 1. Motion is from left to right. (b) Position-time graph for motion in (a).

They found that when students failed to make an appropriate comparison between the motion of the two balls in each case, students commonly used relative positions of the balls to make statements about the speed of the balls. For example, learners identified points during the motions where the balls had the same position, as being points where their speeds were the same. Similarly, if a ball occupied a position ahead of another at a specific time, students associated the "idea of being ahead with having a greater speed" (Trowbridge and McDermott, 1981, 1024).

They conclude, "The principal conceptual difficulty demonstrated by students participating in the study, was an inability to discriminate between position and velocity" (Trowbridge and McDermott, 1981, 1028).

4.1.2 Difficulties with learner understanding of the concept of acceleration

In a study that **explored qualitative understanding of acceleration** as the ratio $\Delta v/\Delta t$, Trowbridge and McDermott (1981) set the following task for learners:

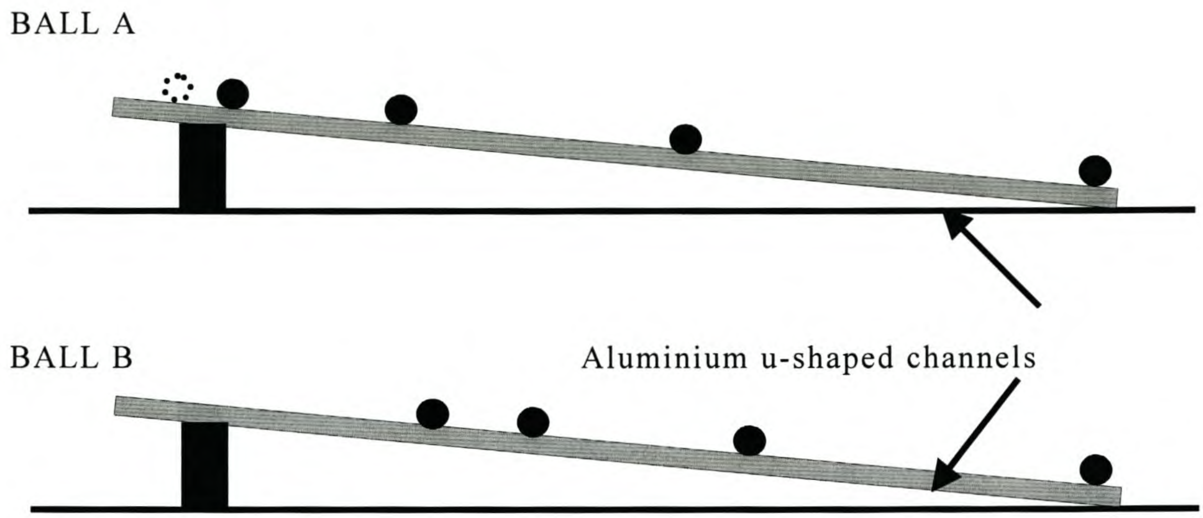


Figure 4.3: Acceleration task: Motion is from left to right. Successive positions are shown, as they would appear in a strobe light photograph. Dashed circle indicates the initial position of ball A. Solid circles indicate positions of ball at equal time intervals.

Two steel balls were allowed to roll down straight u-shaped aluminium tracks of differing widths (The differing widths produced different accelerations of the balls.) Both balls started from rest. Ball A was released first from a point several centimeters behind ball B. Ball A rolled for a few centimeters and then strikes the lever of a micro-switch which released ball B. Both balls reach the same final velocity just as they simultaneously enter a tunnel at the bottom of the channels. Learners were required to observe the motion of the balls and then answer questions about the acceleration of the balls in an interview situation.

Trowbridge and McDermott (1981: 247) suggest that the "procedures" learners used when describing the acceleration of the balls could be interpreted in the following ways:

- Some learners used a non-kinematical approach in the responses they made to interview questions. For example, learners suggested that the balls have the same acceleration because the slopes were the same, or that balls had the same or different accelerations depending on their relative final positions.

- Confusion between the meanings of velocity and acceleration was evident in some responses. Typical learner reasoning included suggestions that:
  - Balls have the same acceleration because their final speeds were the same.
  - Ball A has a greater acceleration because it is catching up to ball B.
  - Ball A has a greater acceleration because it covers a greater distance than ball B in the same time.
  - Balls may have the same acceleration because ball A covers a greater distance than Ball B in a longer time.

- Some learners were able to discriminate between velocity and change in velocity but their reasoning about the acceleration of the balls ignored considerations of the corresponding time interval associated with the change in velocity. For example, learners suggested that ball B has a greater acceleration because its velocity changes by the same amount as the velocity of ball A but in a shorter **distance.** The learners associated acceleration with change in velocity per unit distance rather than change in velocity per unit time. Another response learners gave, which ignored consideration of the time interval, was that ball B had a greater acceleration because its velocity catches up to the velocity of ball A and thus changes by a greater amount.

- The responses of some learners illustrated a qualitative understanding of acceleration as the ratio $\Delta v/\Delta t$. These learners used one of two procedures to correctly describe the balls' acceleration:
  - ➢ They reasoned that ball B has a greater acceleration than ball A because its velocity changes by a greater amount in the same time, or that
  - ➢ They reasoned that Ball B has a greater acceleration than ball A because its velocity changes by the same amount in a shorter time.

Both these responses make use of a change in velocity over a certain time interval to compare the acceleration of the balls.

Trowbridge and McDermott then set a second paper /pencil task to **probe learners quantitative understanding of the concept of acceleration.** Learners were presented with the following scenario on paper (no equipment was used to illustrate the situation).

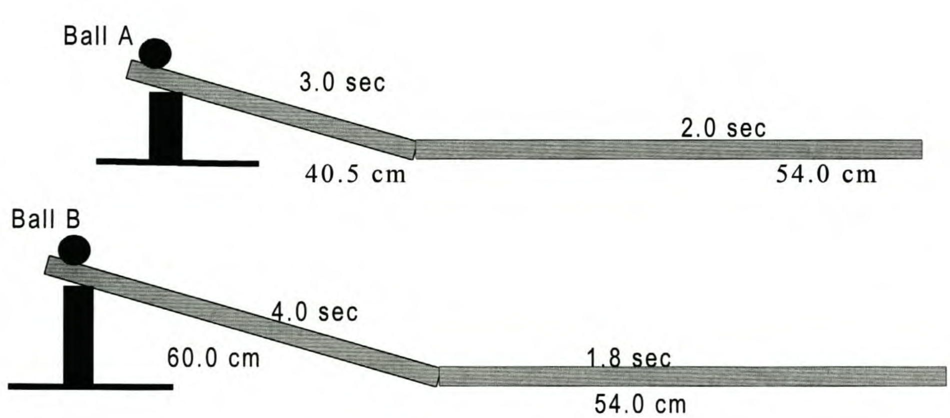


Figure 4.4: Task to probe learners quantitative understanding of acceleration (Trowbridge and McDermott, 1981:247).

Learners were requested to identify which ball has the greater acceleration on the sloping section, and to show their reasoning. (Learners were informed that use of kinematic formula like $s = ut + \frac{1}{2}$

at^2 was not allowed). Learners, who demonstrated a quantitative understanding of acceleration as the ratio $\Delta v/\Delta t$, solved the problem by using the data provided on the level part of the track to calculate the average velocity over this region. They then used this velocity as an instantaneous final velocity at the bottom of the slope, and recognizing that the initial velocity of the ball was zero, computed the acceleration by using the ratio $\Delta v/\Delta t$.

Those learners who had problems handling the task made the following errors:

- Simply substituting figures in kinematic equations to calculate acceleration.

- Learners calculated average velocity on the incline using $v = s/t$ and then used the value they obtained to calculate the acceleration on the slope using $a = v/t$. These learners are confused about the difference between average velocity and instantaneous velocity, and have difficulty understanding acceleration as the rate of change of velocity, where its computation would thus require an initial velocity, a final velocity and the time interval over which the change took place.

A final task **explored learner understanding of a special case of uniform acceleration – projectile motion**. In the experimental setup, of a ball that is given an initial push up an incline. It travels up the gentle incline, reverses direction and then returns to its starting point. The motion of the ball is very similar to projectile motion. Learners were requested to describe the acceleration through the entire motion.

Three parts of the motion were identified:

(1) The part where the ball is travelling up the incline.

(2) The instant at which the ball is at the top of the incline.

(3) The part where the ball is travelling down the incline.

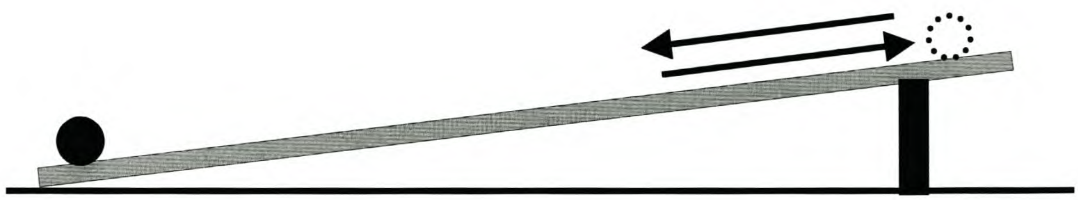


Figure 4.5: Experimental setup to explore learner understanding of constant acceleration during projectile motion. (Trowbridge and McDermott, 1981: 248).

Difficulties that learners experienced here include:

- Suggesting that the ball has zero acceleration at the instant when it reaches its highest point on the slope because, in the words of one of the learners, "... it's stopped. It's not moving; it's turning around" (Trowbridge and McDermott, 1981: 248).

- Suggesting that the sign of the acceleration changes with the sign of the velocity. "The acceleration going up the track would be negative, and equal in magnitude to the positive acceleration coming down the track" (Trowbridge and McDermott, 1981: 248).

Learners seem to have difficulty accepting that the magnitude and direction of the acceleration of the ball remains constant throughout the motion, even though its velocity changes. The expectation seems to be that a changing velocity should produce a changing acceleration.

4.2 Category B - Difficulties associated with reference points and frames of reference, sign convention and graphical representation of negative kinematic quantities

4.2.1 Problems associated with reference points and frames of reference

If learners are unable to assign a reference point it becomes very difficult to describe and/or analyze the object's motion.

In a study of learner preconceptions about the vector characteristics of position, displacement and velocity, Aguirre and Erikson (1984) showed that they can hold a variety of conceptions about reference points and frames of reference, and that these conceptions can have differing degrees of fit with the accepted scientific understanding of these concepts. They used an interview technique to probe understanding of these concepts, and based their interview questions on the two simulation tasks shown below. Large cardboard models (1m x 1m) and short films were used to familiarize students with the problem setting.

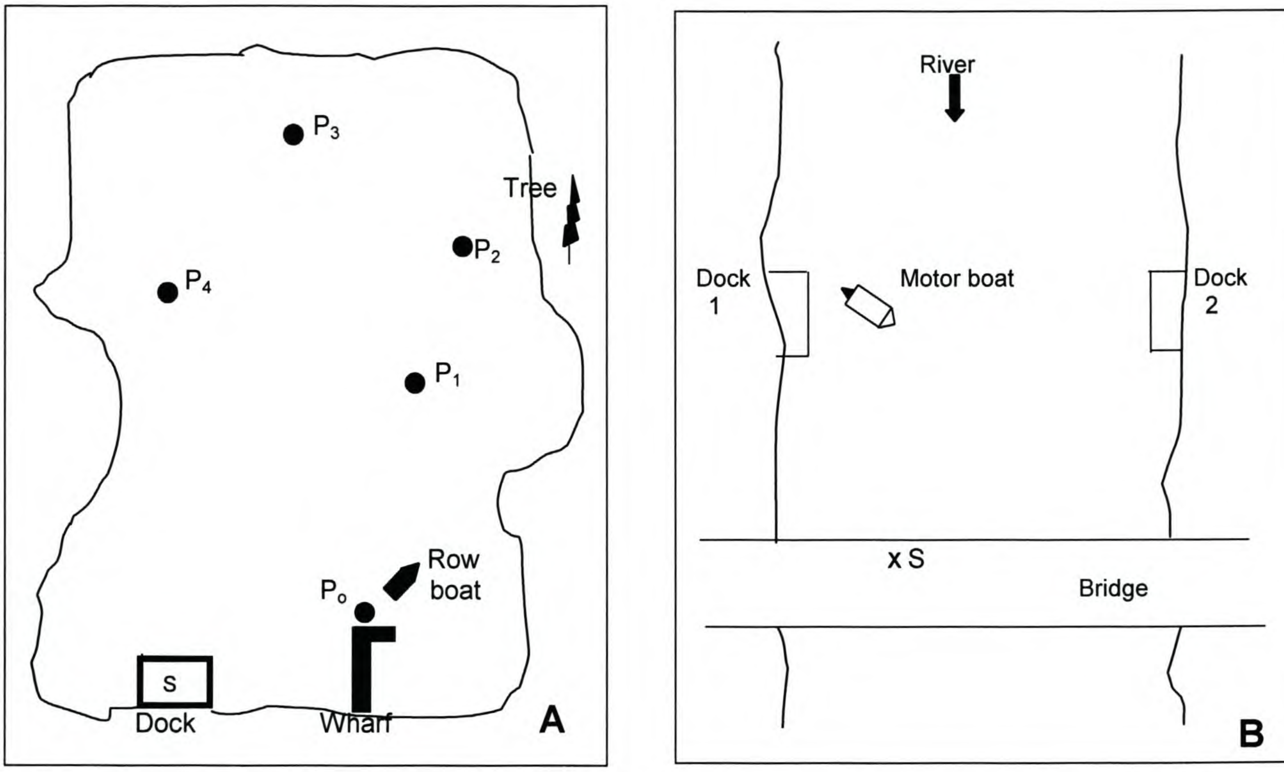


Figure 4.6: A: Diagram of the lake, including the dock (where the subject (S) stands), the wharf, the rowboat, the fishing spots (P_1, P_2, P_3 and P_4), and a tree.
B: Diagram of the river, including the bridge (where the subject stands), the two docks, and the motorboat. (Aguirre and Erickson, 1984: 454-455.)

In the first task, learners being interviewed were asked to imagine that they were standing on the dock and observing the rowing boat move to different fishing spots. In the second task learners were asked to imagine that they were standing on the bridge at position X and observing the motorboat moving across the river. Questions were asked about both scenarios that probed the learners' understanding of the vector characteristics of the rowboat and motorboat's motion. Analysis of responses allowed them to generate a series of what they termed " general rule-models" (Aguirre and Erickson, 1984: 446). In each series, the first rule-model represented a conception furthest removed from the accepted physicist's model of that conception, while the last represented a conception that closely fitted the physicist's model.

General rule-models for reference points for stationary (RPS) bodies included:

- RPS-I: Use of multiple reference points (bodies or places) to locate a stationary body.
- RPS-II: Use of one reference point (body or place) to locate a stationary body but distinct ones to locate other stationary bodies.
- RPS-III: Use of one unique reference point (body or place) to locate a number of stationary bodies. (Aguirre and Erickson, 1984: 446.)

General rule-models for reference points for objects in motion (RPM) included:

- RPM-I: Description of the motion of an object relative to a stationary reference body and relative to a moving reference body are equivalent.
- RPM-II: Descriptions of the motion of an object relative to an implicit stationary reference point and relative to a moving reference body are not equivalent.
- RPM-III: Descriptions of the motion of an object relative to one stationary reference body and relative to a moving reference body are not equivalent. (Aguirre and Erickson, 1984: 449)

4.2.2 Sign convention difficulties

Sign convention provides a useful tool for expressing some of the characteristics of physical quantities. At school level in South Africa, sign convention is used in kinematics to describe the directional properties of physical quantities like displacement, velocity and acceleration, for objects moving in one dimension, using a system of positive (+) and negative (-) signs.

Govender (1999) used a case study approach to explore how students experience, understand and use sign convention. He describes this as the variation in ways of students' experience of sign conventions. He used interviews and paper-and-pencil responses to explore learners' experience of sign conventions in the context of falling bodies and objects moving on inclined planes. Some ways in which learners experience sign convention, which have an impact on this study, include:

Displacement

- Learners may not appreciate the arbitrary nature of allocation of sign conventions.

For example, in many of the examples they are exposed to in Grade 11 textbooks and in examples described by the teacher, or in agreement with representation of the mathematical number line, displacement to the right (for horizontal rectilinear motion) and displacement upwards (in the case of falling bodies), may be described as positive. Learners may memorize this convention as being the only way displacements can be described. They will repeatedly use this convention and experience difficulty when they experience different conventions.

Velocity

- Learners can associate the sign of the velocity with its magnitude. For these learners, a positive (+) sign indicates a large velocity and a negative (-) sign indicates a smaller velocity.

For example, a learner who is asked to describe the behavior of object A, which has a velocity of $+2m.s^{-1}$ and the velocity of object B, which has a velocity of $-2m.s^{-1}$, may respond by suggesting that object A is moving much faster than object B.

- If the velocity of the object changes from positive to negative, this may be interpreted as the object slowing down, and vice versa.

For example, if the velocity of an object changes from $-2m.s^{-1}$ to $+2m.s^{-1}$, the learner may explain this by suggesting that the object is speeding up.

Govender (1999:194) links this experience of sign convention to learner difficulties with conceptual understanding of velocity and acceleration. He suggests that learners do not see velocity as being an "instantaneous" concept, and that relating the "sign convention to the change in velocity rather than the direction for instantaneous velocity", illustrates a lack of differentiation between the concepts of instantaneous velocity and changing velocity (acceleration).

Acceleration

- Learners may associate the sign for acceleration with whether the object is slowing down or speeding up.

For example, for an object moving up an inclined plane, the learner may suggest that because the velocity is decreasing (the object is slowing down) as the object moves up the plane, the acceleration is negative. At its highest point, where it stops, the acceleration is described as being zero, and as it moves downwards, its velocity is described as being positive because its velocity is increasing (it is speeding up).

- Learners may associate the sign for the acceleration with the direction in which the object is moving.

For example, if a ball is projected upwards and then falls towards the earth again, learners may suggest that the acceleration of the ball when it is moving upwards is positive if the upward direction was specified as being positive.

- Learners may use signs to suggest that the magnitude of the acceleration is changing.

For example, in the case of the ball being projected upwards, they may use a negative sign to suggest that the acceleration of the ball is decreasing as it moves upwards and a positive sign to indicate that the acceleration of the ball is increasing as it comes down. Here they fail to recognize that the acceleration of the ball is constant, and are probably having difficulty distinguishing between the concepts of changing acceleration and changing velocity.

4.2.3 Difficulties associated with graphical representation of negative kinematic quantities

Goldberg and Anderson (1989) conducted a study that focused on the difficulty learners' experience with graphical representations of negative values of velocity. They used two activities in an interview setting to probe learners' ability in this area.

In the first activity, learners were asked to describe the motion of a ball moving on the slope as shown in Figure 4.7 below, and then to draw a velocity-time graph for the motion of the ball. Questions were used to get them to explain the reasoning behind their explanations and graphical representations.

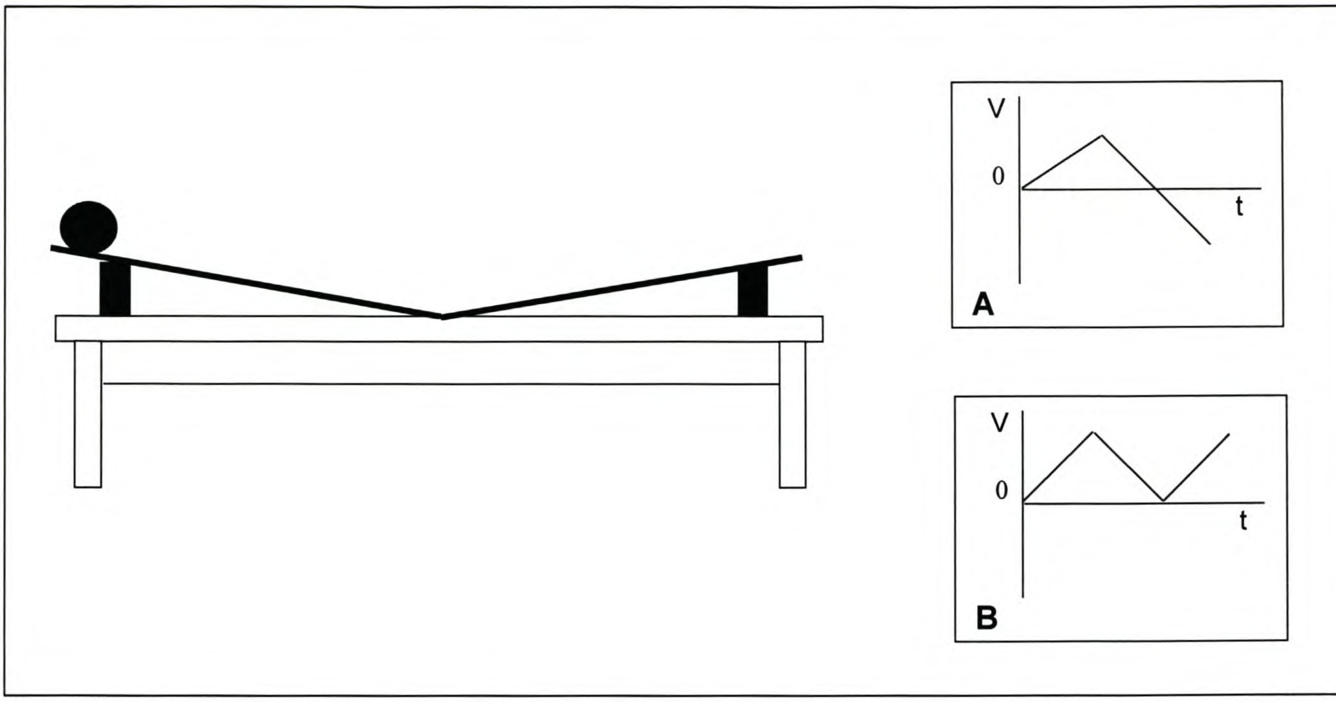


Figure 4.7: Experimental setup for motion of a ball up and down inclines. A shows an acceptable velocity-time graph for the motion of the ball. B shows a common response of learners, where the values of velocity are all positive.

In the second activity, the researchers wanted to test the ability of learners to interpret v-t curves in which there was a change in sign. They presented the graph shown in Figure 4.8 to students.

> The student was asked to describe the graph and then to reproduce the motion, either by setting up the tracks and having the ball roll along them in an appropriate manner or by moving a finger along the table top. (Goldberg and Anderson, 1989: 256.)

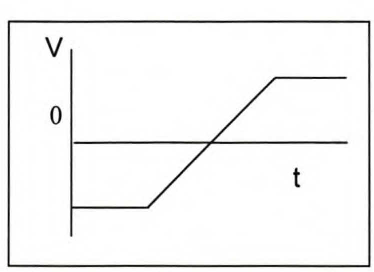


Figure 4.8: Graph used in velocity-time interpretation task. The learner was asked to reproduce the motion described in the graph. (Goldberg and Anderson, 1989: 256.)

Finally, questionnaires were administered to students to check whether their performance changed if they were presented with different forms of v-t graphs. Each questionnaire contained one of the four graphs shown in Figure 4.9.

Students were required to write a few sentences describing the motion of the object represented by that graph.

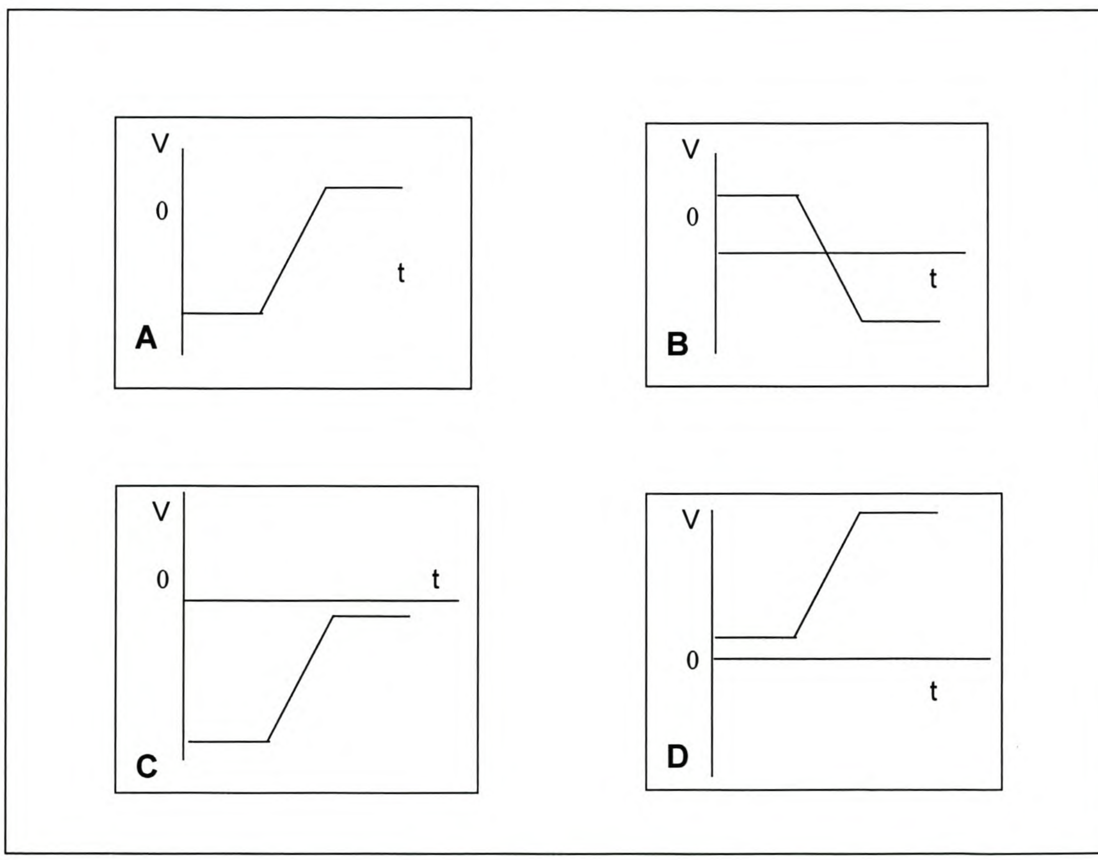


Figure 4.9: Four different versions of velocity-time graphs used in paper-and-pencil questionnaires. Students were asked to give a written description of the motion represented by the graph. (Goldberg and Anderson, 1989: 257.)

Typical learner errors and difficulties that were noted included:

- Not being able to accept that objects can have a negative velocity. This is shown by one student's response, "What is negative velocity? I can understand zero and positive, but a negative velocity is rather difficult for me to think about. It's either going or it's not going, and if it's a negative velocity, then what is that?" (Goldberg & Anderson, 1989: 256). The implication seems to be that the learner associates a positive velocity with moving objects, a zero velocity with stationary objects, but has no conception of objects with negative velocity.

- Not being able to identify that the point where the graph touches or crosses the x-axis corresponds to a zero instantaneous velocity at that point.

- Students were able to describe the motion of objects where the velocity was entirely positive, e.g. graph D, but as soon as they had to interpret representations of negative velocities (graphs A, C and E), they experienced difficulty.

- Suggesting that a positive gradient always meant that the object was speeding up, regardless of whether the velocity was positive or negative. Goldberg and Anderson (1989: 258) called this a "displaced curve" error. Students were interpreting the graph as if it was entirely above the x-axis and were probably thinking in terms of speed only.

Regarding sources of these errors, Goldberg and Anderson (1989: 258) suggest that:

- Students are more familiar with the magnitude of velocity i.e. speed in everyday life, and do not see the necessity of combining both the magnitude and directional aspects of velocity when representing it in a graphical format. In interpreting graphs of velocity, they tend to totally ignore the directional aspect.

- Students may be associating a negative quantity with a "lesser amount" of that quantity, rather than associating it with changes in direction.

4.3 Category C - Graph translation and transformation difficulties.

A number of studies have described difficulties that learners experience when translating between an observed physical situation involving motion of an object, a verbal description of the motion of the object, and a graphical and/or mathematical representation of the motion of the object.

4.3.1 Translating between narrative information and graphical representations

Learners have been shown to experience difficulty when matching narrative information about an object's motion with a graphical representation of the motion, and when producing a graphical representation from narrative information about the motion, or vice versa.

McDermott *et al.* (1987: 506) explored the problem of matching narrative information about an object's motion with a graphical representation by setting the following problem for students:

They provided the following narrative information and graphical representation to students:

> A spaceship has three different rocket engines, each of which gives the ship a uniform acceleration when it is turned on. In the graph in Figure 4.10, point P represents the velocity of a rocket at a particular time. At point P, the captain turns on the #1 engine. At point Q, the #1 engine is turned off and the #3 engine

is turned on. At point R, the #3 engine is turned off and the #2 engine is turned on. We lose all information about the ship after point R. (McDermott *et al*. (1987: 506.)

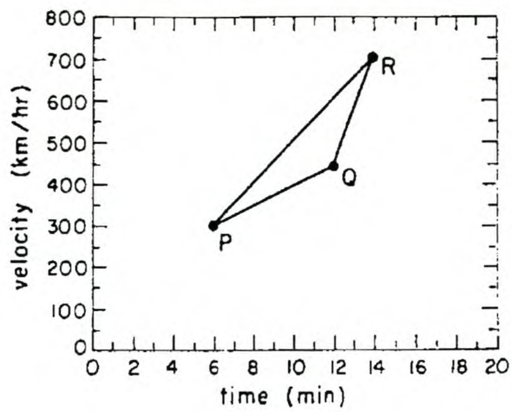


Figure 4.10: Velocity versus time graph for the motion of the rocket.

Learners were expected to find the acceleration produced by each of the engines.

Learner problems and difficulties that were identified included:

- Students did not realize that they needed to determine the ratio $\Delta v/\Delta t$, i.e. the slope, for the period that the rocket was firing in order to determine the acceleration produced by the rocket. Instead, for example, with rocket #1, some students simply divided the co-ordinates of point P or point Q when attempting to find the acceleration. These students were not able to relate slope of a v/t graph with acceleration or where not able to distinguish between the ratio v/t and $\Delta v/\Delta t$.

- For those students who did use the slope to find acceleration, many were unable to match the appropriate rocket with the correct slope.

- By far the most common mistake learners made was the inability to realize that the acceleration produced by rocket 2 could not be found. Instead, they suggested that this acceleration be indicated by slope PR. This may indicate a lack of attention to detail in the narrative description or simple reliance on a rote-learned algorithm, viz. the slope of a v/t graph equals acceleration.

4.3.2 Translating between real-life motions and graphical representations

According to McDermott *et al.* (1987:507) "...the task of representing an observed motion on a graph is very difficult for many students". To investigate the nature of the difficulties learners experience in this regard, they set up the following set of experiments:

In the first experiment a level track was set up to allow the ball to roll uniformly along the track. To overcome effects of friction, the 'level' track was tilted slightly. Learners were provided with stopwatches and metre sticks. The clocks are started synchronously when the ball starts rolling. Each clock is stopped when the ball passes its position. Besides being asked to draw a position-time graph representing the motion, no other instructions were given to the learners.

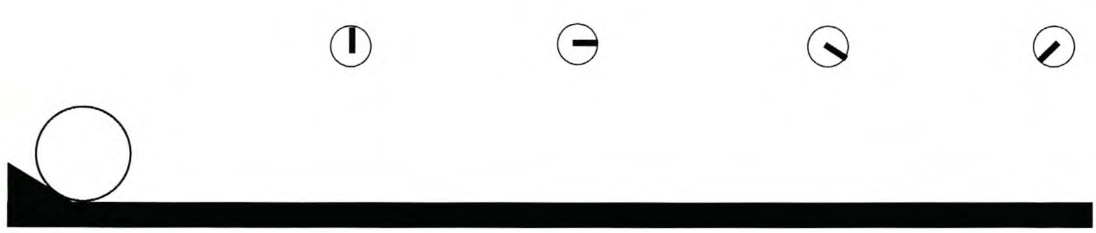
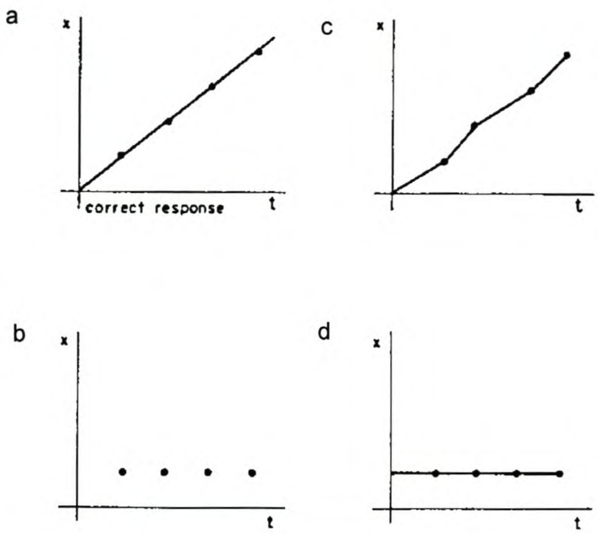


Figure 4.11: Experimental set-up for ball rolling along a level track.



a) Correct position-time graph for the motion in Experiment 1.

b) Successive displacements are plotted as unconnected points.

c) Lines are drawn between data points.

d) Shape of the position-time graph resembles the path of the motion.

Figure 4.12: Required response and some learner responses for Experiment 1.

In a second experiment, the ball was allowed to roll along a level track at a low speed, accelerate down an incline, and then roll along a lower level track at a higher uniform speed. Again, the watches were started synchronously, and stopped as the ball passes that position. Learners were requested to draw position-time and velocity-time graphs representing the motion.

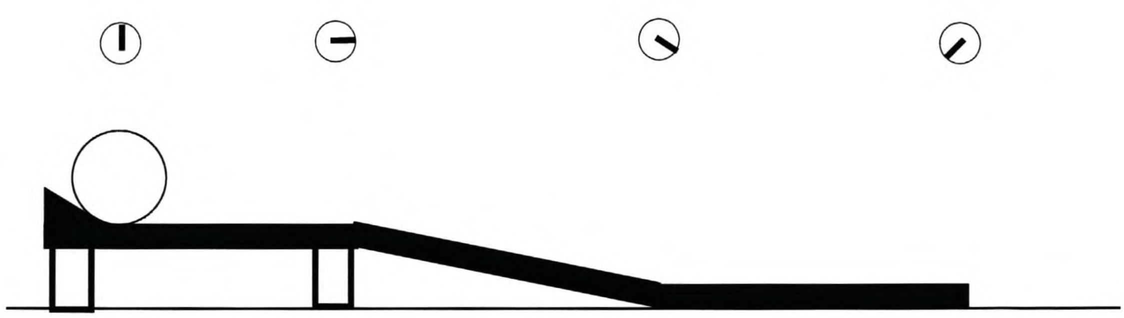
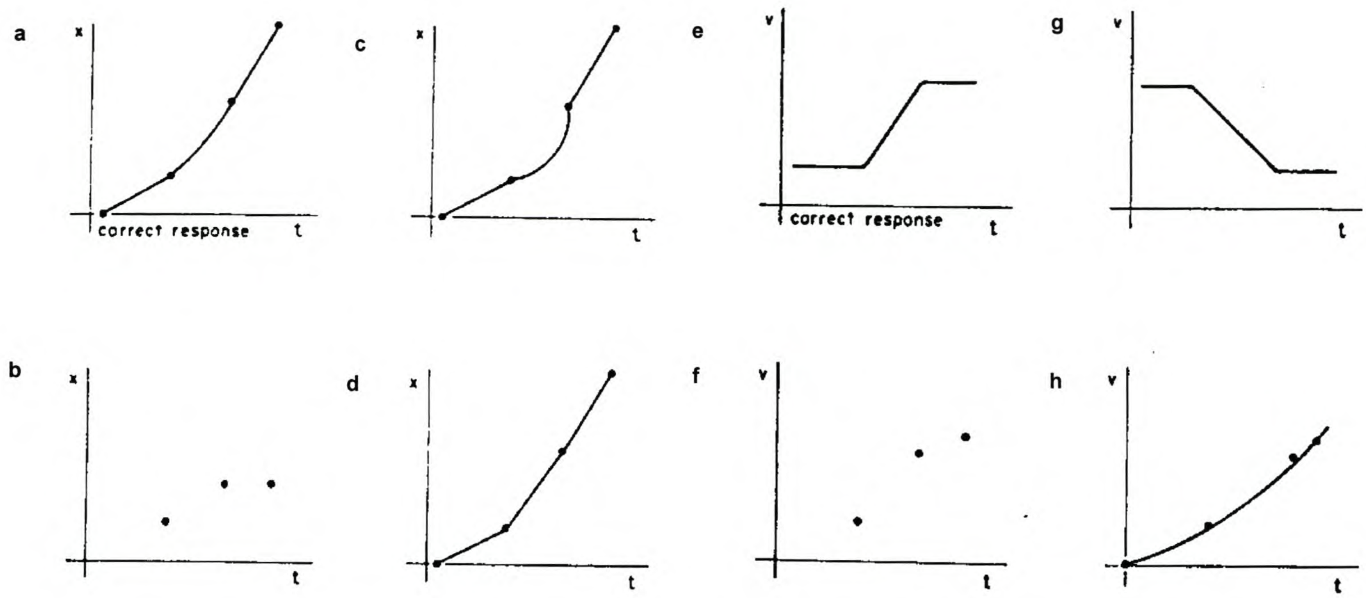


Figure 4.13: Set-up for Experiment 2 where ball rolls along track with level and inclined portions.



a) Correct position-time graph for the motion in Experiment 2

b) Length of each segment is plotted at end of corresponding time interval. Although motion is continuous, points are not connected.

c) Graph segments are connected by kinks instead of smooth curves.

d) Shape of x vs. t graph is straight like the track, instead of curved, during accelerated part of the motion in which ball rolls down straight track.

e) Correct velocity-time graph for the motion in Experiment 2.

f) Velocity for each segment is plotted at the end of a corresponding time interval. Although motion is continuous, points are not connected.

g) Shape of v vs. t graph resembles path of motion.

h) Shape of v vs. t graph resembles shape of x vs. t graph.

Figure 4.14: Required response and some learner responses for Experiment 2.

In the third experiment, an additional segment was added to the track from Experiment 2. This allowed the ball to roll up the second incline, slow down, turn around and accelerate back down again.

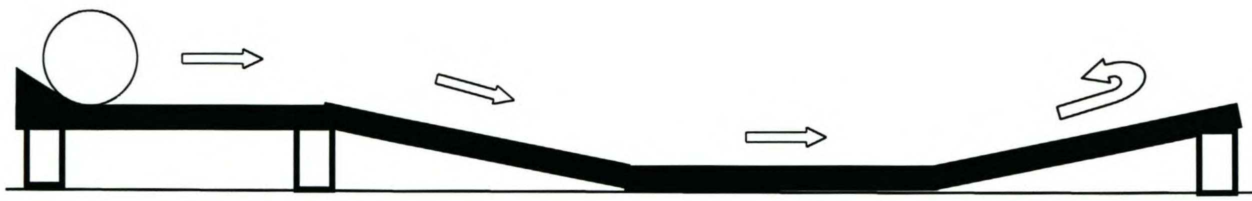
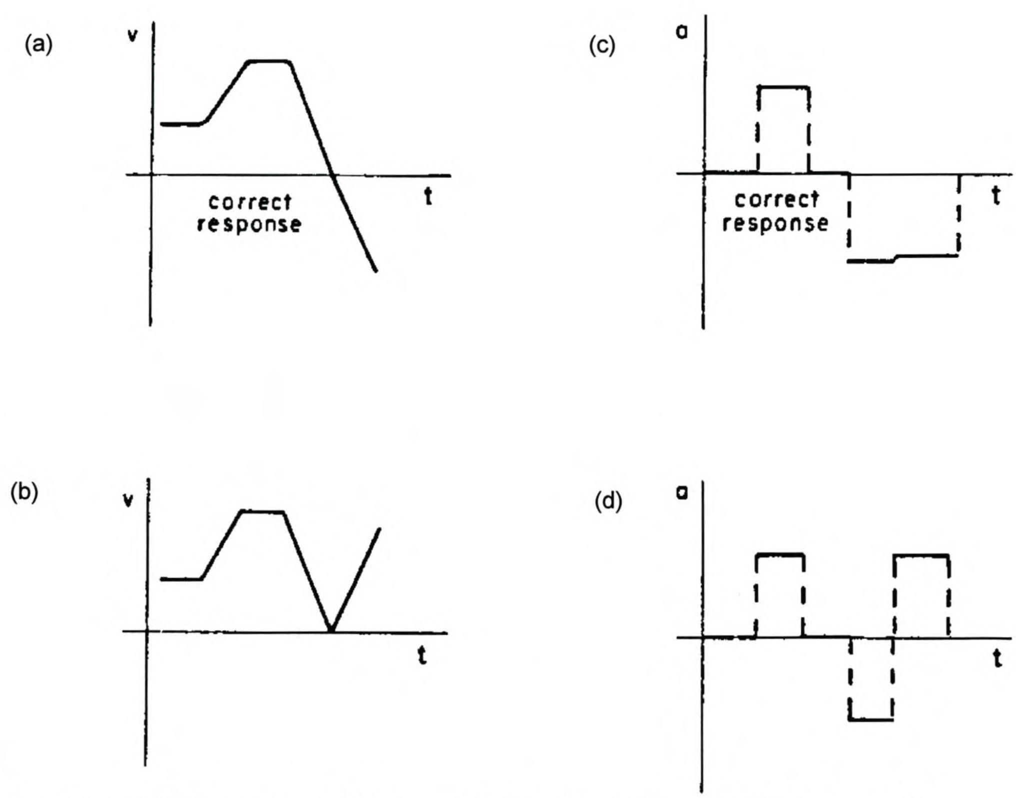


Figure 4.15: Experimental set-up for Experiment 3 where ball rolls down an incline, across a level portion and then up and down another incline.



a

a) Correct velocity versus time graph for the motion in Experiment 3.

b) Velocity versus time graph has 'V' that corresponds to reversal along the path of motion.

c) Correct acceleration time graph for the motion in Experiment 3.

d) Acceleration versus time graph has positive acceleration when velocity is increasing, and negative acceleration when velocity is decreasing.

Figure 4.16: Required response and some learner responses for Experiment 3.

McDermott *et al.* (1987: 508) identified a number of typical learner errors and difficulties. These are elaborated on below:

- Learners have difficulty **deciding which data to take and how to make appropriate use of their measurements.** For example, in Experiment 1, where the learners needed to plot a position-time graph, they had to "choose an origin, establish a coordinate system, and assign position numbers along the track" (McDermott et al, 1987: 509). However, Figure 4.12(b) is an example of a response from a learner who simply measured the length of segments of track and then plotted these lengths versus the clock reading as the ball passes the end of each segment. This student fails "to distinguish between the position of a ball (x) at a particular instant and its displacement (Δx)" (McDermott *et al.*, 1987: 509).

  A similar error in data collection and representation is made with the displacement-time graph in Figure 4.14 (b) and the velocity-time graph in Figure 4.14 (f). In Figure 4.14 (b), the learner plotted the length of each segment against the time taken for the ball to reach the end of that segment. In Figure 4.14 (f), the learner plots a velocity for each segment against the time taken to reach the end of the segment.

- Learners often **do not see the necessity of representing continuous motion by using a continuous line**. For example, Figure 4.12(b), Figure 4.14(b) and Figure 4.14 (f) shows student responses where the motion of the ball is represented by a series of separate points rather than by a continuous line.

  Even when learners do join the separate points, they often "make point-to-point connections that form a disjointed line"(McDermott *et al.*, 1987: 509), rather than attempting to fit a smooth curve to the data points. For example, see Figure 4.12(c).

On a more sophisticated level, a learner may join points with a smooth or continuous straight or curved line, but does not join points correctly. For example, the learner who drew the position time graph in Figure 4.14 (c) "drew kinks instead of smooth curves to connect the segments" (McDermott *et al.,* 1987: 509), thus indicating that abrupt changes in the motion of the object occurred.

- Learners can have difficulty **separating the shape of the graph from the path of the motion.** These learners draw graphs that resemble the physical path of the motion. In other words, they attempt to "reproduce the spatial appearance of the motion". (McDermott et al, 1987). For example, Figure 4.12 (d), Figure 4.14 (d), Figure 4.14(g) are examples of graphs drawn that have a similar appearance to the shape of the track that produced the motion. Writers like Clement *et al.* (1985) have referred to this as the "graph-as-picture" problem. Learners draw a graph that is a picture of the actual physical situation.

- Learners have difficulty **representing negative velocities**. In Experiment 3 the students were requested to draw velocity-time graphs to represent the motion of the ball, part of which involved a change in direction of the ball. Rather than representing the velocity as shown in Figure 4.16 (a), where the motion of the ball is represented by the portion of the graph below the x-axis, some students responded by drawing graphs which resembled Figure 4.16 (b), where the change in direction of the ball is represented by a change in direction of the graph. Whereas the motion up the incline is represented by a line having a negative gradient, the motion down the incline is represented by a line having a positive gradient. It may be that learners concentrate more on representing the magnitude of the velocity and less on its directional aspects. McDermott *et al.* (1987: 511) suggest that learners may again be attempting to "represent on paper the reversal in direction of the actual motion in space" - the graph-as-picture problem again.

- Learners can have **difficulty representing constant acceleration on an acceleration-time graph.** In experiment 3, learners were asked to draw acceleration-time graphs to represent the motion. Most learners were able to represent the first part of the motion accurately. Problems were experienced when learners attempted to represent motion on the second incline. Figure 4.16 (c) shows the correct representation, while Figure 4.16 (d) shows a typically erroneous student representation of the situation.

  In Figure 4.16 (d), learners show a positive acceleration for intervals when the object is speeding up, and a negative acceleration for periods when the object is slowing down. For these students, a negative acceleration means that the object is decelerating and a positive acceleration means that the object is accelerating. These learners fail to realize that "an object with a negative acceleration may either be speeding up (if the velocity is also negative) or slowing down (if the velocity is positive)".

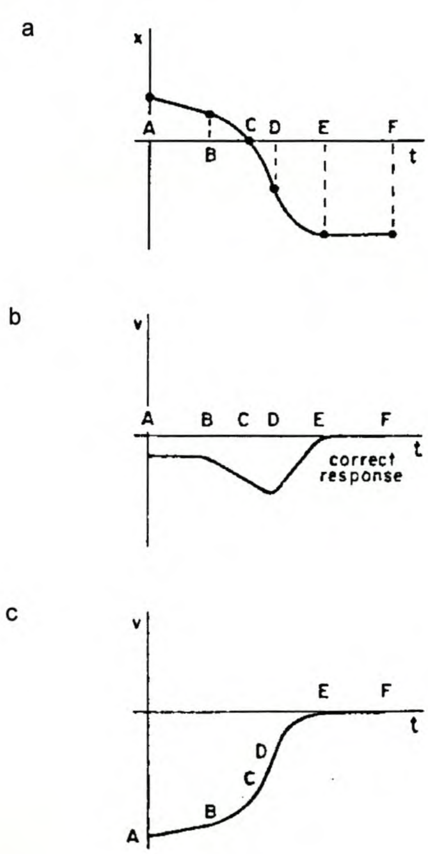
  Some students drew graphs that showed a positive acceleration for the portion of the motion where the object was moving up the incline and a negative acceleration when the object moved down the slope. These students may be associating the direction of the acceleration with the direction of the motion.

  McDermott *et al.* (1987: 510) suggest that "students seem unaware that one cannot tell from an acceleration-versus time graph whether an object is speeding up or slowing down or in what direction it is travelling".

- Finally, students can have **difficulty distinguishing amongst different types of motion graphs.** When asked to draw distance-time, velocity-time and acceleration-time graphs to represent a particular motion, students often respond by drawing graphs that resemble each other. For example, the student who drew the velocity-time graph in Figure 4.14 (h) could have been reproducing the shape of the distance-time graph, similar to Figure 4.14 (a), which he or she had just drawn.

4.3.3 Translating between different motion graphs (graphical transformations)

Learners are often required to transform one type of motion graph into another. For example, in a problem described by McDermott *et al.* (1987: 505), learners were required to sketch a velocity-time graph from the position versus time graph provided below:



a) Position-time graph for a particular motion.

b) Corresponding correct velocity-time graph for the motion.

c) Sample incorrect velocity-time graph. The shape resembles inversion of the position-time graph.

Figure 4.17: Motion graphs for a particular motion.

A common difficulty learners have is not being able to use the slope of a position-time graph as an indication of the height of the velocity-time graph, and not seeing that an increasing slope on the x/t graph meant an increasing height on the v/t graph.

In the incorrect sample (Figure 4.17c) above, the student was probably focussing on the height of the x/t graph rather than its slope, resulting in a graph that is an inversion of the x/t graph. Students have difficulty ignoring the shape of the original graph when attempting to make graph-to-graph transformations.

4.4 Category D - Graph interpretation difficulties

McDermott *et al.* (1987) identify a number of difficulties that students experience when they attempt to relate physical concepts like velocity to features on a graph. They suggest that the majority of these errors "...can be primarily ascribed to an inability to interpret graphs rather than to inadequate experience with the concepts" (McDermott *et al.*, 1987: 504). Interpretation difficulties that learners experience include:

4.4.1 Discriminating between the slope and height of a graph

Learners need to know which feature of a graph relates to a particular physical quantity when interpreting a graph. A common mistake learners make is to confuse the meanings they ascribe to the height and slope of a graph. McDermott *et al.* (1987: 504) describe a typical example of this. Students are asked to compare and then answer questions about the two uniform motions represented on the position (x) versus time (t) graph shown below.

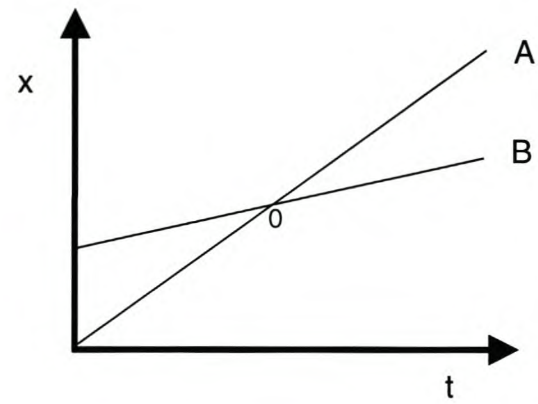


Figure 4.18: Position-time graph for two objects moving at uniform velocity. Learners tend to confuse slope and height when analyzing the motions of the graphs.

When asked to compare the speed of the two objects, a typical learner response would be that object B has a greater speed than object A at points before point O (where the graphs intersect). They reason that the height of graph B is greater than the height of graph A in this area. They fail to use gradient of the lines as an indication of the object's speed.

In response to the question of whether the objects ever have the same speed, a typical incorrect answer learners give is that the speed of the objects is the same at point O where the graphs cross each other. Again, learners may be focussing on an inappropriate feature of the graph to answer the question. Rather than focussing on the slope of the graphs and realizing that the slopes are never the same, therefore the speed can never be the same, learners focus on the point of intersection (the instant when the objects have the same position), and then incorrectly infer that the objects have the same speed at this point as well.

4.4.2 Interpreting changes in height and changes in slope

Learners experience more difficulty interpreting curved graphs. In these graphs, the height and slope of the graph changes. McDermott *et al.* (1987: 504) examine the difficulties learners experience interpreting curved graphs using the following problem:

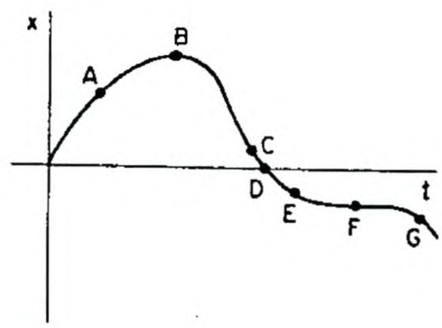


Figure 4.19: Position-time graph for the problem below.

Problem:

At which of the lettered points on the graph in Figure 4.19:

- is the motion slowest?
- is the object speeding up?
- is the object slowing down?
- is the object turning around?

In order to answer these questions, learners had to examine changes in slope and height of the graph at the various points.

Some of the difficulties that learners experienced included:

- Learners often include point D as a point where the object is moving slowest. Their reasoning may be based on the height being 0 at this point. They do not see that the slope is not 0 at this point.

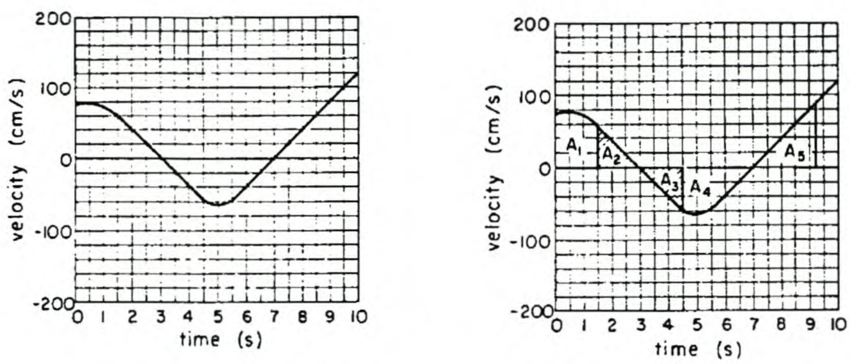
- When identifying points where the object is speeding up, learners typically identify point A. They reason that the height of the graph is increasing here, but fail to see that the slope of the graph is actually decreasing at this point. "Instead of looking for changes in slope, many students focus on the more perceptually obvious changes in height." (McDermott *et al.*, 1987: 505.)

- Choosing point G as a point where the object is slowing down is a common amongst learners. They reason that the slope is negative and therefore this indicates a decrease in speed. They fail to associate the sign of the slope with the direction of motion of the object. "These students base their responses on the sign of the slope rather than on changes in its magnitude." (McDermott *et al.*, 1987: 505.)

- When asked to identify the turnaround point, many learners identify point D. "Instead of looking for a point where the slope changes sign, they identify a point where the height changes sign." (McDermott *et al.,* 1987: 505).

4.4.3 Interpreting the area under a graph

Learners are often requested to determine changes in displacement of an object by considering the area under a velocity-time graph. McDermott *et al*. (1987: 506) write that "Students often find it difficult to envision a quantity that they associate with square units as representing a quantity with linear units". They explored difficulties learners have in this area by using the following problem:



(a) (b)

Figure 4.20: a) Velocity-time graph for the problem below.

b) Crosshatched areas show motion analyzed into series of displacements.

Problem:

Figure 4.20 shows a velocity time graph for an object that is located at x = 0 when t = 0. When is the object located at x = 110cm?

Typical learner errors and difficulties that were identified included:

- Few students were able to interpret the graph to get a qualitative picture of the motion. They could not identify that the areas under the graph above and below the x-axis represented alternating positive and negative displacements and could thus not build up a picture of this object oscillating back and forth.

- On a very basic level, some students did not know how to calculate the area under the velocity-time graph.

- Some students did not know which areas to take into account when determining the displacement or position of the object. For example, "some students included all the squares between the curves and the bottom line of the grid, where the horizontal scale is labeled. By ignoring the v = 0 axis, they fail to perceive its role in defining the positive and negative areas" (McDermott *et al.*, 1987: 507). These students are not able to associate a positive area under the graph with a displacement in the positive direction, and a negative area under the graph with a displacement in the negative direction.

- Some students were not able to access information not included on the graph, e.g. information included in the question itself, in order to solve problems dealing with position of the object.

4.5 Learner difficulties with kinematics and kinematic graphs, textbook treatment of this area, and possible impact of these difficulties on learner performance in the Senior Certificate examinations

Section 2.4.2 of this report explored how this section of knowledge is treated in South African school physical science textbooks, and Section 2.4.3 provided examples of coverage of this knowledge area in the South African Senior Certificate examinations. Having explored specific difficulties that learners experience with kinematics and kinematic graphs here in Chapter 4, it is now possible to speculate on the possible impact that textbook treatment of this area can have on learner experience of these difficulties. Likewise, it is now possible to scrutinize specific examples of Senior Certificate examination questions more closely with a view to identifying how specific difficulties can impact on learner responses to these questions.

4.5.1 Textbook treatment of kinematic graphs in Pienaar and Walters (1987)

The discussion in this chapter identified four areas in which learners experience difficulty with kinematics and kinematic graphs. Textbook treatment of these is explored below:

4.5.1.1 Problems related to conceptual understanding of kinematic quantities.

Learners exhibit much confusion between the meanings they assign to concepts like:

- distance and displacement
- speed and velocity
- uniform velocity, average velocity, instantaneous velocity
- uniform acceleration, negative and positive acceleration, etc.

Kinematic graphs seem to provide an excellent opportunity to develop a qualitative understanding of these concepts. However, textbook treatment of the section fails to take full use of the opportunity. For example, only rectilinear motion in a straight line in one direction is explored in both the practical investigation and the discussion of idealized situations that follow. In this instance distance/time and displacement/time graphs will be identical, likewise with the speed/time and velocity/time graphs. Thus the opportunity to explore scalar/vector differentiation between these is lost.

A similar situation exists with the textbook treatment of acceleration. Only movement in one direction where the velocity of the object increases uniformly is considered in both the practical investigation and in the idealized example. Thus learners are not given the opportunity to develop understanding of terms like 'positive acceleration', 'negative acceleration', 'deceleration', and their representation on kinematic graphs.

4.5.1.2 Problems associated with frames of reference (reference point and reference direction), sign convention and negative kinematic quantities

Frames of reference

This area is neglected in the discussion of kinematic graphs. Without stating it, in most of the examples learners are required to assume that the starting point of the motion is the reference point. Likewise, most examples require the learner to assume that the initial direction of motion is positive. Thus, all displacement-time graphs presented to learners start at the origin.

Sign convention difficulties

Again, this area is, to a large extent, neglected in the discussion of kinematic graphs in the textbook. In the practical investigation and the discussions that follow, an understanding of graphs is built up without reference to a choice of reference direction. Objects that are moving in only one direction are used, and without explicitly stating it, it is implied that the direction of movement and hence the sign of the velocity, is positive. Learners do not get practice actually choosing a reference direction and then observing how this affects representation of the kinematic graphs.

In their discussion of sketch graphs, the authors present examples of sketch graphs for the motion of a ball being thrown up and caught again. In this case, they specify the upward direction as being positive, and then show the resultant shapes of the graphs. They offer no explanation of these shapes, and learners are left to work this out themselves. Learners are also expected to assume that the reference point for the motion is the point at which the ball leaves the person's hand, and that it is caught at exactly the same level again.

Negative kinematic quantities

The first representation learners come across of negative acceleration is in a worked example presented after the discussion of graphs of uniform accelerated motion. The motion of the object on which the velocity-time graph is based is not described and learners have to use the graph to calculate various quantities. One of the calculations involves determining the acceleration represented by a portion of the graph that has a negative gradient. The meaning of this negative gradient is not explored. The emphasis on quantification (determining a value of) and the neglect of a qualitative description of what the value actually means, may be one of the underlying causes of learner difficulty in dealing with negative kinematic quantities.

Likewise, learners are not given opportunities to explore areas of graphs below the x-axis in the practical investigation. It is assumed that learners can extend the understanding they have built up about positive kinematic quantities and their representation to an explanation and/or an analysis of the representation of negative kinematic quantities.

4.5.1.3 Graph transformation and translation difficulties

This ability is not explicitly developed. Discussion in the textbook does not provide learners with opportunity to translate from physical situation to graphical representation, from verbal description to graphical representation, from one type of graph to another and vice versa. Learners are only exposed to this facet of kinematic graphs in the worked examples, and even there, only graphs to verbal description translations are touched on.

4.5.1.4 Graph interpretation difficulties

This area represents one of the strengths of the approach taken in this particular textbook. Learners, through the practical investigation, are encouraged to "discover" relationships and information that can be derived from particular graphs. This is reinforced in the discussions that follow the practical investigations. Thus, learners have good opportunity to develop knowledge and skills of how graphs can be interpreted to derive certain information, e.g. displacement from area under a velocity-time graph.

The approaches used by other popular textbooks do not differ significantly from this one. It is clear then, that the treatment kinematic graphs get in textbooks could influence learner understanding of these graphs and related concepts. While a textbook may not directly cause a particular misconception to be adopted by a learner, many textbooks may not go far enough to ensure that particular misconceptions do not arise.

4.5.2 Learner difficulties with kinematics and kinematic graphs, and Senior Certificate examination questions

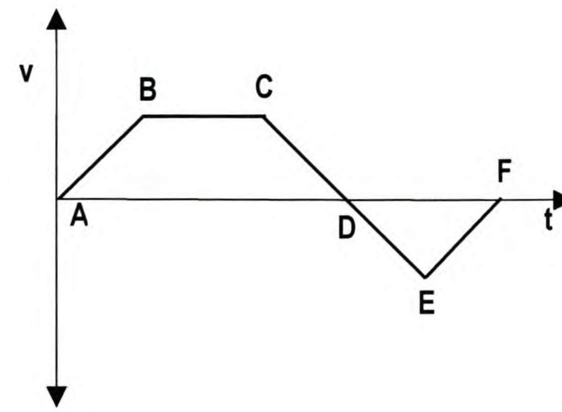
Examples of questions taken from 1999 Physical Science Senior Certificate examination papers highlight the problems that learners who experience these difficulties face when attempting to answer these questions.

South Africa physical science examination question papers generally contain two types of questions, viz. multiple-choice questions, and longer free-response type questions.

4.5.2.1 Multiple choice questions

Example 1: (Western Cape Province First Paper HG – November 1999)

The accompanying velocity-time sketch graph represents the rectilinear motion of an object initially moving in a northerly direction. During which parts of the graph does the object move in a southerly direction?



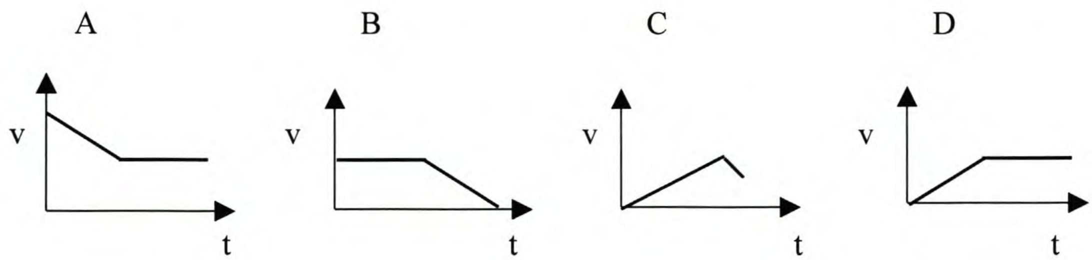
Comment:

Learners who have a poor conceptual understanding of, and are unable to differentiate between the concepts uniform velocity; acceleration and their representation on kinematic graphs (Category A difficulty) will probably have problems with this question. This is an interpretation-type question, which requires that learners are able to assign appropriate signs to represent velocities in opposite directions, and to understand how negative quantities, in particular, negative velocities, are represented on kinematic graphs. Learners who have difficulty interpreting kinematic graphs (Category D difficulty), who have difficulty with using sign convention (Category B difficulty) and who have difficulty dealing with negative kinematic quantities (Category B difficulty) will probably experience problems with this question.

Example 2: (KwaZulu-Natal Province First Paper HG – November 1999)

A frictionless trolley runs down the sloping runway and then over a frictionless horizontal plane.

Which one of the following graphs of velocity best represents the motion of the trolley?



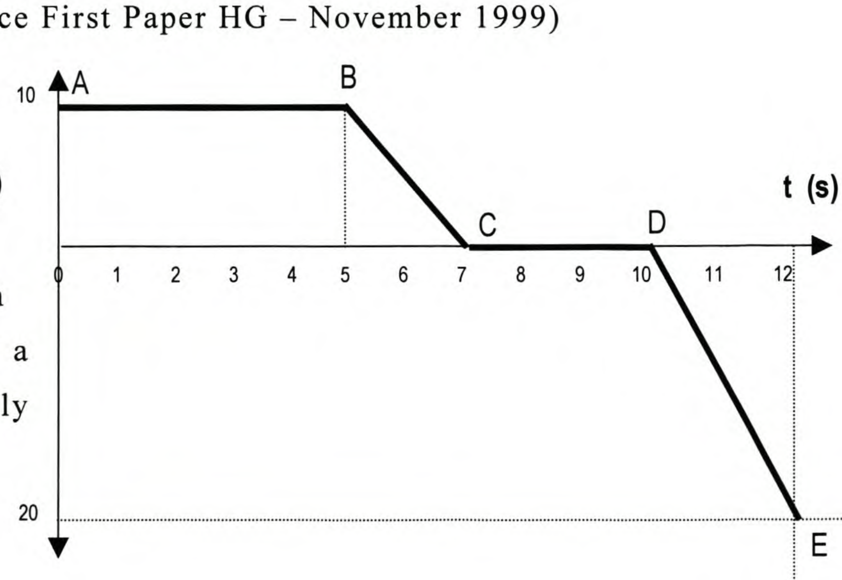
Comment:

Learners need to be able to differentiate between the concepts of uniform velocity and uniform acceleration and the representation of these on a kinematic graph. Learners who have a problem with conceptual understanding of these concepts (Category A difficulty) will have problems with the question. This type of problem requires the learner to translate a physical situation into a graphical representation. Learners who experience graph translation difficulties (Category C difficulty) will have problems answering this question. For example, choice of incorrect Option A illustrates "graph-as-picture" confusion, which many learners exhibit. (McDermott *et al.*, 1987, Clement *et al.*, 1985.)

4.5.2.2 Long questions

Example: (Northern Province First Paper HG – November 1999)

v (m/s)



The velocity-time graph represents the motion of a truck. The truck originally moves eastwards.

Answer the questions below without using equations of motion:

1. Describe the motion of the truck between A and B.
2. Calculate the magnitude of the truck's acceleration between B and C.
3. Describe the motion of the truck between C and D.
4. What was the truck's instantaneous velocity at t = 6s?
5. Calculate the total distance which the truck moved in 12s.
6. What was the truck's displacement after 12s?
7. Calculate the truck's average velocity for the 12s period.

Comment:

In this question, almost all the areas of difficulty identified above are touched on. For example, Questions 1 and 3 require that learners translate a graphical representation of motion into a verbal description of the actual physical situation (Category C difficulty). Learners need to understand and be able to differentiate between the concepts uniform velocity, average velocity, instantaneous velocity and acceleration (category A difficulty) and how the graph can be interpreted and used to get a quantitative indication of these quantities (Category D difficulty). Learners need to be able to work with negative gradients and negative areas under the x-axis (Category B difficulty) in order to answer some of the questions.

These examples from actual examination question papers illustrate the necessity of teachers to specifically teach these aspects (even though textbooks and syllabi do not address them). Teachers also need to identify learners who have these difficulties and to remediate them, using appropriate teaching and learning strategies.

4.6 Using these areas of learner difficulties in this research study.

The table below shows the four main areas in kinematics and kinematics graphs that learners experience difficulty with. A **selection** of specific difficulties is used as an indicator in this research to determine the effect of the use of MBL technology on learner understanding in the four areas. Representative difficulties (two from each of the four main areas) were selected on the basis of the researcher's opinion that they could be dealt with/remediated using MBL technology. The difficulties selected formed the focus of hypotheses tested by specific questions in the pre- and post-questionnaire, and of the learning activities that made up the learning programme used in the research study. Appendices 5, 8 and 10 show how this was done.

Table 4.1 Selected representative difficulties that form the focus of this research project.

Area of difficulty	**Two examples of specific difficulties that learners experience in this area**
A: **Problems associated with conceptual understanding of kinematic quantities.**	1.The learner has a weak understanding of different kinematic concepts and thus experiences difficulty differentiating between kinematic quantities.
	2. The learner has difficulty accepting that an object at rest (e.g. a bouncing ball at the top of its path) can still be accelerating, and that the acceleration remains constant throughout the motion.
B: **Problems associated with reference points, sign convention and negative kinematic quantities.**	1. The learner does not recognise that reference points and positive and negative signs to represent direction of the motion are arbitrarily allocated.
	2. The learner associates the sign of velocity and/or acceleration with the magnitude of these quantities rather than with the direction of movement (in the case of velocity) and the direction of the resultant force (in the case of acceleration).

C: **Graph translation and transformation difficulties.**	1. The learner draws/chooses a graph which closely resembles the shape of the path that the object takes.
	2. The learner cannot distinguish between different kinematic graphs representing the same motion. Draws/chooses graphs that resemble each other.
D: **Graph interpretation difficulties**	1. The learner focuses on an incorrect aspect of the graph when describing features of the motion.
	2. The learner interprets negative slopes in a s/t graph to mean that the object is slowing down rather than moving in a negative direction.

CHAPTER 5

Literature Survey: Using microcomputer-based laboratories to develop learners' understanding of kinematic graphs

The first part of this chapter in the literature survey examines research studies carried out around the use of MBL technology in the teaching of science, specifically in the teaching of kinematic graphs (Linn *et al,* 1987; Mokros and Tinkler, 1987; Brassel, 1987; Thornton and Sokoloff, 1990; Svec, 1999 and Russel *et al.,*1999). Some attention is paid to the research design used in the various studies described here, and this is used by the researcher in Chapter 6 to compare and rationalise the research design used in this study. The second part of the chapter looks at studies which explore how learning and understanding develops when learners are engaged in MBL learning activities. Part three of the chapter describes reasons why MBL technology has been perceived to be an effective teaching and learning tool in this area, drawing from the studies that are examined here. The chapter concludes with a description of how the various studies explored here, impacted on this research project.

5.1 Using MBL to develop learner understanding of kinematics and kinematics graphs

In a study conducted by Linn *et al.*, (1987), the researchers explore the consequences of a microcomputer-based laboratory on students' graphing skill acquisition. They designed a programme of instruction around what was termed an "ideal chain of cognitive accomplishments".

> To identify an ideal chain of cognitive accomplishments we relied on the advice of expert teachers, on observations of students learning about graphs, on students' difficulties with graphs, and on recent advances in understanding memory and

> problem solving. The ideal chain of cognitive accomplishments consists of four main links: graph features, graph templates, graph design skills, and graph problem-solving skills. (Linn *et al.*, 1987: 246.)

A pre-test, post-test control group design was used, and evaluation instruments were designed to determine how far along the hypothetical chain of cognitive accomplishments in understanding graphic relationships students had moved. The researchers felt that the fourth level of accomplishment, viz. graph problem-solving skills, would occur when students have considerably more experience than what was envisaged in the study, and consequently this level of accomplishment was not evaluated in the study. The researchers found that the use of MBL allowed most students to master graph features and greatly increased the ability of students to "identify trends and locate extreme points" (Linn *et al.*, 1987: 250). During the course, students made substantial progress in acquiring "robust temperature templates" (Linn *et al.*, 1987: 251), and they conclude that a microcomputer-based laboratory is effective in teaching students about graphing, in particular, graphing skills and subject matter templates.

They emphasize the need to examine how MBL contributes to student cognitive development in this regard.

> The mechanisms governing success of MBL are not yet clear. We suspect that the memory support available in this environment facilitates learning. In addition, these experiences seem to provide more powerful templates for temperature than have been previously learned. We plan to continue these investigations. (Linn *et al.*, 1987: 252.)

This forms one of the areas of focus of this study.

An article by Mokros and Tinkler (1987) reports on the findings of two preliminary studies and a longitudinal study.

The first preliminary descriptive study attempted to provide an in-depth examination of middle school children's graphing skills and graph-related misconceptions. Clinical interviews were conducted with 25 Seventh and Eighth Grade students, selected on the basis of availability and self-nomination. A carefully constructed set of graphing problems was administered to the students in individual interviews. Problems included some based on graph interpretation and graph evaluation, and on different scientific content areas, within the realm of the students' experience. During interviews, learners were asked to "think aloud" as they solved the problem and answered a series of questions about the graphical problem. Analysis of student responses allowed the researchers to classify several types of misconceptions related to graphs. Two major types of errors were observed, viz. the graph as picture problem and the slope/height confusion error.

The second preliminary observational study explored the ways in which children learn graphing skills as they worked through a MBL unit on motion. Classroom observations, consisting of narrative records of each lab group were conducted as students worked through an MBL unit on motion. The goal of the unit was to teach students to measure and plot position and velocity. Students had to work through various activities involving making predictions and generating specific real-time graphs, over a period of five days. Observers recorded student interactions with each other and with the hardware and software, and a record of their verbalizations as the completed worksheets was kept. In addition, a quiz assessing mastery of distance and velocity graphs was administered on the last day. The observation data was analysed qualitatively, while the results of the quiz were subjected to a quantitative analysis. The writers assert that their results showed "solid understanding of distance and velocity graphs". (Mokros and Tinker, 1987: 374.)

The three-month longitudinal study investigated the effect of appropriate MBL experiences in facilitating graphing communication, and was designed to provide more evidence about the effect of MBL on children's graphing skills. In developing the MBL curriculum material, the researchers decided to use graphs as the central means of communication. Data is presented to the students in the form of graphs that evolve as the experiment is underway. The students predict results in terms of graphs, and if there is a discrepancy between the graphs of the observations and the predictions, students must recognize this and make the correction in either the experiment, or the prediction, on the basis of this graphical information. Pre- and post-test questionnaires were administered to assess "graphing conventions as well as understanding of the relationships exhibited by graphs" (Mokros and Tinker, 1987: 375) before and after the 3-month long MBL learning programme, which incorporated units on illusions, heat and temperature, sound, and motion.

The researchers reported that:

> Scores on the 16 graphing items indicate a significant change in students' ability to interpret and use graphs between pre- and post-tests...The mean on the pre-test was 8.3 items correct...while the mean on the post-test was 10.8. This represents an average gain of 2.5 points, for an effect size of 81% . (Mokros and Tinker, 1987: 376.)

The researchers use the term "how" as in "...to determine **how** middle school children's graphing skills develop over a course of three months..." to mean to what extent, in other words, a somewhat quantitative evaluation of the effect of MBL. A more qualitative description of 'how' (actual mechanisms producing the increased understanding) MBL affects graphing skill development and the correction of misconceptions is not dealt with in this study.

Brassel (1987) describes a study which assessed the "effect of a brief treatment with a kinematics unit on the ability to translate between a physical event and a representation of it", and "the effect of real-time graphing as opposed to delayed graphing of data." (Brassel, 1987: 385). The experimental set-up involved the use of four groups. Each group wrote a pre- and post-test before and after a different experience:

- One group was set up to work though a learning programme using MBL technology, where graphical representation occurred in real time.
- The second group worked through a MBL learning programme where graphical representation was delayed.
- A third control group worked through non-MBL but similar paper-and-pencil type kinematic activities.
- A fourth group was involved in no motion graphing exercises, and only wrote the pre-test and post-test.

The research was carried out with full Physics classes in seven different schools. Each class had 7-17 students. A complete set of data for 18-20 students was collected across all the schools and analysed. The real-time MBL students showed improvement in performance when compared to the other groups. According to the researcher:

> Mean scores of treatments indicate that real-time graphing ...accounted for nearly all (90%) of the improvement within the Standard-MBL treatment relative to the Control. At no time was the performance of Delayed MBL students significantly superior to that of students in the Control treatment. These results indicate that the real-time graphing feature of the MBL was effective in improving graphing performance. (Brassel, 1987: 392).

Again, this study did not attempt to explore how or through which mechanisms 'improved graphing performance' occurs.

Thornton and Sokoloff (1990) describe a study into the effect of using a MBL kinematics laboratory experience versus a traditional lecture approach with college students in an "introductory Physics Laboratory course". A pre-test, intervention, post-test methodology was employed.

Essentially, the study showed that MBL students improved in their understanding of kinematics. Their rate of error on homework tasks, tests and examinations decreased as a result of having participated in the MBL-based curriculum unit. This improvement was sustained over time. Thornton and Sokoloff (1990: 865) emphasise that student gains in understanding are not just an automatic result of use of computer-based laboratory tools, but probably more of a result of participation in an MBL learning environment made possible by the 'tools, the curriculum, and the social and physical setting'.

A later study (Thornton, 2004) begins to explore how interactions between these dimensions results in gains in understanding. This study is described in section 5.2 which follows in this chapter.

Svec (1999) describes a study that attempted to answer three research questions around the use of MBL as a teaching and learning tool. Two of his questions are of particular relevance to this study:

- Does MBL's graphic presentation improve students' abilities to interpret distance-time graphs, velocity-time graphs and acceleration-time graphs?
- Does MBL's graphic presentation improve students' understanding of velocity and acceleration? (Svec, 1999: 2.)

A quantitative research approach was used. An experimental group and a control group were set up. The experimental group participated in an MBL-based learning experience, while the control group received 'traditional' instruction. Both groups were required to complete pre- and post-tests, using two instruments, the Motion Concept Test, and the Graphing Interpretation Skills Test. Various specific hypotheses were written for each research question, and item analysis of the test items using a 'matrix method' was used to prove or refute each hypothesis and thus make claims about MBL's potential with regard to the research questions.

Svec (1999: 13) concluded that:

> The results on the Graphing Interpretation Skills Test and Motion Content Test indicated significant differences between a traditional laboratory and a micro-computer-based laboratory. MBL was more effective at engendering conceptual change in students. (Svec, 1999: 13)

All the studies described above provide much evidence and support for the use of MBL technology as a tool to improve learner understanding of graphing in general, and graphs of motion in particular. However, none of these studies explicitly explored how or through which mechanisms learning takes place while learners participate in MBL-based learning experiences, although some of the writers point to the importance of finding this out. "...it is important to document what the students are learning when using MBL labs and how they are learning those topics" (Svec, 1999: 2).

5.2 Learning through the use of MBL

A paper by Russel *et al.* (1999) describes the first phase of a larger research project which attempts to explore this area. The project intended to "increase understanding of how MBL activities specifically designed to be consistent with a constructivist theory of learning support or constrain student construction of understanding". Part of the research reported in this paper aimed to document and interpret:

- "the patterns of interaction between experimental phenomena, computer display, collaborative student groups, individual students and their teacher";

- "the role of the computer in presenting information, engaging student collaboration, and mediating between experimental phenomena and student understanding of physics concepts." (Russel *et al.*, 1999: 4.)

Seventeen students participated in the study (seven pairs and one group of three). One pair (which they refer to as a 'dyad') was chosen as a focus group for the research. Data was collected through video and audio recordings, as well as teacher observation and semi-structured interviews. The notes that students compiled as they worked through a series of MBL activities were also added to the database. Transcripts of the audio recordings were made, and descriptions of the students' actions as recorded by the video camera were added to this. Copies of graphs (from computer printouts or students own notes) were attached to the transcript in the relevant places to illustrate learner discussions and conclusions. The teacher played a facilitatory role in the process, posing questions, making suggestions and focussing students' attention on various aspects on the graphs, etc.

The researchers used the techniques of discourse (verbal) analysis to identify themes, which provided insights into what was taking place. They summarise their analysis as follows:

- the MBL provided opportunities for student-student interactions, and supported student construction of understanding of kinematics graphs and concepts;
- the dyad used a variety of techniques to make meanings of the graphs, such as:
    - using feedback from a graph to repeat experiments and generate new graphs,
    - pointing to, gesturing, touching, and writing on the monitor screen,
    - enlarging, superimposing, and comparing multiple graphs,
    - applying quantitative analysis and examinations;

- the students' initial understanding of kinematics concepts was often challenged by data presented on the screen, and their negotiation of new meaning was mediated in a variety of ways by the computer display;
- the visual patterns conveyed meanings (positive/negative values, rising/falling curves, fast/slow motion, increasing/decreasing values);
- the sequence of lessons developed concepts progressively (from displacement through velocity to acceleration) often presenting the same ideas from multiple perspectives;
- the display helped draw out and reveal student's thoughts, facilitated their thinking, and structured their conversation;
- the display effectively directed and corrected students by reason of its visual and textual messages;
- the monitor made the phenomenon (physical motion of the wheel) concrete (in the form of an electronic display), a reality, an unquestioned authority to which reference and appeal was made;
- the display provided a memory aid, a constant reminder, of the 'frozen' results of an earlier experiment.

(Russel *et al.*, 1999: 11-12.)

In a study conducted by Thornton (2004), groups of students were directly observed and video-recorded as they participated in a series of introductory physics learning laboratories. Students were administered a "Force and Motion Conceptual Evaluation (FMCE) for pre- and post-measures of conceptual understanding of kinematics and Newton's Laws" (Thornton, 2004: 3).

Analysis of video and direct observations were made to identify behaviours of students learning conceptually or not, as students participated in the motion laboratories. Three categories of students were identified for scrutiny:

- Low-low students (L-L) started and ended the programme with scores below 25%. These students appear in the lower left-hand corner of Figure 5.1 below.
- Low-high (L-H) students were those who began low and ended high (above 75%). These students appear in the upper left-hand corner of Figure 5.1 below.
- Medium-high (M-H) students were those who started between low and high and ended high. These students appear in the upper-middle of Figure 5.1 below.

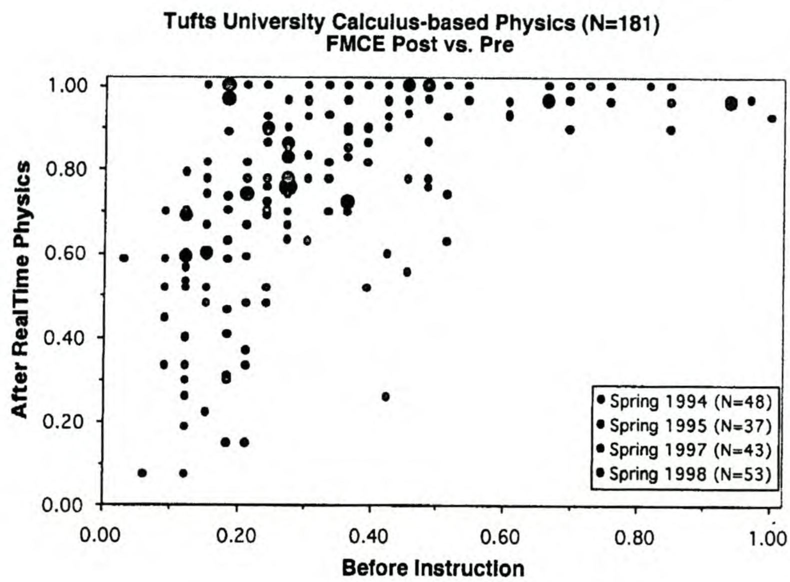


Figure 5.1: Comparison of pre- and post-performance scores on the Force and Motion Conceptual Evaluation (FCME) for 181 students. Students who started low and finished low are in the lower left hand corner. Students who finish high are along the top edge of the figure. (Thornton, 2004: 3.)

Thornton (2004:4) points out that these results indicate a 'threshold effect'. Students who begin above a 'threshold' of 25% on the pre-test are essentially guaranteed a high finish on the post-test as a result of their participation in the laboratory course. Thus, students who begin below 25%, an indication that they possess very little initial knowledge of kinematics and mechanics, fail to learn significantly, and this is a possible indication of the effect of learner prior knowledge on success in programmes of this nature.

One of the interests in this particular study was to identify the behaviours of successful and unsuccessful learners as they participated in the group activities. Four learning behaviours were surveyed:

Student questions

The study found that successful and unsuccessful students both asked questions as they participated in the activities, but that they differed on the nature of the questions asked. Successful learners were more likely to ask more open questions while unsuccessful learners tended to ask more closed questions.

Student explanations based on cause or principle

Thornton (2002:8) describes as "common knowledge" the perception that unsuccessful learners propose incorrect or inconsistent explanations while successful learners do not. This study showed that unsuccessful learners proposed about one-third less explanations than the successful learners did, and that the successful learners also proposed incorrect or inconsistent explanations as they participated in the activities.

Student use or linking of multiple representations

The study showed that successful learners made more use of multiple representations like spoken and written language, mathematical formulas, graphical presentations, and physical demonstrations than the unsuccessful learners.

Student attention

Again, Thornton (2002:10) describes as "common knowledge" that successful learners are more involved in the learning activities than unsuccessful learners. However, the study showed that unsuccessful learners are most often as involved as the successful learners are, and so being actively involved may not be sufficient on its own to stimulate learning.

Thornton (2004:11) concluded by suggesting that:

> We have found that the behaviour of students who learn concepts differs from those who do not and that specific behaviours correlate with conceptual learning. (Thornton, 2004:11.)

These two studies describe various mechanisms and modes of action of learners and the computer as learners participate in MBL learning activities. Further studies in this area would probably need to show how these contribute to a cohesive explanation of how learning happens as learners engage in MBL activities. This TRAC PAC–based research study hopes to contribute in this regard.

5.3 Proposed reasons for the effectiveness of MBL

Many of the researchers in the studies described above, and in others, identify features of the MBL learning experience which they think contributes to its success as an effective tool for developing learner understanding. These include:

- The dynamic, on-line and real-time feedback reduces the memory load required and allows learners to immediately associate and couple physical phenomena with its graphical representation (Salomon, 1985; Pea, 1985; Mokros and Tinker, 1987; Thornton and Sokoloff, 1990; Linn, Layman and Nachmias, 1987; Friedler, Nachmias and Linn, 1990).

- It reduces the drudgery of data collection and graph generation and allows learners to focus on the scientific concepts being explored (Mokros and Tinker, 1987; Thornton and Sokoloff, 1990).

- It encourages collaboration, co-operative learning and interaction in an environment where ideas can be discussed and tested (Thornton and Sokoloff, 1990; Russel *et al.*, 1999).

- It allows learner to participate in genuine scientific experiences – investigations of concrete physical phenomena rather than only manipulating symbols and discussing abstractions (Mokros and Tinker, 1987; Thornton and Sokoloff, 1990).

- It uses multiple modalities (Mokros and Tinker, 1987).

- It allows students to understand the specific and familiar before moving to the more general and abstract (Thornton and Sokoloff, 1990).

- It provides learners with the opportunity to engage in behaviours which have been shown to be positively correlated with conceptual learning (Thornton, 2004).

5.4 How these research studies impact on this study

The studies reviewed in this chapter contribute to the study described in this report in the following ways:

5.4.1 Choice of focus area for this study

This chapter has provided a review of studies conducted around the use of MBL to address learner difficulties and/or enhance learner understanding of kinematics and graphs of motion. The review has clearly shown that much work has been done in quantifying the effect of MBL on learning. Most studies have taken this approach, i.e. they have shown that MBL does improve learner understanding of kinematics and kinematics graphs, mostly using a quantitative pre-test, intervention, post-test methodology. The need to investigate how learning takes place when learners participate in MBL learning activities is a gap or area of focus, which many of the researchers involved in these studies have identified. The studies by Russell *et al.* (1999), and Thornton (2000) begin to explore this area, by focussing on the interactions that take place when learners engage in MBL learning activities.

The research study described in this report focuses on this area and contributes to knowledge about how learning takes place when learners are involved in MBL learning activities.

5.4.2 Choice of methodology

Various methodologies described in the studies above have also been used in this study, including:

- The use of pre- and post- questionnaires and diagnostic interviews to determine whether learner understanding has developed as a result of involvement in the MBL learning programme.

- The use of audio, video and observational techniques to collect data as learners participate in the MBL learning programme.

- The use of 'hypothesis generation' and item analysis using a 'matrix method' as described by Svec (1999) is adapted for use in the quantitative phase of this study.

- The use of discourse (verbal) analysis to generate themes, similar to that used by Russell *et al.* (1999) is used in the qualitative phase of this study.

CHAPTER 6
Research Methodology

Bogdan and Biklen (1992) suggest that all research is guided by some theoretical position, which may or may not be overtly stated, that good researchers are aware of the theoretical positions from which they operate, and that these positions inform the methods the researcher chooses to collect and analyze data.

Any research design process therefore should begin with, and be explicitly and continuously influenced by considerations of theoretical affiliation.

6.1 Philosophical positions underpinning social research

Hammersly and Atkinson (1985: 2) suggest that the conflict between quantitative and qualitative method as competing modes of research, which existed in many fields in the past, and still continues in many today, can often be seen as conflict between competing philosophical positions or paradigms. They identify two broad theoretical positions - "positivism" (which underpins quantitative research) and "naturalism" (which underpins qualitative research).

Nueman (1998) provides a useful summary of the two paradigms.

Table 6.1: Major paradigms in social research. (Neuman,1998)

Positivism	Naturalism
• Research is carried out to discover and document universal laws which govern human behaviour. • Physical science, as conceived in the logic of the experiment, is the model for social research. • Events are explained in deductive fashion by	• The goal of research is to develop an understanding of social life and how people construct meaning in natural settings. • People construct their social reality on the basis of the interpretation of particular situations in which they find themselves. It is therefore not possible to generate universal

appeal to universal laws. • Science is value–free i.e. it is not dependent on values, opinions, attitudes or beliefs. • Phenomena being investigated are directly observable. • Theories are open to, and are subjected to testing. They can be confirmed, or at least falsified with certainty. • Standardization of the research procedure allows for objectivity, generalization and replication.	laws to explain behavior. • Meaning is inferred from action. • Direct experience of, and immersion in the social world being investigated allows opportunity for authenticity.

Criticisms against these paradigms, even from within the paradigms themselves, have led to the emergence of alternative frameworks to guide research.

The figure below shows paradigms which have emerged and provides a short explanation of each:

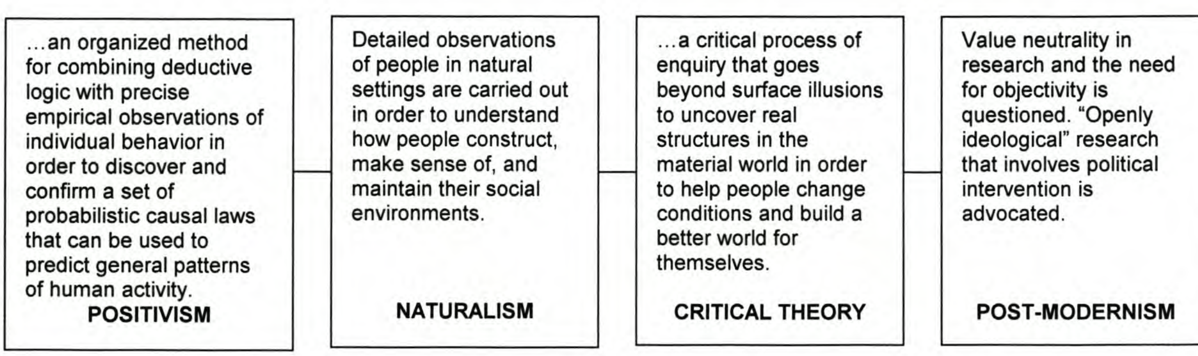


Figure 6.1: Philosophical positions underpinning social research. Sources: Neuman (1998), Hammersley and Atkinson (1995).

It is possible for different parts of a research project to be influenced by different philosophical positions and a number of writers have suggested that this approach may actually enhance the research process.

Ragin (1994) quoted in Neuman (1998: 14) explains how the different research styles can complement each other:

> The key features common to all qualitative methods can be seen when they are contrasted with quantitative methods. Most quantitative data techniques are data condensers. They condense data in order to see the big picture... Qualitative methods, by contrast, are best understood as data enhancers. When data are enhanced, it is possible to see key aspects of cases more clearly. (Ragin, 1994, in Neuman, 1998:14)

Neuman (1998: 14) echoes the view that perhaps the best approach to research is to combine elements of both styles when he writes:

> Although both styles of research share basic principles of science, the two approaches differ in significant ways. Each has its strengths and limitation...I agree...that the best research often combines the features of each. (Neuman, 1998: 14)

Mixed modes of research were therefore used in this research project because the researcher felt that both quantitative and qualitative research styles could make a contribution to providing answers for the research questions posed. Quantitative research techniques could possibly provide insight into the bigger question of whether or not the use of computer technology like the TRAC PAC enhanced learners' understanding of science concepts. These techniques were used in the empirical investigation described in this chapter. Qualitative research techniques could be used to investigate more deeply the question of how learner understanding of science concepts is enhanced. Such techniques were used in the ethnographic exploration.

An overview of the research methodology is described in Chapter 1 of this report. Figure 1.1 in Chapter 1 provides a diagrammatic overview of the project. Section 6.2 below describes the more quantitative empirical phase of this research, and Section 6.3 below described the more qualitative ethnographic phase of the project.

6.2 An empirical study into the effect use of a TRAC PAC-based learning programme has on learner understanding of kinematic graphs

6.2.1 Techniques for identifying learner conceptions

A number of writers emphasize the necessity of identifying learner preconceptions when attempting to teach for conceptual change. It can be a very difficult task attempting to do this for each and every learner in a class. However, it may not be necessary to attempt to identify the preconceptions of each and every learner before teaching and learning can take place. Driver *et al.* (1985: 8) write that:

> One of the recurring themes in the studies ...is that, although there is variety in the ideas that children use to interpret phenomena, there are clearly some general patterns in the types of ideas that children of different ages tend to use. (Driver *et al.*, 1985: 8.)

and that:

> Studies of this kind suggest that despite the variety of ideas suggested in science classrooms, there may be some value in attempting to take account of general trends in children's thinking, both in planning learning activities and in order to improve communication in the classroom itself. (Driver *et al.*, 1985: 8.)

A number of these "general trends in children's thinking" in science education have been documented in the literature. A review of typical ideas that learners have about kinematic concepts and kinematic graphs has been described in the Literature Review Section (Chapter 4) of the research report.

However, for the purpose of this research, it was necessary to accurately document the status of learner conceptions before and after exposure to specific learning experiences, in order to assess the effect of these learning experiences. The question arises, "How can one identify learner preconceptions, and the changes, if any, that take place as a result of specific learning experiences?"

Hewson and Thorley (1989: 550) suggest that the only way that teachers (or researchers) can know if conceptual change has taken place is if they continuously monitor the status of learners' conceptions. They suggest that the only way to do this is to examine the comments learners make about the conception.

> It is important to note that evidence of status cannot be derived, in principle, from details of the content of the conception itself. It can only come from comments **about** the conception: dissatisfaction, intelligibility, plausibility and fruitfulness all refer to the **learner's** viewpoint. Such evidence is thus in the metacognitive realm. (Hewson and Thorley, 1989: 550)

Data collection techniques such as the use of diagnostic questionnaires, which may be more quantitative nature, and clinical interviews, which can be more qualitative in nature, are thus important tools that were used for identifying the status of learners' conceptions in this study.

6.2.2 Diagnostic questionnaires

These paper-and-pencil type questionnaires are useful for identifying the extent to which misconceptions that have already been identified in other learner populations are also present in the population under study. They can provide a quantitative picture of the misconceptions that are present. They are more limited when used to identify new misconceptions.

Treagust (1988: 161) describes a diagnostic test as "a multiple choice test which has items specifically designed to identify misconceptions in a limited and clearly defined content area".

Treagust (1988: 161) describes a method for designing and using diagnostic tests to identify learner misconceptions, which incorporates use of interviews and paper and pencil responses. The method consists of ten steps grouped under three broad headings as summarized below:

Defining the content

Step 1: Identifying propositional knowledge statements.

This is a set of statements that describe the content knowledge learners are expected to know in the area being investigated.

Step 2: Developing a concept map.

Related concepts in the area are built into a concept map, with lines showing links between related concepts, and short statements describing the actual relationship between them. Like the propositional knowledge statements, the concept maps allows the researcher "...to carefully consider the nature of the content which has been selected for instruction" (Treagust, 1988: 161).

Step 3: Relating propositional knowledge to the concept map.

This allows the researcher to check that the content area chosen for investigation has been comprehensively covered. "The propositional knowledge statements are related directly to the concept map to ensure that the content being covered is internally consistent" (Treagust, 1988: 162).

Step 4: Validating the content.

The propositional statements and concept map is scrutinized, criticized and validated by educators, subject specialists and experts in the field.

Obtaining information about students

Step 5: Examining related literature.

Existing literature is examined for research on misconceptions already carried out in the area that is being investigated. This allows the researcher to build up a base of information on which multiple choice questions can be designed.

Step 6: Conducting unstructured student interviews.

Interviews are conducted with learners who have already worked through the area under investigation to validate the existence of misconceptions documented in the literature, and to identify additional misconceptions or areas of difficulty which were not previously documented. This builds up the information base that can be used to design test items.

Step 7: Developing multiple choice content items with free response.

Multiple choice test items based on the propositional statements are designed, which focus on the misconceptions identified in the literature review and interviews. Learners are requested to provide reasons for their choice in the space left after each question. The multiple-choice test is then given to a class group to complete. "Further misconceptions as well as acceptable scientific conceptions become further evident in the free response answers" (Treagust, 1988: 163).

Developing a diagnostic test

Step 8: Developing the two-tier diagnostic test.

The first part of a two-tier test item consists of a multiple choice test question having two or three choices. The second part consists of a set of four possible reasons for the answer chosen in the first part. The reasons here are derived from responses learners gave in the free-response multiple-choice questions and from the interviews and the literature.

Step 9: Designing a specification grid.

This ensures that the diagnostic test fairly covers the propositional knowledge statements and the concept map, which were generated earlier.

Step 10: Continuing refinements.

The test can be refined and improved upon after each time it is administrated to a group of students.

Treagust suggests that tests such as these, which have gone through a stringent design process in a research setting, can then be used by classroom-based teachers as aids to identifying learner misconceptions. "The existence of reliable and valid pencil and paper, easy to score, test instruments will enable science teachers to better assess students' understanding of science upon which improved teaching can be based." (Treagust, 1988, 167.)

6.2.3 Clinical interviews

Posner and Gertzog (1982:195) describe clinical interviews as interviews that are directed towards information gathering.

> Its chief goal is to ascertain the nature and extent of an individual's knowledge about a particular domain by identifying the relevant conceptions he or she holds and the perceived relationships among these conceptions. (Posner and Gertzog, 1982:195.)

Hewson (1987: 37) writes that the clinical interview "provides rich information about student conceptions". It requires that the interviewer or researcher attempt to adopt a value-free, non-judgmental stance while attempting to elicit and probe into students' ideas about a topic.

> The interviews are taped, even video-taped, and then verbatim transcripts of each interview are made. The researcher then sets about cataloguing the ideas of the respondents and only in the very final stages is an analysis and synthesis made of what was said. (Hewson 1987:37.)

Osborne and Gilbert (1980) develop the technique of critical interviews further when they propose the use of Interviews about Instances (IAI) and Interviews about Events (IAE). The method is based on the view that concept attainment is closely related to the ability of learners to classify instances not previously encountered as instances or non-instances of the concept (see Klausmeier 1992). The assumption is that:

> ...the best way to explore a student's domain of understanding of a concept is to confront him with instances to categorize as examples and non-examples of the concept class (and for the student to give reasons for each categorization). (Osborne and Gilbert, 1980: 313.)

In this interview technique the researcher typically prepares and presents a visual representation of an instance or allows the interviewee to view an actual event. Questions are used to probe the interviewee's understanding of the interview or event.

6.2.4 How these techniques are used in this study

As described earlier in this report, the methodology employs both quantitative and qualitative research techniques.

The diagnostic test technique suggested by Treagust (1988) was adapted to suit this research study. The first two phases of his suggested methodology were used in earlier parts of this study. The content analysis in Chapter 2 used his "defining the content" phase as a framework to carry out a content analysis of kinematic graphs. In Chapter 3, part of the literature review involved identifying common learner misconceptions in this area. Rather than using diagnostic tests to identify new misconceptions and/or difficulties learners experience with graphs of motion, they were used to identify whether misconceptions exist prior to, and after a period of instruction. Essentially then, two similar diagnostic tests were needed, one used as a pre-test and the other as a post-test. Test items were based on misconceptions already identified in previous research, in particular on a recent South African study carried out in this area of graphs of motion. (See Frauenknecht, 1998). Test questions focussed on misconceptions that can possibly be addressed using the TRAC PAC.

The diagnostic tests were trialed in a Grade 12 class at a local school, adapted, and then used in the actual research in a pre-test, post-test scenario.

Appendix 3 contains the pre-questionnaire and Appendix 4 contains the post-questionnaire. The specification grid for the questionnaires can be found in Appendix 5.

Clinical interviews with learners were used to complement the questionnaires and to provide some degree of triangulation. However, rather than individual demonstration clinical interviews being used here, group demonstration clinical interviews were used. The focus group learners were required to observe motion in a physical setting and asked probing questions about it, which they were required to respond to in written format. They were then required to observe the same motion, but this time they were also able to observe the graphs for the motion as captured and displayed by the TRAC MBL equipment. Again, probing questions were asked which required the learners to compare their initial responses with the graphical representations on the computer. Lack of resources (time and person-power) necessitated the use of group demonstration interviews.

Thus, while the main objective of this research study was to investigate the capacity of the TRAC PAC to address learner misconceptions about graphs of motion, the TRAC PAC was also used as a research data collection tool.

The pre-instruction interview protocol can be found in Appendix 6, and the post-instruction interview protocol can be found in Appendix 7.

Analysis of data collected through the pre- and post-questionnaires were analysed through inspection, using the hypothesis generating, item and matrix analysis technique described by Svec (1999). It was used as follows:

- Sixteen two-tier multiple-choice questions (as described by Treagust, 1988) were set for the pre-test and post-test. The use of two-tier questions helped to eliminate guesswork. The correct choice of answer and correct choice of reason will indicate understanding of the concept being tested. Also, incorrect choices will be a 'window' into the misconceptions that the learners hold.

- Four questions in each test focussed on two specific difficulties (two questions for each specific difficulty) in each of the four areas of difficulty identified earlier in this study.

- Eight hypotheses (a hypothesis for each pair of questions (items) on the pre-test and post-test) were written, and learner responses were analysed to prove or refute each hypothesis. The hypotheses and their relation to specific questions on the pre- and post-questionnaire can be found in the table in Appendix 8.

- The understanding of each learner with respect to the concept or skill being tested was determined in the following manner:
  - For a judgement of **substantial understanding** to be made, a learner had to get both questions targeting a particular difficulty correct, i.e. for the two-tier multiple–choice questions, he had to choose the correct option (indicated by a letter (A, B, C, D) in the multiple choice question, and the correct reason (indicated by a number (i, ii or iii) in the multiple choice question).
  - For a judgement of **some understanding** to be made the learner had to at least make the correct choice of option (indicated by the letters A, B, C or D), and correct choice of reason (indicated by the numbers i, ii or iii) for one of the questions targeting a particular difficulty.
  - For a judgement of **little understanding** to be made, the learner failed to match option and reason in both questions that targeted a particular difficulty.

- Matrices were compiled to record learners responses to the various questions on the test, and comparison between matrices generated from pre- and post-test questionnaires allowed the researcher to make claims about the efficacy of the MBL learning programme in addressing learner difficulties and misconceptions related to kinematics graphs.

Twenty learners participated in the learning programme, and all twenty completed the pre- and post-questionnaires.

Chapter 8 reports on and analyses the results of this phase of the project.

Five learners were selected as a focus group and these five were subjected to more intense scrutiny using interviews, video and audio recordings and observation of their interactions as they participated in the learning programme. These five learners also served as the subjects for the ethnographic investigation described in Section 6.3 below.

6.3 An ethnographic exploration of ways of learning as learners participate in a TRAC PAC-based learning programme

Ethnography and the development of grounded theory are qualitative research perspectives that are pertinent to this part of the study and these are elaborated on further.

A deductive approach involves beginning with a broad hypothesis and the collecting evidence during the study that supports or refutes this hypothesis. It is sometimes called a top-down approach. In qualitative studies, an inductive approach is normally used.

Bogdan and Biklen (1992) describe the inductive approach when they write that:

> ...abstractions are built as the particulars that have been gathered are grouped together. Theory developed this way emerges from the bottom up (rather than from the top down, from many disparate pieces of collected evidence that are interconnected. It is called grounded theory. (Bogdan and Biklen, 1992: 87.)

The term ethnography can be interpreted as referring to the methods used in research which uses an inductive approach. Hammersley and Atkinson (1995: 1):

> ...see the term as referring primarily to a particular method or set of methods. In its most characteristic form it involves the ethnographer participating, overtly or covertly, in people's daily lives for an extended period of time, watching what happens, listening to what is said, asking questions – in fact, collecting whatever data are available to throw light on the issues that are the focus of the research. (Hammersley and Atkinson, 1995: 1.)

Ethnographic methods of data collection and analysis were predominantly employed in this part of the study which focused on investigating how use of the TRAC PAC affects learners' understanding of science concepts. This meant that significant amounts of time were spent in the field (the classroom setting) collecting data through observation, compiling field notes, conducting interviews and discussions, and making video and audio recordings of classroom activities. Data analysis techniques like thematic analysis and verbal analysis were used in an attempt to portray and accurately interpret the realities of the social situations that were being researched.

Thematic analysis involves sorting through the data collected from various sources, and reducing them to a few themes or categories through coding, and using these to make assertions which can be tested by scrutiny against further data.

Chapter 9 of this report provides more detail about the ethnographic phase of this study and the findings that were made using these approaches.

6.4 Conclusion

In conclusion to this discussion on methodology, it is important to clarify what this study attempts and did not attempt:

- It does not attempt to show that MBL approaches are better than traditional approaches, although some of the studies reviewed in the literature review section did show this to be the case.

- It does not attempt to make claims about generalisabilty, so research design did not involve the use of experimental and controls, etc.

- It does attempt to establish if MBL has any effect on remediation of misconceptions and development of understanding within the context it was used in this study.

- It does attempt to explore how learning occurs, and to identify mechanisms for learning when MBL technology is used.

- It was carried out after students have received traditional instruction in kinematics and kinematics graphs, and is thus making an important assumption that if misconceptions have remained/arisen after a first round of traditional learning experiences (for a description of what 'traditional approach' means here, see Chapter 2, Section 2.4.2 which describes the way textbooks treat this area, and thus the way many teachers teach the topic), then there is no reason why they shouldn't still be there after more of the same, e.g. the Brassel (1987) study did show this to be the case.

CHAPTER 7

Designing and implementing a TRAC PAC-based learning programme for addressing learner misconceptions related to kinematic concepts and their representation using kinematic graphs

This chapter describes the learning programme that learners worked through as part of this research project. Section 7.1 describes the learners that participated in the learning programme. Section 7.2 describes the structure and organisation of the research setting. Teacher (researcher) and learner roles are described in Section 7.3. Section 7.4 describes the MBL equipment used and set-up, and Section 7.5 describes the learning programme that learners worked through.

7.1 Selection of participants

As described earlier, twenty learners participated in the learning programme and thus formed the subjects for the research. These learners were drawn from local schools on a voluntary basis. A flyer was distributed at local high schools advertising the workshop, and Grade 11 and 12 learners were asked to respond. A copy of this flyer can be found as Appendix 1. Learners were selected on a first-come, first-serve basis. The only criteria learners had to satisfy were:

- They were doing Physical Science on the Higher Grade – as this area of knowledge is applicable only to Higher Grade learners in the current South African syllabus.

- They had already worked through this area with their teachers – The research aimed, in part, to identify if misconceptions and difficulties in kinematics and kinematics graphs still remained after their initial teaching and learning experiences, and whether use of

MBL remediated these difficulties and misconceptions. So, the emphasis of the research was on the use of the TRAC PAC as a remediation tool, rather than a tool through which learners are exposed to kinematics and kinematics graphs for the first time. Thus, the research attempted to identify if the TRAC PAC could be used as a remediation tool for correcting learner misconceptions and overcoming difficulties associated with graphs of motion. This was a conscious choice made by the researcher, as this is most often the scenario in which the TRAC PAC is used in the South African school setting.

The table below provides biographical and other information about the twenty learners who participated:

Table 7.1 Biographical and other information of participating learners. (Learners marked with an asterisk were part of the focus group that formed the research subjects for the qualitative phase of this study described in Chapter 9 of this report.)

Learner	School (See descriptions of schools below)	Medium of Instruction at school	Home language	Present Grade	Gender	Physical Science result at end of Grade 11 (All HG)
1	A	English	IsiZulu	12	Male	Between 40-49%
2	A	English	IsiZulu	12	Female	Between 50-59%
3	A	English	IsiZulu	12	Female	Between 50-59%
4	A	English	isiZulu	12	Male	Between 50-59%
5	A	English	IsiZulu	12	Male	Between 50-59%
6	A	English	Sesotho	12	Male	Between 50-59%
7	N	English	English	12	Male	Between 60-69%
8	N	English	English	12	Male	Between 60-69%
9	N	English	English	12	Female	Between 60-69%
10	N	English	English	12	Female	Between 50-59%
11	N	English	English	12	Female	Between 60-69%
12	N	English	English	12	Male	Between 70-79%
13	N	English	English	12	Female	Greater than 80%

14*	A	English	IsiZulu	12	Male	Between 70-79%
15*	C	English	English	12	Male	Greater than 80%
16*	C	English	English	12	Female	Greater than 80%
17	C	English	English	12	Male	Between 50-59%
18	C	English	English	12	Male	Between 60-69%
19*	C	English	IsiZulu	12	Female	Between 50-59%
20*	H	English	English	12	Male	Between 60-69%

School A is an ex-model C[1] state school situated in the city within walking distance from the centre of town, and is thus easily accessible to learners from the suburbs and townships, as transport is easily available. It has good academic and sporting facilities and extensive grounds. The demographics at the school have changed over the last few years, from a predominantly White learner population to a predominantly Black learner population. The majority of teachers are White. School fees are R4000 – R5000 per year. This, coupled with the transport costs in getting to the school, means that learners from families who have the necessary financial resources attend the school. English is the language of instruction at the school.

School N is an ex-House of Delegates[1] school, situated in an area which has a predominantly Indian population (as a result of the Group Areas policies of the former apartheid government), but is slowly changing as more Black families move into the area. The school's learner population also shows this shift. The teachers at the school are predominantly Indian. The school has limited resources. The school is situated some distance from the centre of town, and learners from other areas who wish to attend this school would need to travel first to the city centre and then to the school. Transport costs for learners who do not live in the area are thus quite high. School fees charged at the school are in the region of R800 – R1200 per year. English is the language of instruction at the school.

School C is an ex-model C school situated in a suburb which has a predominantly White population (as a result of the Group Areas policies of the apartheid government). The school's learner population is very mixed, and of all the secondary schools in the city, is probably the one which displays the most integration at this stage. The majority of teachers are White. The school has excellent sporting and academic facilities. School fees are in the range of R5000 – R6000 per year. English is the medium of instruction in the school.

School H is an ex-House of Representatives[1] school situated in an area which had a predominantly Coloured population (as a result of the Group Areas policies of the apartheid government), but is now probably 50% Coloured and 50% Black. The school's learner population also demonstrates this change. The majority of teachers are Coloured. The school is situated some distance from the centre of town, and learners from other areas who wish to attend this school would need to travel first to the city centre and then to the school. The school has limited sporting and academic resources. School fees are in the range of R800 – R1200 per year. English is the language of instruction in the school.

All learners were in Grade 12, doing Physical Science on the Higher Grade, and attending schools where the medium of instruction was English.

Other information displayed in Table 7.1 above, is shown in the series of pie charts which follow.

[1] Schools in South Africa still display the effects of the apartheid dispensation in relation to demographics, resources, etc at the schools. Likewise, some sectors of the population still experience more barriers to learning than others. Use of the terms White, Black Indian and Coloured are an attempt to capture this. An ex-model C school is a school which, in the previous dispensation, catered for White learners. Similarly, an ex-House of Delegates school catered for Indian learners and an ex- House of Representatives school catered for Coloured learners.

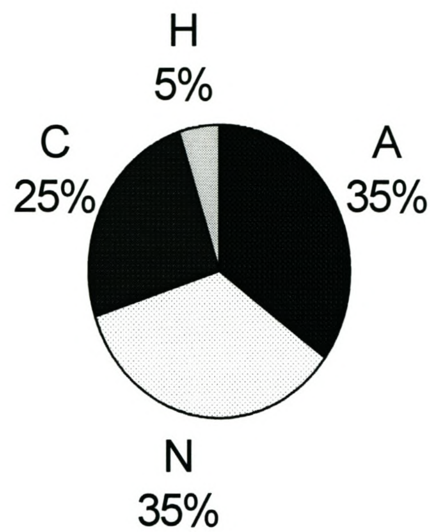


Figure 7.1: School distribution of participating learners.

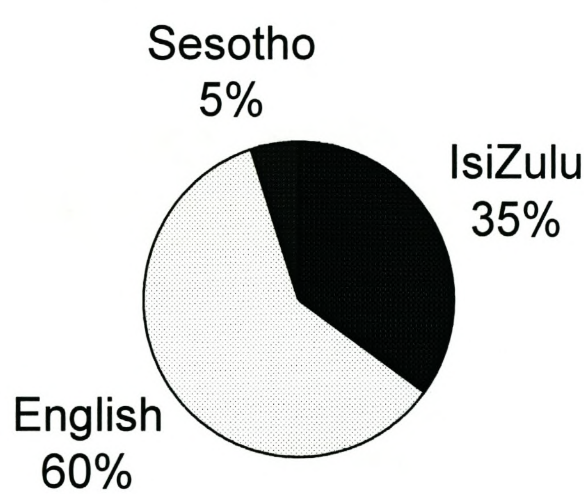


Figure 7.2: First (home) language distribution of participating learners.

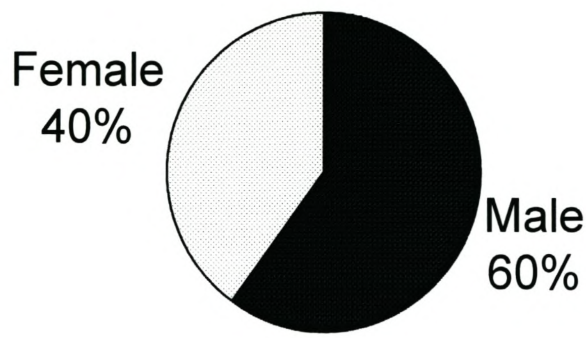


Figure 7.3: **Gender distribution of participating learners.**

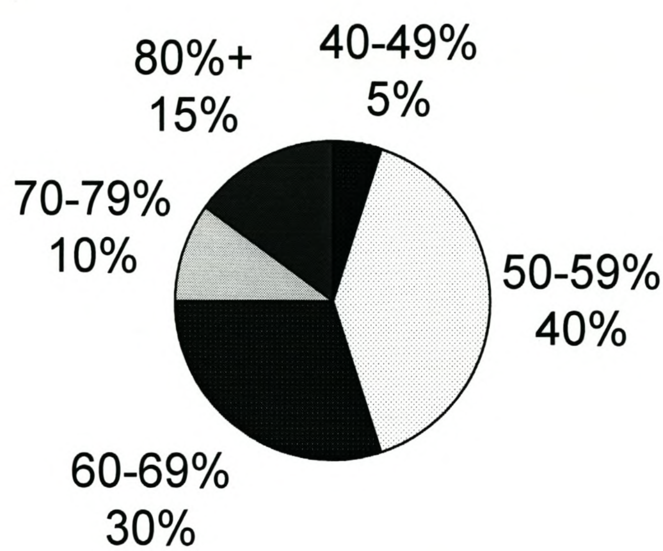


Figure 7.4: **Participating learners achievement in their Grade 11 final examinations.**

7.2 Organisation and layout of the research setting

The research was conducted at a central venue outside of the normal classroom experience of learners. There were a number of reasons for this:

- It was easier to set up the required equipment at a central venue, and to obtain technical assistance when needed at such a venue.

- This fitted most closely the reality or possible reality for the majority of learners with respect to their use of and exposure to MBL technology in South Africa. The vast majority of schools in South Africa do not have this technology available to them, and if learners are to have access to MBL technology, it will be in specialized labs like TRAC labs. Learners from schools will visit, most probably as an extension of their traditional learning experiences of kinematics. The question then arises, how effective is the TRAC PAC as a remedial tool in dealing with difficulties around graphs of motion that persist, even after traditional classroom-based learning has taken place?

Learners were organised into four groups of five learners each. Each group had their own set of MBL equipment, and thus worked through the learning activities simultaneously. One of the groups was chosen as a focus group for more detailed and in-depth investigation. Four of the groups were located in a large common room and the focus group in an adjoining space separated by a vinyl folding door (to provide more conducive audio and video recording conditions). The sketch and the photographs below illustrate the research setting.

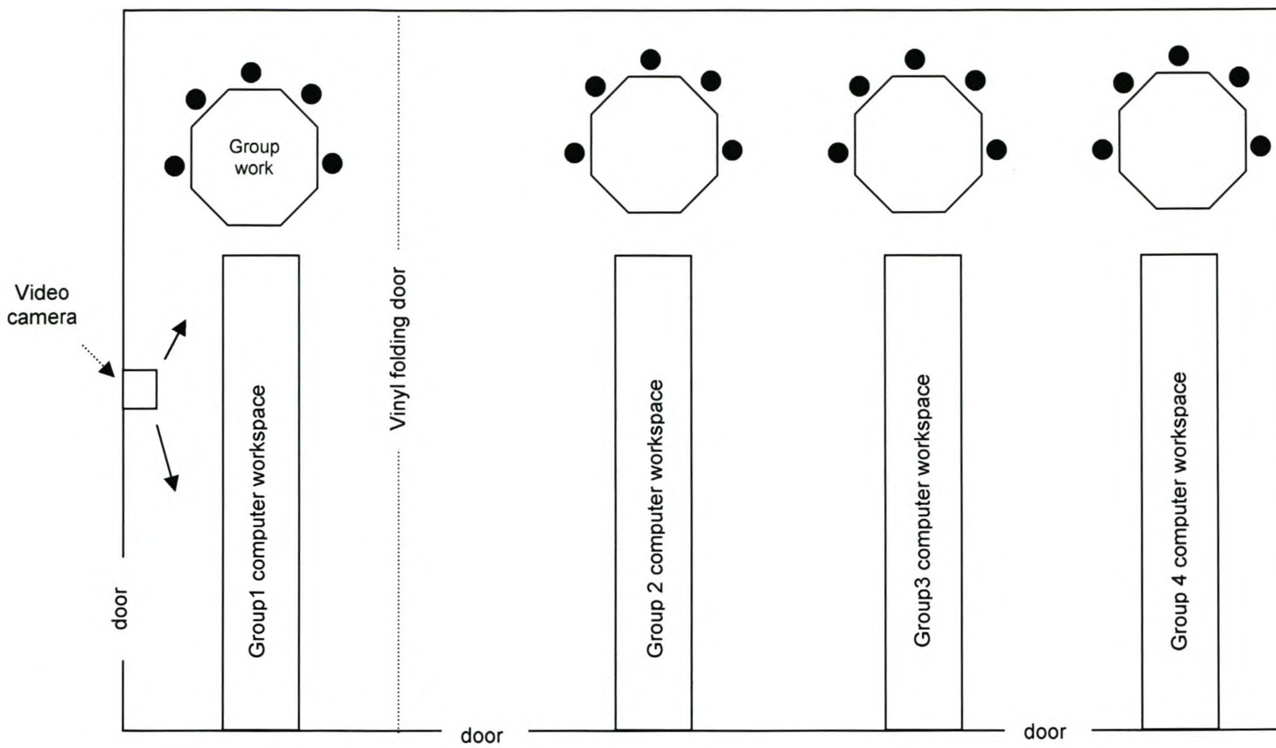


Figure 7.5: Physical layout of the research setting.

Figure 7.6: Photograph of common room setting – learners engaged in MBL activities.

A **B**

Figure 7.7: Photographs of small group settings. In A the learners are interacting with the computer display and each other. In B the learners are involved in discussions prior to, or after carrying out a computer-based data collection task.

7.3 Teacher and learner roles in the learning programme

All twenty learners completed the pre- and post-questionnaires and attended and participated fully in the learning activities making up the 3-day learning programme. In addition, the five learners selected as the focus group participated in pre- and post-interviews.

The teacher (who was also the researcher) played a largely facilitatory role, moving between groups, responding to questions, making suggestions, drawing attention to specific issues, etc. and providing technical support.

7.4 Setting up the MBL equipment

All the learning programme MBL activities relied on the use of the TRAC PAC. The TRAC PAC is a microcomputer-based laboratory which uses sensors connected to a computer to collect data, which the computer is able to display graphically. The motion sensor component of the TRAC PAC was used to capture data related to the motion of various moving objects and to generate displacement-time, velocity-time and acceleration-time graphs of these motions.

The motion sensor uses sonar waves to monitor the position and motion of objects. It emits short pulses of high frequency and detects and amplifies the echoes of nearby objects, and is thus able to record position for the object (much like how a bat operates). From this data, TRAC PAC computer with the Multi-Purpose Laboratory Interface (MPLI) software programme is able to generate displacement-time, velocity-time and acceleration time graphs. The photograph below shows the TRAC PAC computer and motion sensor set up to collect data for a ball rolling on an incline.

Figure 7.8: Computer and motion-sensor set up to record data for a ball rolling on an incline.

Since the motion sensor picks up the movement of objects within a 30^0 cone and up to 11m away from it, it is essential to set up the equipment in a room where a number of groups will be working in such a way that the potential for sonic interference is minimised. The classroom set-up shown in Figures 7.5, 7.6 and 7.8 took this into account.

7.5 The learning activities

Learners worked through six three-hour learning activities. The activities were designed to focus on common areas of difficulty that learners experienced with kinematic graphs. Chapter 3 of this report provides a detailed description of important theories of teaching, learning and conceptual change, and how these theories have been used to make choices about the design of learning activities and the teaching approach used to deliver the learning programme. Appendix 9 shows the learning difficulties that were selected as those that could possibly be remediated through use of MBL learning activities, and identifies the activities where learners would have an opportunity to work with particular difficulties.

The learning activities were presented to the learners in the form of a laboratory manual, which they worked through as the learning programme progressed. This manual can be found as Appendix 10 accompanying this report.

CHAPTER 8

Results and analysis of an empirical investigation of the effect use of a TRAC PAC-based learning programme has on learner understanding of kinematic graphs

This empirical investigation attempted to provide an answer for the second research question in this study i.e. Does use of the TRAC PAC contribute to learner understanding of graphs of motion and related concepts?

This chapter reports on the results obtained in the diagnostic pre- and post-questionnaire. This methodology was comprehensively described in Chapter 6 and Chapter 7. The focus here is on a report of the results obtained and an analysis of these.

The chapter is laid out as follows:

8.1 The general results of learners (in the form of absolute scores) in the pre-test and post-test are presented, analysed and discussed.

8.2 An example of the matrix used to capture learners' responses to the pre- and post-questionnaires is presented, and used to explain how information about learners' understanding in relation to three categories (substantial understanding, some understanding and little understanding) can be obtained from it.

8.3 Each hypothesis is presented. The reader is directed to a perusal of the matrices for the hypothesis. On a broader analytical level, a summarizing table portraying changes in learner understanding over the pre- and post-tests is constructed, and the results are discussed. At a deeper analytical level, learner responses to specific questions are analyzed to identify prevalent misconceptions and/or difficulties, and to identify whether any changes (shifts in understanding) occurred in these over the period between the pre- and post-test as a result of learner participation in the MBL learning programme.

8.4 The significance and nature of possible shifts in understanding observed in relation to each of the hypotheses are tested statistically using a Stuart-Maxwell analysis, and where appropriate, a McNemar Test.

8.5 'Alternative learner ideas' and difficulties displayed by this group of learners in their responses to the questionnaire are listed.

8.6 Observations about the overall impact of the MBL learning experience on learner understanding in relation to the four areas of difficulty in kinematics and kinematic graphs are made.

8.7 Finally, an attempt is made to link theories about the nature of learners' ideas and of concept learning to the observations made in 8.6.

8.1 Presentation, analysis and discussion of pre- and post-test results

Twenty learners wrote the pre- and post-tests. One mark was allocated for the correct choice (i.e. A, B, C or D), and a second mark was allocated for the appropriate reason (i.e. i, ii, iii or iv). A learner could only get the second mark for appropriate reason if the correct choice of answer was made. However, 1 mark was allocated if the correct choice was made, but an inappropriate reason selected. Hence there was a possible total of 32 marks for the 16 questions in the test. The table below shows the scores that learners achieved on the pre-test and the post-test.

Table 8.1 **Pre- and Post- test scores. (Learners marked with an asterisk were part of the focus group that formed the research subjects for the qualitative phase of this study.)**

Learner	Pre-Test (32)	Post-Test (32)	Change in mark between pre-test and post-test
1	10	15	+5
2	8	22	+14
3	8	9	+1
4	6	18	+12
5	7	6	-1
6	6	11	+5
7	6	17	+11
8	10	18	+8
9	12	24	+12
10	5	19	+14
11	7	11	+4
12	11	14	+3
13	17	24	+7
14*	18	23	+5
15*	23	32	+9
16*	13	29	+16
17	4	11	+7
18	14	22	+8
19*	12	15	+3
20*	14	25	+11
Mean	10.6	18.3	+7.7
Mean %	32.9	57.0	24.1
Standard Deviation	4.79	6.89	4.65

A two-tailed Student's t-test for matched pairs was applied to the results of the pre- and post-tests in order to test the null hypothesis that:

H_o: There is no significant difference between the two sets of scores and they both come from the same population.

The t-value (t) was calculated using the following formula:

$$t = \frac{\bar{x} - \mu}{\frac{s}{\sqrt{n}}}$$

where:

$\bar{x}$ is the sample mean;

μ is the population mean

s is the standard deviation of the difference scores;

n is the number of difference scores.

The t-value for the data presented in Table 8.1 worked out to 7.5. This is significantly larger than the t-value at the 0.05 level of significance for 19 degrees of freedom (N-1): $t_{.05}(19) = 2.093$

This means that the null hypothesis can be rejected with confidence. In practical terms, this means that the two sets of scores come from two different populations, and consequently that the learning programme intervention has made a significant improvement on learner understanding as measured by changes in performance of the learners over the pre- and post-tests.

Changes in learner achievement over the two tests are graphically illustrated in Figure 8.1 below.

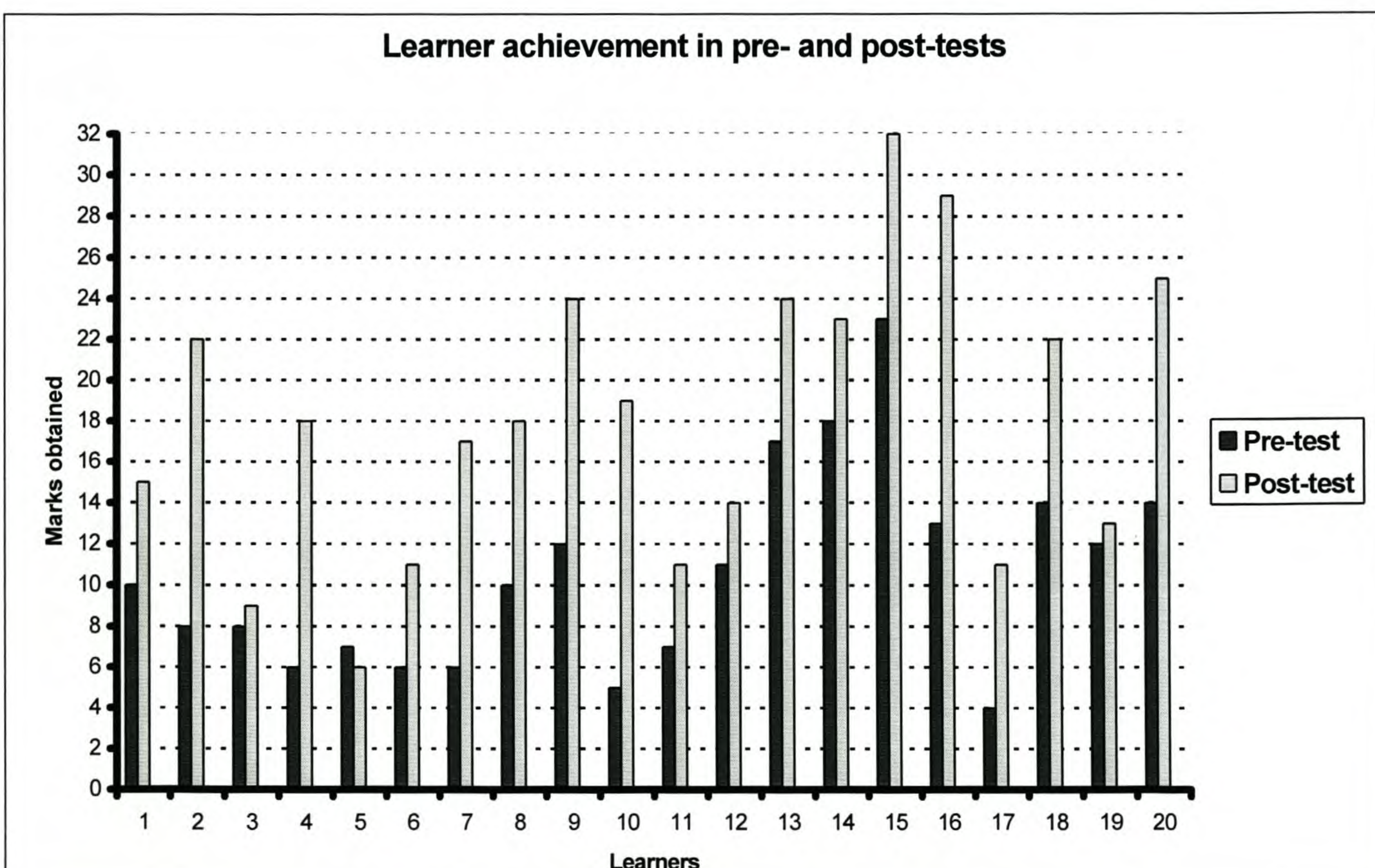
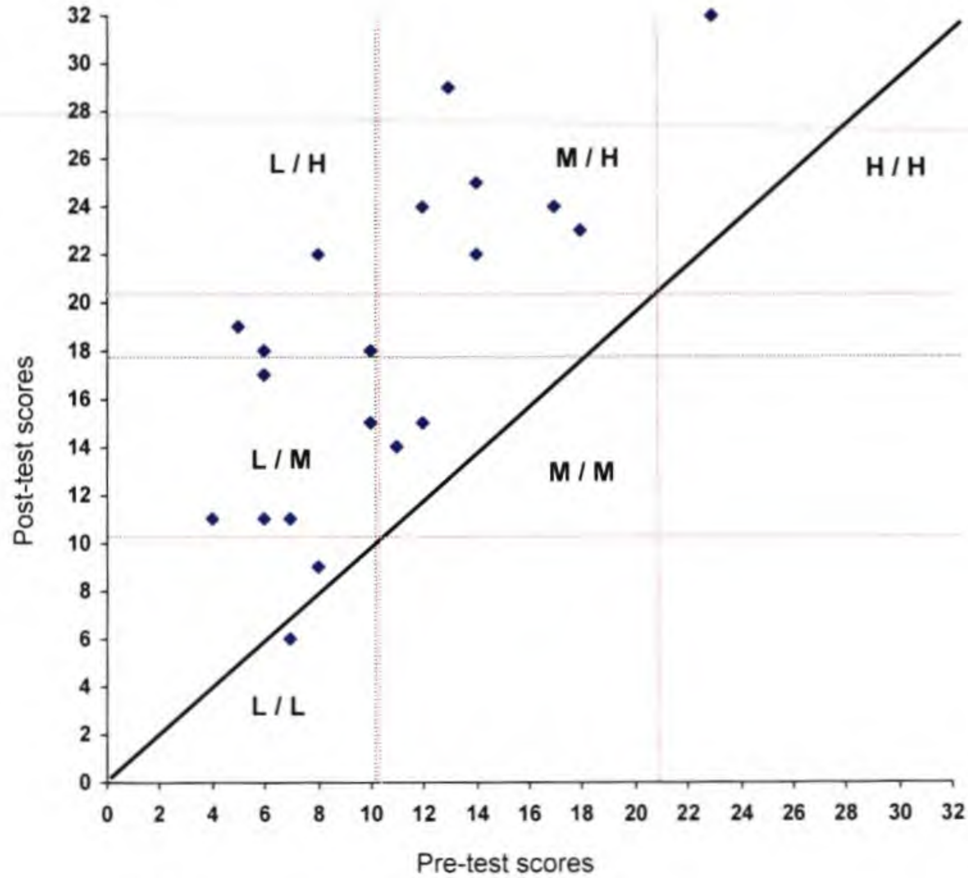


Figure 8.1: Learner achievement in the pre-test and the post-test.

Besides one learner whose score decreased by 1 over the two tests, changes in learner performance as measured by the increase in their scores over the two tests, ranged from an increase of 1 to an increase of 16. The average increase for the group of twenty learners was 7.7. This corresponded to an average percentage increase of 24.1% for the group. The standard deviation increased from 4.8 in the pre-test to 6.9 in the post-test, indicating a wider spread of marks around the mean in the post-test, and thus that the sample of students became more heterogenous as a result of the learning programme experience, possibly indicating differential experiences for learners in the programme.

A scatter diagram of learner pre-test scores on the x-axis versus post-test scores on the y-axis highlights some interesting relationships. This diagram is shown on the next page.



KEY:

Line of no change

Mean on pre- and post-tests

Dividing lines for performance sectors

L / L — Learners who started with a low score and ended with a low score fall into this sector

L / M — Learners who started with a low score and ended with a medium score fall into this sector

L / H — Learners who started with a low score and ended with a high score fall into this sector

M / M — Learners who started with a medium score and ended with a medium score fall into this sector

M / H — Learners who started with a medium score and ended with a high score fall into this sector

H / H — Learners who started with a high score and ended with a high score fall into this sector

◆ Data point indicating pre- and post-test score for each learner

Figure 8.2 A scatter plot of pre-test scores versus post-test scores.

The solid line dissecting the graph is a line of ‘no change’. Learners whose data points fall above this line have all showed some degree of improvement. The greater the distance between the line and the data point, the greater improvement that particular learner demonstrated. Nineteen of the twenty points are above the line and one below. However, the two closest to the line have shown small changes and they can be considered to be insignificant. Thus 18 of the 20 learners can be considered to have improved performance on the test.

The mean on the post-test was substantially higher than the mean on the pre-test, indicating a general improvement in the performance of the group. If the scatter graph is examined closely, it can be observed that learners who performed below the mean on the pre-test, also tended to perform below the mean on the post-test, and a large portion of those who performed above the mean on the pre-test also performed above the mean on the post-test. By counting the data points, one can identify that of the eleven learners whose pre-test marks fell on or below the mean on the pre-test, nine of these learners also achieved marks in the post test which fell on or below the post-test mean. Likewise, of the nine learners who performed above the mean on the pre-test, seven of these learners also performed above the mean on the post-test. Two learners who performed below the mean on the pre-test, made significant gains to score above the mean on the post-test. One learner who performed above the mean on the pre-test, performed below the mean on the post-test. This may be an indication of the effect of learners’ prior knowledge on learning success in a programme like this. While the majority of the learners showed some degree of improvement on the programme, learners who started lower (possibly because of a lack of prior knowledge) also tended to finish lower.

The dotted red lines on Figure 8.2 divide the graph into performance sectors. This allows a comparison between the results displayed here, and those reported in a similar analysis by Thornton (2004). The Thornton study was a much larger scale analysis which reported on the performance of 181 American university students on a pre- and post-Force and Motion Concept Evaluation (FMCE) separated by learning experiences in a force and motion introductory physics MBL course. The study being reported on here took place in a different context, a South African one, and involved a smaller number of learners (20), who were still at school level.

Patterns that are similar to those described in the Thornton (2004) analysis include:

- Very few students ended up with a low-low description of performance. In this study 1 student fell into this category. Thornton (2004: 4) ascribes this to the "effective learning environment" afforded in the MBL context. He also notes that there were essentially no medium-medium (M-M) students in his study. This was also the case here, where only one student fell into this category. It's interesting that this particular student was part of the focus group for the phase of the study described in Chapter 9. Insight into this learner's lack of improvement can be gained from the analyses and discussion in that chapter.

- Thornton (2004:4) also describes a "threshold effect". In his analysis, students who started above a "threshold" of 25% on the pre-test were essentially guaranteed a high finish on the post-test. The same effect was observed in this study, with the threshold here being 30% on the pre-test. All the learners (except the two who stayed M-M) who started above 30% on the pre-test achieved a high finish on the post-test. Also in line with an observation by Thornton (2004), it is difficult to make any predictions about the performance of learners who start below the 'threshold' point. If the scatter chart is inspected it can be seen that these learners end up with a range of finishes, from low through medium to high.

The commonalities between this study and the more comprehensive Thornton (2004) study, lend some weight to the findings here, and help to negate a potential weakness of this study – the relatively small number of students who formed the subjects for the study.

What does all this mean?

By rejecting the null hypothesis in relation to the t-value between the two sets of scores, it can be accepted that the pattern and development observed in the results of the pre- and post-test did not occur by chance, but is due to other explanations, an important one in this case probably being the experience of the learners in the learning programme.

As 18 of the 20 learners scores increased measurably over the two tests, it can be accepted that, overall, the experience of the MBL-based learning programme had a positive influence on the development of learner understanding in the area of kinematics and kinematic graphs.

The relatively high positive correlation between the pre-test and post-test scores indicates that, although the majority of learners showed good improvement (an average percentage increase of 24.1% for the group), learners who did best on the pre-test, also did best on the post-test. Likewise, learners who were lower achievers on the pre-test were also lower achievers on the post-test, again a possible indication of the impact of learner prior knowledge on learning success. The 'threshold effect' described earlier is another possible indication of the impact of prior knowledge on learning success. In this case, all the learners except two, who had more than 30% on the pre-test, indicating possession of a certain degree of prior knowledge, had a high finish on the post-test, and could thus be classified as successful learners in the context of the study.

Generally, the MBL experience did not result in spectacular gains in understanding, where learners who demonstrated poor initial understanding, suddenly demonstrated vastly improved levels in the post-test. (There were one or two exceptions to this.)

On this basis, it can be cautioned that while the MBL learning experience did seem to enhance learner understanding in the area of kinematics and kinematic graphs, the technology should not be viewed as some sort of 'miracle' tool, which will 'rectify' all learner difficulties in this area. Other factors like learners' prior knowledge/understanding and expertise, which has been demonstrated here, and factors like the actual design of learner activities, and of learner experiences in the learning activities, which will be discussed in the next chapter, also play a significant role in the impact of such technology on learner performance.

8.2 How to read the matrices

A set of matrices is shown below. Explanatory notes follow:

Difficulty A1

Pre-test

Question 2 (A1.1)	Question 15 (A1.2)																	
	Ai	Aii	Aiii	Aiv	Bi	Bii	Biii	Biv	Ci	Cii	Ciii	Civ	Di	Dii	Diii	Div	NA	Row Tot
Ai														1				1
Aii						1	1							3				5
Aiii							3							3	1			7
Aiv																		0
Bi														1				1
Bii																		0
Biii							2										1	3
Biv							1											1
Ci																		0
Cii																		0
Ciii							1											1
Civ																		0
Di																		0
Dii						1												1
Diii																		0
Div																		0
NA																		0
Col Tot	0	0	0	0	0	2	8	0	0	0	0	0	0	8	1	0	1	n = 20

Post-test

Question 14 (A1.1)	Question 5 (A1.2)																	
	Ai	Aii	Aiii	Aiv	Bi	Bii	Biii	Biv	Ci	Cii	Ciii	Civ	Di	Dii	Diii	Div	NA	Row Tot
Ai														1				1
Aii														3	2			5
Aiii						1	4							5				10
Aiv																		0
Bi																		0
Bii																		0
Biii						1								1				2
Biv																		0
Ci																		0
Cii																		0
Ciii																		0
Civ																		0
Di														1				1
Dii																		0
Diii														1				1
Div																		0
NA																		0
Col Tot	0	0	0	0	0	2	4	0	0	0	0	0	0	12	2	0	0	n = 20

Figure 8.3 An example of a set of matrices.

- There are eight sets of matrices, 1 set for each of the difficulties/misconceptions identified for possible remediation through use of a TRAC PAC-based learning programme. So each set of matrices provided data which was used to support or refute one of the hypotheses generated. The set of matrices shown here was used to support or refute the hypothesis generated for Difficulty A1. (See Appendix 8 for a list of the hypotheses generated for each area of difficulty.

- Two questions were designed for each hypothesis. For hypothesis A1, these were Question 2 and Question 15 in the pre-test. Although the same questions were used in the post-test, random mixing resulted in Question 2 of the pre-test appearing as Question 14 in the post-test, and Question 15 in the pre-test appearing as Question 5 in the post-test.

- Each pair of identical questions from the pre- and post-tests were given a code, so that the researcher could refer to them with ease in the report and analysis section of this report. For example, the pair of Question 2 in the pre-test and Question 14 in the posttest were allocated to code **A1.1**. The pair of Question 15 in the pre-test and Question 5 in the post-test were allocated the code **A1.2**. For Question A1.2:
  - **A** means that it is a question which focuses on Category A of the four broad areas of learner difficulties and misconceptions with kinematics and kinematic graphs. (See Chapter 4).
  - **1** means that the question focuses on specific difficulty 1 selected from within this broad area.
  - **2** means that it is the second of two questions which do this.

- Highlighted rows and columns indicate the correct response (answer-A, B, C or D and reason – i, ii, iii or iv)) for the particular question. For example in the pre-test matrix above, the correct answer for Question A1.1 was Aiii, while the correct answer for Question A1.2 was Dii. For the pre-test, 7 learners (highlighted row) answered question A1.1 correctly, while 8 learners answered question A1.2 correctly. For the post-test, these numbers increased to 10 and 12 respectively. The intersection between highlighted rows and columns are important because they show the number of learners who were able to answer both questions correctly (selecting both the correct answer and the correct reason), and thus demonstrating substantial understanding according to the classification described on page 192 of this report. Other learners who fall outside of this intersection but still in a highlighted column or row, have chosen the correct answer and appropriate reason for one of the questions relating to a specific difficulty, and thus demonstrate some understanding. Learners who fall into areas of the table which are not highlighted have not been able to match correct answer and reason for both questions and thus demonstrate little understanding in that area.

- The column and row totals are useful because they provide a record of the popularity of the various combinations (choice and reason) for learners, and can thus be used to identify prevalent difficulties/misconceptions that learners display in the various areas.

In the section which follows, results for the various hypotheses are presented and discussed.

8.3 Presentation and discussion of results in relation to eight hypotheses

The reader will need to refer to the pre-test and post-test for the wording of the questions in the tests in order to make sense of the discussion that follows here. These can be found as Appendices 3 and 4 in this report.

8.3.1 Hypotheses A1

As a result of working through a series of MBL learning activities, learners will demonstrate an improved understanding of, and ability to differentiate between velocity and acceleration.

Questions A1.1 and A1.2 were used to test this hypothesis. Question A1.1 appeared as Question 2 in the pre-test and as Question 14 in the post-test. Question A1.2 appeared as Question 15 in the pre-test, and as Question 5 in the post-test. The matrices illustrating learner performance in relation to these questions, are shown below:

Difficulty A1

Pre-test

Rows: **Question 2** (A1.1); Columns: **Question 15** (A1.2)

	Ai	Aii	Aiii	Aiv	Bi	Bii	Biii	Biv	Ci	Cii	Ciii	Civ	Di	Dii	Diii	Div	NA	Row Tot
Ai														1				1
Aii						1	1							3				5
Aiii							3							3	1			7
Aiv																		0
Bi														1				1
Bii																		0
Biii							2										1	3
Biv							1											1
Ci																		0
Cii																		0
Ciii							1											1
Civ																		0
Di																		0
Dii						1												1
Diii																		0
Div																		0
NA																		0
Col Tot	0	0	0	0	0	2	8	0	0	0	0	0	0	8	1	0	1	n = 20

Post-test

Rows: **Question 14** (A1.1); Columns: **Question 5** (A1.2)

	Ai	Aii	Aiii	Aiv	Bi	Bii	Biii	Biv	Ci	Cii	Ciii	Civ	Di	Dii	Diii	Div	NA	Row Tot
Ai														1				1
Aii														3	2			5
Aiii						1	4							5				10
Aiv																		0
Bi																		0
Bii																		0
Biii						1								1				2
Biv																		0
Ci																		0
Cii																		0
Ciii																		0
Civ																		0
Di														1				1
Dii																		0
Diii														1				1
Div																		0
NA																		0
Col Tot	0	0	0	0	0	2	4	0	0	0	0	0	0	12	2	0	0	n = 20

Figure 8.4: Set of matrices for difficulty A1.

Analysis of the matrices for this hypothesis reveals the patterns and information shown in the table and graph below.

	Pre-Test	Post-Test
Little understanding	8	3
Some understanding	9	12
Substantial understanding	3	5

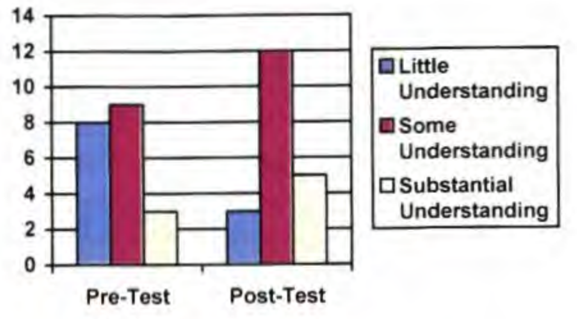


Figure 8.5: Table and graph showing changes in understanding in relation to Difficulty A1.

8.3.1.1 Discussion of results

The results above show that the number of learners showing little understanding in relation to Difficulty A1 decreased from 8 to 3 between the pre-test and the post-test, the number of learners showing some understanding increased from 9 to 12, and the number of learners showing substantial understanding increased from 3 to 5.

On the basis of this it can be accepted that the TRAC PAC-based learning experience led to some improvement in learner understanding of difficulties relating to understanding of, and ability to differentiate between, velocity and acceleration.

8.3.1.2 Examining student responses to Question A1.1 more closely

In the pre-test, thirteen learners selected the correct option A, but of these, only seven chose the appropriate reason. The number of learners who chose the correct option A increased to sixteen in the post-test, and of these, ten chose the appropriate reason as well. Clearly, learner performance in this area has improved over the two tests.

Prevalent misconceptions and/or difficulties demonstrated in responses to Question A1.1 in the pre-test and/or post-test.

- *A positive velocity means an increasing velocity, and a negative velocity means a decreasing velocity.*

In the pre-test, five learners supported their choice of Option A by suggesting that a positive velocity meant an increasing velocity, and a negative velocity meant a decreasing velocity. This was also the case in the post-test. So, rather than relating the sign of the velocity to the direction in which the object was moving, these learners related it to the speed of the object.

- *When an object covers greater successive distances in the same time period, its acceleration is increasing.*

In the pre-test, five learners associated covering greater consecutive distances in the same period of time with increasing acceleration, but this figure dropped to two in the post-test. So, for the two learners, classifying increased distance covered per time unit as increasing acceleration remained a problem.

8.3.1.3 Examining student responses to Question A1.2 more closely

In the pre-test, nine learners selected the correct Option D, and of these, eight chose the appropriate Reason ii. The number of learners who chose the correct Option D increased to fourteen in the post-test, and of these, twelve chose the appropriate reason as well. Learner performance on this question improved over the two tests, as a result of participation in the learning programme.

Prevalent misconceptions and/or difficulties demonstrated in responses to question A1.2 in the pre-test and/or post-test

- *This difficulty probably cannot be classified as a misconception as such, rather an inability to consider factors which influence how a ticker tape should be read.*

In the pre-test, ten learners selected B as their answer for Question A1.2, and of these, eight learners selected Reason iii, suggesting that this response is a major area of misunderstanding for learners. A possible source of the error that learners made here was to fail to identify that the left-hand side of the ticker tape was attached to the trolley, even though this information was provided to them in the question. These learners answered as if the right-hand side of the tape was attached to the trolley. In the post-test, this difficulty persisted, although to a lesser extent, with six learners opting for Option B, and of these, four learners opting for Reason iii.

8.3.2 Hypotheses A2

As a result of working through a series of MBL learning activities, learners are more likely to accept that, in the case of projectile motion, the acceleration of the object is unchanged through the motion.

Questions A2.1 and A2.2 were used to test this hypothesis. Question A2.1 appeared as Question 12 in the pre-test and as Question 4 in the post-test. Question A2.2 appeared as Question 1 in the pre-test, and as Question 3 in the post-test. The matrices illustrating learner performance in relation to these questions, are shown below:

Difficulty A2

Pre-test

Question 12 (A2.1) / Question 1 (A2.2)	Ai	Aii	Aiii	Aiv	Bi	Bii	Biii	Biv	Ci	Cii	Ciii	Civ	Di	Dii	Diii	Div	NA	Row Tot
Ai																		0
Aii																		0
Aiii																		0
Aiv					1													1
Bi																		0
Bii					1					1	1			2				5
Biii						1												1
Biv																		0
Ci				1	4	1					1			1				8
Cii																		0
Ciii					2													2
Civ														1				1
Di																		0
Dii												1		1				2
Diii																		0
Div																		0
NA																		0
Col Tot	0	0	0	1	8	2	0	0	0	1	2	1	0	5	0	0	0	n = 20

Post-test

Question 4 (A2.1) / Question 3 (A2.2)	Ai	Aii	Aiii	Aiv	Bi	Bii	Biii	Biv	Ci	Cii	Ciii	Civ	Di	Dii	Diii	Div	NA	Row Tot
Ai																		0
Aii																		0
Aiii																		0
Aiv																		0
Bi			1															1
Bii			3								5							8
Biii																		0
Biv																		0
Ci		1	1		3				1		2							8
Cii															1			1
Ciii					1								1					2
Civ																		0
Di																		0
Dii																		0
Diii																		0
Div																		0
NA																		0
Col Tot	0	1	5	0	4	0	0	0	1	0	7	0	1	0	1	0	0	n = 20

Figure 8.6: Set of matrices for Difficulty A2.

Analysis of the matrices for this hypothesis reveals the patterns and information shown in the table and graph below.

	Pre-Test	Post-Test
Little understanding	15	10
Some understanding	5	7
Substantial understanding	0	3

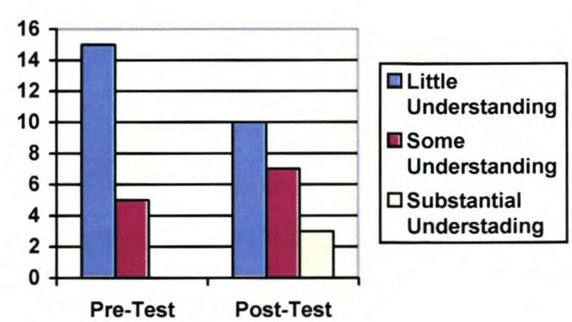


Figure 8.7: Table and graph showing changes in understanding in relation to difficulty A2.

8.3.2.1 Discussion of results

The results above show that the number of learners showing little understanding in relation to Difficulty A2 decreased from 15 to 10 between the pre-test and the post-test, the number of learners showing some understanding increased from 5 to 7, and the number of learners showing substantial understanding increased from 0 to 3.

Thus, there were improvements in learner performance over the two tests in relation to the difficulty posed by this question. The small improvement however, indicates that it appears as if this difficulty still posed significant challenges to the majority of the learners, even after the MBL learning experience.

8.3.2.2 Examining student responses to Question A2.1 more closely

Bii was the correct choice for this question. Six students were able to select Option B in the pre-test, and of these, five chose the correct Reason ii as well. This improved to nine learners being able to choose the correct Option B in the post-test, with eight of these choosing the appropriate Reason ii as well.

Prevalent misconceptions and/or difficulties demonstrated in responses to Question A2.1 in the pre-test and/or post-test

- *Acceleration of a projectile is zero at its highest point because it is at rest at this point.*

Eleven learners selected Option C in the pre-test, with eight of these choosing Reason i to support their choice. These figures remained exactly the same for the post-test. So, learners have a major problem accepting that the acceleration of a projectile is non-zero at its apex, and tend to identify the acceleration as being zero because the object is not moving at this point, rather that associating the acceleration with the resultant force acting on the object. This is a major area of difficulty for learners, and this difficulty persisted, even after participation in MBL learning activities where this difficulty was explored.

8.3.2.3 Examining student responses to Question A2.2 more closely

Aiii represented the correct choice for this question. In the pre-test, only one learner was able to select option A, but this learner selected an inappropriate Reason iv, indicating that he/she was uncertain about the choice. In the post-test, six learners were able to choose option A, with five also selecting the appropriate Reason iii, thus indicating some measure of improvement in the post-test.

Prevalent misconceptions and/or difficulties demonstrated in responses to question A2.2 in the pre-test and/or post-test

- *Acceleration of a projectile is zero at its highest point, and changes as the speed of the object changes.*

Again, the dominant misconception amongst learners visible in responses to this question was the belief that the object must have zero acceleration at its highest point, and that in order for it to be zero at this point, the acceleration must be decreasing from a maximum at its starting point to zero at its apex. Ten learners chose Option B, which reflected this misconception. Eight of the ten learners chose Reason i to support their choice, linking change in acceleration of an object to changes in its speed.

- *For a projectile, the direction of the acceleration changes when the object changes direction.*

Options C and D represented this misconception. Four learners chose C in the pre-test, and eight in the post-test. The increase in numbers here possibly indicates that more learners appreciated that the magnitude of the acceleration of the projectile remained unchanged (which was part of the wording of this option), as a result of their participation in the learning programme. However, they still have difficulty recognizing that it's direction remains unchanged as well, preferring to link the direction of the acceleration with the direction (up or down) in which the object was moving.

Five learners chose D in the pre-test, and this figure dropped to 2 in the post-test.

8.3.3 Hypotheses B1

As a result of working through a series of MBL learning activities, learners are more able to recognise that reference points and reference directions to describe a particular motion are arbitrarily chosen.

Questions B1.1 and B1.2 were used to test this hypothesis. Question B1.1 appeared as Question 6 in the pre-test and as Question 12 in the post-test. Question B1.2 appeared as Question 10 in the pre-test, and as Question 10 in the post-test. The matrices illustrating learner performance in relation to these questions, are shown below:

Difficulty B1

Pre-test

		Question 10 (B1.2)																	
		Ai	Aii	Aiii	Aiv	Bi	Bii	Biii	Biv	Ci	Cii	Ciii	Civ	Di	Dii	Diii	Div	NA	Row Tot
Question 6 (B1.1)	Ai														1				1
	Aii							1											1
	Aiii		1					2			1	1			1	1	1		8
	Aiv																		0
	Bi			1	1									1					3
	Bii																		0
	Biii																		0
	Biv												1						1
	Ci																		0
	Cii		1					1								1			3
	Ciii																		0
	Civ																		0
	Di																		0
	Dii																		0
	Diii			1				1											2
	Div																1		1
	NA																		0
	Col Tot	0	2	2	1	0	0	5	0	0	1	1	1	1	2	2	2	0	n = 20

Post-test

Question 12 (B1.1)	Question 10 (B1.2)																	
	Ai	Aii	Aiii	Aiv	Bi	Bii	Biii	Biv	Ci	Cii	Ciii	Civ	Di	Dii	Diii	Div	NA	Row Tot
Ai																		0
Aii		1				1	1											3
Aiii																		0
Aiv																		0
Bi														1				1
Bii							1											1
Biii																		0
Biv																		0
Ci																		0
Cii			1			1	**7**							3				12
Ciii														1				1
Civ																		0
Di																		0
Dii																		0
Diii											1			1				2
Div																		0
NA																		0
Col Tot	0	1	1	0	0	2	9	0	0	0	1	0	0	6	0	0	0	n = 20

Figure 8.8: Set of matrices for difficulty B1.

Analysis of the matrices for this hypothesis reveals the patterns and information shown in the table and graph below.

	Pre-Test	Post-Test
Little understanding	13	6
Some understanding	6	7
Substantial understanding	1	7

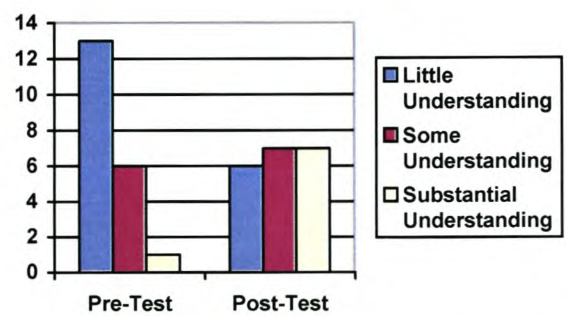


Figure 8.9 Table and graph showing changes in understanding in relation to difficulty B1.

8.3.3.1 Discussion of results

These results display a clear improvement in learner understanding in relation to the difficulty associated with the arbitrary allocation of reference point and reference direction. Learners demonstrating little understanding in this area decreased from 13 to 6. Learner showing some understanding increased from 6 to 7 and learners showing substantial understanding increased from 1 to 7. It appears as if the

MBL learning experience was effective in remediating learner difficulty in this area.

8.3.3.2 Examining student responses to Question B1.1 more closely

The correct answer for this question was C and the correct reason Option ii. Three learners chose the correct answer and reason in the pre-test. This improved to thirteen learners choosing the correct answer C in the post-test, with twelve of these choosing the correct Reason ii as well. Thus, learners demonstrated significant improvement on this question over the two tests.

Prevalent misconceptions and/or difficulties demonstrated in responses to Question B1.1 in the pre-test and/or post-test

- *Parts of a displacement-time graph, which appear below the x-axis, indicate movement in an opposite direction to that for parts above the x-axis.*

Option A represented this misconception. Ten learners selected this option with eight of them using Reason iii to support their choice. The number of learners selecting this option decreased to 3 in the post-test, suggesting that the MBL learning experience had a positive impact on learner understanding in this area.

8.3.3.3 Examining student responses to Question B1.2 more closely

Biii represents the correct combination of answer and reason for this question. In the pre-test, five learners selected A as an answer and all five also selected Reason iii. In the post-test, eleven learners selected Option A, with 9 of these selecting the appropriate reason as well.

Prevalent misconceptions and/or difficulties demonstrated in responses to Question B1.2 in the pre-test and/or post-test

- *Graph-as-picture problem - Choosing graphs which have the same shape.*

Learner responses were spread widely over almost all the possible options in this question, but D stands out as an area of persistent difficulty because of the number of learners who selected this in the pre-test and the post-test remained almost the same (six in the pre-test and seven in the post-test). Learners chose Graphs 2 and 4 as graphs representing the same motion, probably because they had similar shapes.

8.3.4 Hypotheses B2

> *As a result of working through a series of MBL learning activities, learners demonstrate improved ability to associate the sign of a kinematic quantity with its direction rather than its magnitude.*

Questions B2.1 and B2.2 were used to test this hypothesis. Question B2.1 appeared as Question 8 in the pre-test and as Question 1 in the post-test. Question B2.2 appeared as Question 9 in the pre-test, and as Question 2 in the post-test. The matrices illustrating learner performance in relation to these questions, are shown below:

Difficulty B2

Pre-test

Question 9 (B2 2) across; Question 8 (B2 1) down

	Ai	Aii	Aiii	Aiv	Bi	Bii	Biii	Biv	Ci	Cii	Ciii	Civ	Di	Dii	Diii	Div	NA	Row Tot
Ai	2				1	2									4			9
Aii																		0
Aiii	1												1		1			3
Aiv																		0
Bi	2																	2
Bii															1			1
Biii																		0
Biv																		0
Ci																		0
Cii																		0
Ciii																		0
Civ																		0
Di			1												2			3
Dii														1				1
Diii															1			1
Div																		0
NA																		0
Col Tot	5	0	1	0	1	2	0	0	0	0	0	0	1	1	9	0	0	n = 20

Post-test

Question 2 (B2 2) across; Question 1 (B2 1) down

	Ai	Aii	Aiii	Aiv	Bi	Bii	Biii	Biv	Ci	Cii	Ciii	Civ	Di	Dii	Diii	Div	NA	Row Tot
Ai	3		2			9												14
Aii																		0
Aiii						1								1				2
Aiv																		0
Bi						1												1
Bii																		0
Biii																		0
Biv																		0
Ci																		0
Cii																		0
Ciii																		0
Civ																		0
Di															1			1
Dii																		0
Diii	1		1															2
Div																		0
NA																		0
Col Tot	4	0	3	0	0	11	0	0	0	0	0	0	0	1	1	0	0	n = 20

Figure 8.10: Set of matrices for difficulty B2.

Analysis of the matrices for this hypothesis reveals the patterns and information shown in the table and graph below.

	Pre-Test	Post-Test
Little understanding	11	4
Some understanding	7	7
Substantial understanding	2	9

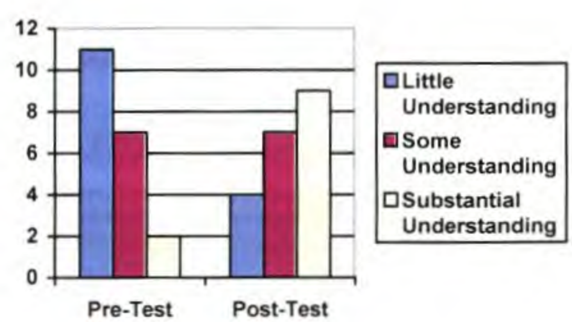


Figure 8.11: Table and graph showing changes in understanding in relation to difficulty B2

8.3.4.1 Discussion of results

The number of learners demonstrating little understanding dropped from 11 in the pre-test to 4 in the post-test. The number of learners demonstrating some understanding stayed constant at 7, while the number of learners demonstrating substantial understanding changed from 2 in the pre-test to 9 in the post-test. On this basis, it can be accepted that the MBL learning experience resulted in improved ability to associate the sign of a kinematic quantity with its direction rather than its magnitude.

8.3.4.2 Examining student responses to Question B2.1 more closely

Ai represented a correct choice and reason for this question. In the pre-test, 12 learners were able to select A as their choice, and of these, 9 selected the appropriate Reason i as well. In the post-test, 16 were able to choose Option A, with 14 choosing the appropriate Reason i.

Prevalent misconceptions and/or difficulties demonstrated in responses to Question B2.1 in the pre-test and/or post-test

- *Graph-as-picture problem - Choosing graphs which have the same shape.*

This misconception was again evident in the responses to this question. Five learners in the pre-test chose Option D, which represented a velocity-time graph that had a similar overall shape to the displacement-time graph on which the question was based. This number decreased to three in the post-test.

8.3.4.3 Examining student responses to Question B2.2 more closely

Bii represented the correct choice and reason for this question. In the pre-test, 3 students chose Option B, and of these, 2 chose the appropriate Reason ii as well. In the post-test, this improved to 11 learners choosing the correction Option A and correct Reason ii as well.

Prevalent misconceptions and/or difficulties demonstrated in responses to question B2.2 in the pre-test and/or post-test

- *Linking the sign of the acceleration to the magnitude of the velocity.*

Learners suggested that an object which is slowing down will have a negative acceleration and an object which is speeding up should have a positive acceleration.

This misconception was represented by Option A. Six learners demonstrated this misconception in the pre-test, and seven in the post-test, indicating that it is a relatively resistant misconception, still evident even after learners' experience of MBL learning activities which explored this difficulty.

- *Linking the sign of the acceleration to the direction in which the object is traveling.*

Here learners suggest that if the object is traveling in a positive direction, it should have a positive acceleration. Likewise, if it's traveling in a negative direction, it should have a negative acceleration.

This misconception was represented by Option D. 11 learners demonstrated this misconception in the pre-test. This decreased to 2 in the post-test, indicating that the experience of an MBL learning programme consisting of learning activities which allowed learners to explore this difficulty, probably had a positive impact on learner understanding of this difficulty.

8.3.5 Hypotheses C1

> *As a result of working through a series of MBL learning activities, learners are more able to choose graphs which describe the variation over time in the kinematic quantity, rather than graphs which resemble the shape of the path that the object takes.*

Questions C1.1 and C1.2 were used to test this hypothesis. Question C1.1 appeared as Question 14 in the pre-test and as Question 9 in the post-test. Question C1.2 appeared as Question 5 in the pre-test, and as Question 13 in the post-test. The matrices illustrating learner performance in relation to these questions, are shown below:

Difficulty C1

Pre-test

Question 14 (C1.1)	Question 5 (C1.2)																	
		Ai	Aii	Aiii	Aiv	Bi	Bii	Biii	Biv	Ci	Cii	Ciii	Civ	Di	Dii	Diii	Div	NA	Row Tot
	Ai																		0
	Aii																		0
	Aiii																		0
	Aiv																		0
	Bi														1				1
	Bii																		0
	Biii																		0
	Biv									1									1
	Ci																		0
	Cii																		0
	Ciii		1																1
	Civ																		0
	Di	1	1				1			6				3		1			13
	Dii																		0
	Diii			1			1							2					4
	Div																		0
	NA																		0
	Col Tot	1	2	1	0	0	2	0	0	7	0	0	0	5	1	1	0	0	n = 20

Post-test

Question 9 (C1.1)	Question 13 (C1.2)																	
		Ai	Aii	Aiii	Aiv	Bi	Bii	Biii	Biv	Ci	Cii	Ciii	Civ	Di	Dii	Diii	Div	NA	Row Tot
	Ai																		0
	Aii																		0
	Aiii																		0
	Aiv																		0
	Bi																		0
	Bii																		0
	Biii																		0
	Biv																		0
	Ci																		0
	Cii																		0
	Ciii																		0
	Civ																		0
	Di			1						10		4		1	1				17
	Dii									1									1
	Diii									1					1				2
	Div																		0
	NA																		0
	Col Tot	0	0	1	0	0	0	0	0	12	0	4	0	1	2	0	0	0	N = 20

Figure 8.12: Set of matrices for difficulty C1.

Analysis of the matrices for this hypothesis reveals the patterns and information shown in the table and graph below.

	Pre-Test	Post-Test
Little understanding	6	1
Some understanding	8	9
Substantial understanding	6	10

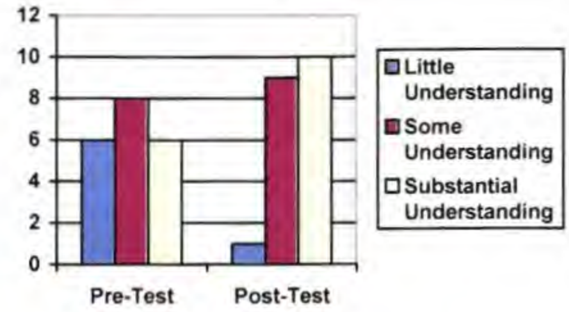


Fig. 8.13 Table and graph showing changes in understanding in relation to difficulty C1.

8.3.5.1 Discussion of results

The number of learners showing little understanding in relation to this difficulty decreased from 6 to 1, the number of learners showing some understanding increased from 8 to 9, and the number of learners demonstrating substantial understanding increased from 6 to 10. On this basis, it can be accepted that the computer-based learning experience resulted in improved ability to choose graphs which describe the variation over time in the kinematic quantity, rather than graphs which resemble the shape of the path that the object takes.

8.3.5.2 Examining student responses to Question C1.1 more closely

Di represented the correct choice for this question. Seventeen learners were able to choose Option D for this question in the pre-test, with 13 of them choosing the appropriate Reason i as well. This improved to all twenty learners selecting the correct Option D in the post-test, with seventeen of the learners selecting the appropriate Reason i as well. Interestingly here, none of the learners selected Option A, which represented the graph-as-picture problem, where the graph was the same shape as the slope on which the object was travelling.

Prevalent misconceptions and/or difficulties demonstrated in responses to question C1.1 in the pre-test and/or post-test

- *Linking the magnitude of the acceleration to the magnitude of the velocity.*

Here learners suggested that the acceleration of an object was increasing because it's going faster and faster, or decreasing because the object was going slower and slower, or is uniform because the object is traveling at the same speed.

In the pre-test, 5 learners demonstrated this difficulty through their choice of Reason iii to support their answer to Question C1.1. This decreased to 2 learners in the post-test.

8.3.5.3 Examining student responses to Question C1.2 more closely

Ci represented the appropriate choice and reason for this question. In the pre-test, 7 learners were able to choose Option C, with all 7 choosing the appropriate Reason i as well. In the post-test 15 learners were able to choose Option C, with 11 of the learners choosing the appropriate Reason i as well.

Prevalent misconceptions and/or difficulties demonstrated in responses to Question C1.2 in the pre-test and/or post-test

Option D represented a significant difficulty for learners. In the pre-test, 7 learners opted for this graph, which was a straight-line s/t graph passing through the origin. Two possible reasons can be proposed to explain why learners chose this option initially.

- *Graph-as-picture problem: Choosing graphs which resemble each other.*

Learners may have difficulty distinguishing between different types of motion graphs, and so chose an s/t graph which has the same shape as a v/t graph for the motion described.

- *Graph-as-picture problem: Choosing graphs which resemble the path of the motion.*

Learners may be choosing a graph which resembles the path of the motion, in this case, the ball-bearing would follow a straight-line path downwards towards the earth, and so learners choose graphs which are straight lines – in this case Graph B and Graph D.

These problems seem to have been reduced as a result of participation in the MBL learning programme, since, in the post-test, 1 learner opted for B, and 3 opted for D.

8.3.6 Hypotheses C2

> *As a result of working through a series of MBL learning activities, learners are more able to choose graphs which describe the variation over time in the kinematic quantity, rather than graphs which resemble each other.*

Questions C2.1 and C2.2 were used to test this hypothesis. Question C2.1 appeared as Question 11 in the pre-test and as Question 7 in the post-test. Question C2.2 appeared as Question 4 in the pre-test, and as Question 16 in the post-test. The matrices illustrating learner performance in relation to these questions, are shown below:

Difficulty C2

Pre-test

Question 4 (C2.2) by Question 11 (C2.1)

	Ai	Aii	Aiii	Aiv	Bi	Bii	Biii	Biv	Ci	Cii	Ciii	Civ	Di	Dii	Diii	Div	NA	Row Tot
Ai										1				2				3
Aii														1		1		2
Aiii							1			3				2		1		7
Aiv																		0
Bi																		0
Bii			1															1
Biii							1											1
Biv																		0
Ci							1											1
Cii																		0
Ciii																		0
Civ																		0
Di																		0
Dii	1						3											4
Diii						1												1
Div																		0
NA																		0
Col Tot	1	0	1	0	0	1	6	0	0	4	0	0	0	5	0	2	0	n = 20

Post-test

Question 16 (C2.2) by Question 7 (C2.1)

	Ai	Aii	Aiii	Aiv	Bi	Bii	Biii	Biv	Ci	Cii	Ciii	Civ	Di	Dii	Diii	Div	NA	Row Tot
Ai						1												1
Aii														2				2
Aiii										3				9	1			13
Aiv																		0
Bi																		0
Bii	1																	1
Biii														1				1
Biv																		0
Ci														1				1
Cii																		0
Ciii																		0
Civ																		0
Di																		0
Dii																		0
Diii														1				1
Div																		0
NA																		0
Col Tot	1	0	0	0	0	1	0	0	0	3	0	0	0	14	1	0	0	n = 20

Figure 8.14 Set of matrices for difficulty C2.

Analysis of the matrices for this hypothesis reveals the patterns and information shown in the table and graph below.

	Pre-Test	Post-Test
Little understanding	10	2
Some understanding	8	9
Substantial understanding	2	9

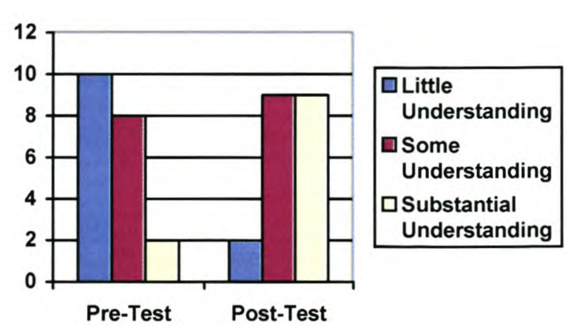


Figure 8.15 Table and graph showing changes in understanding in relation to difficulty C2.

8.3.6.1 Discussion of results

The number of learners demonstrating little understanding in relation to this difficulty decreased from 10 to 2, learners showing some understanding increased from 8 to 9, while those showing substantial understanding increased from 2 to 9.

This indicates that MBL learning experiences resulted in an improvement in learner ability to choose graphs which describe the variation over time in the kinematic quantity, rather than choosing or drawing graphs which resemble each other.

8.3.6.2 Examining student responses to Question C2.1 more closely

Aiii represented the correct choice for this question. In the pre-test, 12 learners were able to choose Option A, with 7 learners choosing the appropriate Reason iii as well. In the post-test, 16 learners were able to choose Option A, with 13 choosing the appropriate Reason iii as well.

Prevalent misconceptions and/or difficulties demonstrated in responses to question C2.1 in the pre-test and/or post-test

- *Graph-as-picture problem: Choosing graphs which resemble each other.*

Option D seemed to present a significant difficulty for some learners, since 5 learners selected this option in the pre-test. The graph in this option was an a/t graph which had an identical shape to the v/t graph on which the question was based. The MBL learning experience seemed to have a positive impact on this difficulty, since only 1 learner opted for this choice in the post-test.

8.3.6.3 Examining student responses to Question C2.2 more closely

Dii represented the correct choice and reason for this question. Seven learners selected Option D in the pre-test, with 5 of them being able to select to appropriate Reason ii as well. These figures increased significantly to 15 learners being able to select Option D in the post-test, with 14 of them selecting the appropriate Reason ii as well.

Prevalent misconceptions and/or difficulties demonstrated in responses to Question C2.2 in the pre-test and/or post-test

- *Graph-as-picture problem: Choosing graphs which resemble the path of the motion.*

Seven learners selected Option B, which showed a v/t graph going up and then down. For these learners, this graph probably represented the actual picture in their minds of the pathway that lifts follow in real-life scenarios i.e. up and down. Their choice of reason (6 of the seven learners here chose Reason iii which suggested that the lift goes up at a constant velocity, stops and then comes down with the same constant velocity) seems to bear this out.

This difficulty seemed to be minimized by the experience of the MBL learning programme, as only 1 learner selected this option in the post-test.

8.3.7 Hypotheses D1

As a result of working through a series of MBL learning activities, learners are more able to use appropriate features to interpret the graph, rather than attempting to use more obvious and perhaps inappropriate features of the graph.

Questions D1.1 and D1.2 were used to test this hypothesis. Question D1.1 appeared as Question 3 in the pre-test and as Question 16 in the post-test. Question D1.2 appeared as Question 16 in the pre-test, and as Question 15 in the post-test. The matrices illustrating learner performance in relation to these questions, are shown below:

Difficulty D1

Pre-test

Rows: Question 3 (D1.1); Columns: Question 16 (D1.2)

	Ai	Aii	Aiii	Aiv	Bi	Bii	Biii	Biv	Ci	Cii	Ciii	Civ	Di	Dii	Diii	Div	NA	Row Tot
Ai																		0
Aii					1										1			2
Aiii											1							1
Aiv																		0
Bi											1							1
Bii																		0
Biii					2	1									1			4
Biv																		0
Ci					1		1								9			11
Cii																		0
Ciii																		0
Civ								1										1
Di																		0
Dii																		0
Diii																		0
Div																		0
NA																		0
Col Tot	0	0	0	0	4	1	1	1	0	0	2	0	0	0	11	0	0	n = 20

Post-test

Rows: Question 8 (D1.1); Columns: Question 15 (D1.2)

	Ai	Aii	Aiii	Aiv	Bi	Bii	Biii	Biv	Ci	Cii	Ciii	Civ	Di	Dii	Diii	Div	NA	Row Tot
Ai																		0
Aii						1									1			2
Aiii																		0
Aiv																		0
Bi																		0
Bii																		0
Biii		1			3	1			1						1			7
Biv																		0
Ci						2					1				7			10
Cii											1							1
Ciii																		0
Civ																		0
Di																		0
Dii																		0
Diii																		0
Div																		0
NA																		0
Col Tot	0	1	0	0	3	4	0	0	1	0	2	0	0	0	9	0	0	n = 20

Figure 8.16: Set of matrices for difficulty D1.

Analysis of the matrices for this hypothesis reveals the patterns and information shown in the table and graph below.

	Pre-Test	Post-Test
Little understanding	14	13
Some understanding	4	4
Substantial understanding	2	3

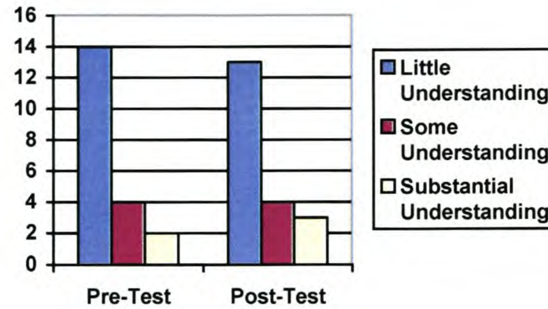


Figure 8.17: Table and graph showing changes in understanding in relation to difficulty D1.

8.3.7.1 Discussion of results

In the pre-test 14 learners demonstrated little understanding in relation to this difficulty. This improved marginally to 13 in the post-test. The number of learners showing some understanding remained constant at 4 on both the pre-and post-test, while the number of learners demonstrating substantial understanding increased marginally from 2 in the pre-test to 3 in the post-test.

The results demonstrate no significant change in understanding of learners between the pre-test and the post-test. It appears as if the MBL learning experience had essentially no effect on learner ability to focus on appropriate features of the graph when describing aspects of the object's motion.

8.3.7.2 Examining student responses to question D1.1 more closely

Biii represented the appropriate choice and reason for this question. In the pre-test, 5 learners were able to select Option B, and four of the five selected the appropriate Reason iii as well. In the post-test, 7 learners were able to select Option B, with all 7 selecting the appropriate Reason iii as well. It seems as if the MBL learning experience had a marginal effect on learner performance on this question.

Prevalent misconceptions and/or difficulties demonstrated in responses to Question D1.1 in the pre-test and/or post-test

- *Focusing on inappropriate (and attention-grabbing) features when interpreting the graph, in this case the intersection point of two graphs that cross each other.*

12 learners selected Option C in the pre-test, with 11 of these learners selecting Reason i. This choice focused on the point of intersection between the two graphs. Instead of using the gradient of the graph to make comparisons between the speed of the two objects, students focused on the point of intersection, and interpreted this as being a point where the objects have the same speed.

In the post-test, 11 learners selected Option C, with 10 of them selecting Reason i, indicating that the experience of the MBL learning programme had little impact on this difficulty.

8.3.7.3 Examining student responses to Question D1.2 more closely

Bi represented the appropriate choice and reason for this question. In the pre-test, 7 learners were able to select Option B, with 4 of these learners selecting the appropriate Reason i as well. In the post-test, 7 learners selected Option B; with 3 learners selecting the appropriate reason i as well. The experience of the MBL learning programme seemed to have no effect on learner performance on this question.

Prevalent misconceptions and/or difficulties demonstrated in responses to question D1.2 in the pre-test and/or post-test

- *Focusing on inappropriate (and attention-grabbing) features when interpreting the graph, in this case the intersection point of two graphs that cross each other.*

The choice represented by Option D proved to be a significant difficulty for learners. Eleven learners selected option D on the pre-test, with all 11 using Reason iii to support their choice. So, rather than using change in height of an s/t graph to determine the distance the two objects covered in a particular time, these students focused on the point of intersection of the two graphs, and suggested that the objects have covered equal distances up to this point.

Nine learners selected the same option in the post-test, indicating that the MBL learning experience had a minimal effect on this difficulty.

8.3.8 Hypotheses D2

As a result of working through a series of MBL learning activities, learners are more able to identify that a negative slope in an s/t graph means that the object is moving in a negative direction, rather than meaning the object is slowing down.

Questions D2.1 and D2.2 were used to test this hypothesis. Question D2.1 appeared as Question 7 in the pre-test and as Question 6 in the post-test. Question D2.2 appeared as Question 13 in the pre-test, and as Question 11 in the post-test. The matrices illustrating learner performance in relation to these questions, are shown below:

Difficulty D2

Pre-test

	Question 13 (D2 2)																	
Question 7 (D2 1)	Ai	Aii	Aiii	Aiv	Bi	Bii	Biii	Biv	Ci	Cii	Ciii	Civ	Di	Dii	Diii	Div	NA	Row Tot
Ai																		0
Aii														1				1
Aiii									2			1		1				4
Aiv																		0
Bi							2								1			3
Bii									1		1			2				4
Biii																		0
Biv																		0
Ci														1				1
Cii																		0
Ciii																		0
Civ															1			1
Di							1											1
Dii									1									1
Diii							2		1					1				4
Div																		0
NA																		0
Col Tot	0	0	0	0	0	0	5	0	5	0	1	1	0	6	2	0	0	n = 20

Post-test

	Question 11 (D2 2)																	
Question 6 (D2 1)	Ai	Aii	Aiii	Aiv	Bi	Bii	Biii	Biv	Ci	Cii	Ciii	Civ	Di	Dii	Diii	Div	NA	Row Tot
Ai							3											3
Aii							1				1							2
Aiii						1	3		5	1				1				11
Aiv																		0
Bi																		0
Bii														2				2
Biii							1											1
Biv														1				1
Ci																		0
Cii																		0
Ciii																		0
Civ																		0
Di																		0
Dii																		0
Diii																		0
Div																		0
NA																		0
Col Tot	0	0	0	0	0	1	8	0	5	1	1	0	0	4	0	0	0	n = 20

Figure 8.18: Set of matrices for difficulty D2.

Analysis of the matrices for this hypothesis reveals the patterns and information shown in the table and graph below.

	Pre-Test	Post-Test
Little understanding	13	9
Some understanding	5	6
Substantial understanding	2	5

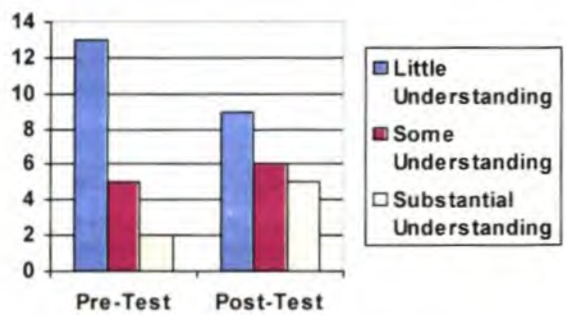


Figure 8.19: Table and graph showing changes in understanding in relation to difficulty D2.

8.3.8.1 Discussion of results

In the pre-test 13 learners demonstrated little understanding in relation to this difficulty. This decreased to 9 in the post-test. The number of learners showing some understanding changed from 5 in the pre-test to 6 in the post-test, while the number of learners demonstrating substantial understanding increased from 2 in the pre-test to 5 in the post-test.

The results demonstrate a slight improvement in understanding of learners between the pre-test and the post-test, however not enough to completely accept the hypothesis relating to the difficulty tested. Thus, it cannot be claimed with complete confidence that the learners are more able to identify that a negative slope in an s/t graph means that the object is moving in a negative direction, rather than meaning the object is slowing down, as a result of their MBL learning experiences.

8.3.8.2 Examining student responses to Question D2.1 more closely

Aiii represented the correct choice and reason for this question. Five learners were able to select Option A in the pre-test, with four of these learners choosing the appropriate Reason iii as well. In the post-test, 16 learners were able to choose Option A, with 11 of these learners selecting the appropriate Reason iii as well. Learners thus demonstrated significant improvement in this question over the two tests, as a result of their experience of the MBL learning programme.

Prevalent misconceptions and/or difficulties demonstrated in responses to Question D2.1 in the pre-test and/or post-test

- *A negative gradient for an s/t graph means that the object is slowing down.*

Learners displayed this misconception through their selection of Options B and D, both implying that this was the case. Seven learners selected Option B and 6 learners Option D in the pre-test, so a total of 13 learners demonstrated this misconception in the pre-test. In the post-test, these figures dropped to 3 learners selecting Option B, and no learners selecting Option D, indicating a substantial improvement in learner understanding of this difficulty as a result of their participation in the MBL learning programme.

8.3.8.3 Examining student responses to Question D2.2 more closely

Ci represented the correct choice for this question. In the pre-test, 7 learners were able to select Option C, with 5 of these learners selecting the appropriate Reason i as well. These figures remained the same for the post-test, seemingly indicating that the MBL learning experience had no effect on learner understanding in this area.

Prevalent misconceptions and/or difficulties demonstrated in responses to Question D2.2 in the pre-test and/or post-test.

- *Focusing on inappropriate (and attention-grabbing) features when interpreting the graph, in this case the intersection point of the graph with the x-axis.*

A number of learners suggested that the object is stationary at the point where the s/t graph touches or crosses the x-axis. This difficulty was represented by Option B. Five learners selected this option in the pre-test and 9 in the post-test, indicating that it is a strong area of difficulty, with the experience of the MBL learning activities actually appearing to have compounded this difficulty.

- *A negative gradient on an s/t graph means the object is slowing down.*

This difficulty was represented by Option D. Eight learners demonstrated this difficulty in the pre-test, and four in the post-test, thus suggesting a small gain in understanding in relation to this difficulty as result of learner experience of the MBL learning activities.

The improvement here is not as large as that observed in the responses to Question D2.1 above, where the same difficulty was evident. This can possibly be explained by the fact that the graph in this case actually touched the x-axis whereas the graph in D2.1 did not. So the difficulty discussed above (point at which graph touches indicates a point where the object is at rest) is probably a dominant misconception here, and is overriding/conflicting with learning understanding of negative gradient in an s/t graph to mean movement in the negative direction. These learners probably reasoned that if point Y indicates a point where the object comes to a stop, then it must have been slowing down in order to do that.

8.4 Statistical tests of the significance and nature of the shifts in understanding in relation to each hypothesis

8.4.1 Testing the significance of learner shifts in understanding using a Stuart-Maxwell analysis

How significant are the shifts in understanding in relation to each of the eight hypotheses which were set up, and which have been captured in the results that are presented in this chapter? What is the likelihood that the observed changes in learner understanding with regard to the eight hypotheses set up, occurred purely by chance (they are entirely independent of one another), or can they be explained by other factors, in this case probably learner experience of the MBL-based learning programme?

To answer this question, a Stuart-Maxwell Test (Stuart, 1957; Maxwell 1970; Everitt, 1977), a chi-squared test for matched pairs with more than two outcomes or categories, was carried out on the 'shifts in understanding' results observed over the pre- and post-test, for each of the eight hypotheses that were set up.

The Stuart-Maxwell Test is a useful statistical test for testing the significance of observed changes (in this case observed shifts in understanding) for small sample sizes, when there are three categories being tracked. It allows for the determination of significance of change, through a calculation of the p-value.

The p-value is "the probability that a particular result would occur by chance if H_o is true." (Howell, 1995: 230.)

The following null hypothesis was set up and tested for the changes in understanding observed here:

H_o: The shifts in levels of understanding demonstrated by learners over the pre- and post-tests, in relation to each of the eight hypotheses, occurred purely by chance, i.e. the scores calculated for different levels of understanding in relation to each hypothesis in the post-test and the scores calculated for different levels of understanding in relation to each hypothesis in the pre-test, come from identical population of learners.

Tables used to capture possible shifts in understanding for each learner, and then for the group, in relation to each of the hypotheses, as well as computed p-value for the results, can be found in Appendix 13.

A summary of the p-values computed for each of the hypotheses is shown in the table below:

Table 8.2: Summary of calculated p-values using the Stuart-Maxwell Test.

Hypothesis	p-value
A1	0.67958
A2	0.02458
B1	0.02773
B2	0.01034
C1	0.04137
C2	0.00469
D1	0.76593
D2	0.31308

Since the p-values computed for hypotheses A2, B1, B2, C1 and C2 are below 0.05, it means that the shifts observed in relation to these hypotheses are statistically significant at the 5% level of significance. This means that the shifts in understanding observed in relation to these hypotheses have a 5% or smaller probability of having occurred by chance, and thus must have been caused by other factors, in this case the MBL learning experience.

The same cannot be said of hypotheses A1, D1 and D2. The p-values for these are substantially higher than 0.05, meaning that the null hypothesis in relation to these hypotheses cannot be rejected with confidence.

8.4.2 Identifying the nature of learner shifts in understanding using McNemar's Test

The Stuart-Maxwell test allowed for the determination of significance of change in learner understanding, as measured through performance on the pre- and post-tests. Since there are three categories of understanding under consideration here, there are several possibilities of change, both in the direction of improved and decreased understanding. It's possible to use a McNemar test (Agresti, 1990; Cramer, 1997; Somes, 1983) to obtain some idea about the nature of the change that took place **for those hypotheses** where the Stuart-Maxwell showed the changes to be significant i.e. hypotheses A2, B1, B2, C1 and C2.

The McNemar test "compares the frequencies of a dichotomous variable from two related samples of cases. These two samples may consist of the same or matched cases tested on two occasions or receiving two treatments." (Cramer, 1997: 140.)

In this particular case, the dichotomous variable being tracked is level of understanding demonstrated in two cases, a pre-test and a post-test for the same sample of learners. It also results in the computation of a p-value, which can be used to describe the significance of change.

Because this test tracks changes between two categories, the three categories of learner understanding were collapsed into each other to form two categories. Two possible scenarios, which resulted in **improved understanding**, were investigated, with the intention being to check if the significant changes shown by the Stuart-Maxwell Test, were changes which resulted in improved understanding:

- The categories 'Little Understanding' (LU) and 'Some Understanding' (SO) are combined to form a single category LU/SO, and the other category 'Substantial Understanding' (SU) formed the second category. The McNemar Test was used to test the significance of the change from LU/SO to SU.

- In the second scenario, 'Little Understanding' formed one category, and the categories 'Some Understanding' and 'Substantial Understanding' where combined to form a single category SO/SU.

The McNemar Test was used to test the significance of the change from LU to SO/SU.

The McNemar p-values for these scenarios for each of the hypotheses where significant change was shown to take place using the Stuart-Maxwell Test are shown in the table below. The data from which these p-values were computed can be found in Appendix 13.

Table 8.3: Summary of calculated p-values using the McNemar Test

Hypotheses	Change in understanding from LU/SO to SU	Change in understanding from LU to SO/SU	Conclusion
A2	p = 0.248	**p = 0.023**	The p-value for the change from **LU to SO/SU** is less than 0.05, thus it **is statistically significant.**
B1	p = 0.023	**p = 0.070**	The p-value for the change from **LU/SO to SU** is less than 0.05, thus it **is statistically significant.**
B2	**p = 0.013**	p = 0.134	The p-value for the change from **LU/SO to SU** is less than 0.05, thus it **is statistically significant.**
C1	p = 0.134	p = 0.131	The value for p for both cases is greater than 0.05, thus both changes are statistically insignificant.
C2	**p = 0.023**	**p = 0.013**	The p-value for **both changes** is less than 0.05, thus **both are statistically significant**.

Thus, in the cases of hypotheses A2, B1, B2 and C2, significant changes in understanding identified through the use of the Stuart-Maxwell Test, have been shown to be significant in the direction of improved understanding (either from LU/SO to SU, from LU to SO/SU, or both), using the McNemar Test.

C1 in this McNemar analysis shows an insignificant change for both cases considered. If the results of the Stuart-Maxwell Test for hypothesis C1 are revisited (see Table 8.2), it can be seen that although the p-value calculated there shows a significant change, this judgment can just barely be made as the calculated p-value is very close to 0.05.

When a multiple comparison is attempted using the McNemar Test, it is not possible to detect the difference that may exist between the two cases of changes in understanding considered. So for C1, it is possible to say that a significant change in understanding occurred (based on the results of the Stuart-Maxwell Test) but not possible to be able to identify the nature of the change (based on the results of the McNemar Test).

8.4.3 Summary of statistical analysis

The results of the statistical analysis described here corresponds with and seems to reinforce observations made as a result of the matrix analysis carried out earlier in this chapter, where it was seen that the MBL experience seemed to have had a bigger positive impact on learner understanding in relation to areas of difficulty B and C (see Sections 8.3.3, 8.3.4, 8.3.5 and 8.3.6), lesser impact on understanding in area A (see Sections 8.3.1 and 8.3.2), and almost no impact in area D (see Sections 8.3.7 and 8.3.8).

8.5 'Alternative learner ideas' and difficulties displayed by this group of learners in their responses to the questionnaire

The 'alternative learner ideas' and/or difficulties that were made evident through the item and matrix analysis, for the group of learners who participated in this study, are recorded on the table below. They are categorized into the four areas of difficulty described in Chapter 4 of this report.

Table 8.4: 'Alternative learner ideas and difficulties exhibited by learners in their responses to the questionnaire.

Area of difficulty	'Alternative learner ideas' or difficulties exhibited as learners worked through learning activities in the learning programme
A: **Problems associated with conceptual understanding of kinematic quantities.**	When an object covers greater successive distances in the same time period, its acceleration is increasing.
	Acceleration of a projectile is zero at its highest point, and changes as the speed of the object changes.
	For a projectile, the direction of the acceleration changes when the object changes direction.
B: **Problems associated with reference points, sign convention and negative kinematic quantities.**	A positive velocity means an increasing velocity, and a negative velocity means a decreasing velocity.
	Parts of a displacement-time graph, which appear below the x-axis, indicate movement in an opposite direction to that for parts above the x-axis.
	Linking the sign of the acceleration to the magnitude of the velocity.
C: **Graph translation and transformation difficulties.**	Graph-as-picture problem - Choosing graphs which resemble each other.
	Graph-as-picture problem: Choosing graphs which resemble the path of the motion.
D: **Graph interpretation difficulties.**	Focusing on inappropriate (and attention-grabbing) features when interpreting the graph, in this case the intersection point of two graphs that cross each other.
	Focusing on inappropriate (and attention-grabbing) features when interpreting the graph, in this case the intersection point of the graph with the x-axis.
	A negative gradient for an s/t graph means that the object is slowing down.

8.6 Observations about the overall impact of the MBL learning experience on learner understanding in relation to the four areas of difficulty in kinematics and kinematic graphs

Overall, it was clear that the MBL learning experience had a positive impact on learner understanding of kinematics and kinematic graphs. The 24.1% average increase in marks over the pre- and post-tests provided evidence of this, as well as the fact that of the eight hypotheses set up for testing, learners demonstrated improved understanding in relation to six of them.

- Learners demonstrated largely improved levels of understanding in relation to Hypotheses B1, B2, C1 and C2.
- Learner understanding improved, but to a smaller extent, in relation to Hypotheses A1 and A2.
- Very little or no improvement in understanding was demonstrated by learners in relation to Hypotheses D1 and D2.

How can this pattern of development of learner understanding be explained?

It appears as if more significant gains in learner understanding were made in relation to the difficulties described by Category B (problems associated with reference points, sign convention difficulties and difficulties dealing with negative kinematic quantities), and Category C (graph translation and transformation difficulties). The MBL technology is particularly strong in the areas that these two difficulties rely on. It is a simple matter for learners to manipulate the technology in order to set up different reference points and reference directions, and to observe the effects that this has on graphical representation of the motion in real time. A number of the activities in the learning programme allowed them to do this, and this probably contributed to development of understanding in relation to Category B.

The ability of the technology to capture details of the motion and to represent it in the form of a graph in real time allows learners to immediately make comparisons and connections between the actual motion and its graphical representation. Concrete links can be made between the nature of the motion, and the way it is represented as an s/t, v/t and/or a/t graph. The technology also has the ability to allow display of the three sets of graphs (s/t, v/t and a/t) for a particular motion at the same time on the screen, and analysis tools allow learners to make comparisons between various points on the three graphs. Again, learners had a number of opportunities to do this as they participated in the learning activities, and this probably contributed to development of understanding in relation to Category C.

Learners demonstrated smaller improvements in understanding in relation to Category A (problems related to conceptual understanding of kinematic quantities). This result and observation raises a question: Do learners need a strong conceptual grasp of the meaning of different kinematic quantities before they can make sense of their representation in graphical form, or can experience with graphical representations of a quantity lead to development of understanding in relation to that quantity? This study was not designed to provide an answer to this question, and it is probably a key question which could form the focus of another study in this area. It was clear in this study however, that experience with graphical representations of various quantities led to improved understanding of the quantities for some learners (who may already have possessed sufficient background knowledge to allow them to engage with the graphical representations of the quantities), but for other learners (who may not have possessed sufficient background knowledge to allow them to engage with the graphical representations of the quantities), smaller or no gains were made.

And what of Category D (graph interpretation difficulties)? Learners demonstrated very little development of understanding in relation to hypotheses D1 and D2. The following issues could have impacted on the results observed here:

- This is probably the highest level of engagement with graphs for learners and thus requires that many of the misconceptions and difficulties described in the other categories be minimized or removed if learners are to engage successfully at this level. Interpretative skills require that learners draw on a rich background of sound knowledge, which they are able to integrate if they are to interpret features of the graph successfully.

- In a similar fashion that concepts can be understood at successively high cognitive levels, a hierarchy of misconceptions may exist, with more dominant, and more resistant misconceptions overriding gains in understanding made with others. This was possibly demonstrated in learner responses to Question D2.1 and D2.2 which asked learners to consider similar graphs. However, an important difference was that in the case of D2.2, the s/t graph actually intersected the x-axis and thus created an attention-focusing feature, which learners interpreted as being a point where the object stopped. Understanding about a negative s/t gradient meaning movement in the negative direction, which learners demonstrated in Question D2.1, was not evident in their responses to Question D2.2, probably because the difficulty around interpretation of what it means when the s/t graph intersects the x-axis.

- Misconceptions/difficulties around attention-focusing features of graphs seem to be particularly resistant to change. In an examination of student responses to a physically observed motion rather than a graphical representation of motion, Trowbridge and McDermott refer to this phenomenon as students' tendency to 'focus attention on the perceptually obvious phenomenon...' (Trowbridge and McDermott, 1981:1023.)

This emphasizes the role of the visual impact of graphs on the conclusions/decisions/understandings that learners reach. It's almost as if, for learners, the visual input and impact of the graphical representation overrides/over-shadows the necessity for engaging in higher level cognitive or interpretive processes in order to make sense of the graph. In this sense, the visual representation and impact of the graph may be a drawback that actually hinders learning.

It also suggests that areas of learner understanding in relation to kinematics and kinematic graphs are not independent of each other. Misconceptions and or difficulties in understanding in one area will have a negative influence on understanding in other areas.

Thus misconceptions and difficulties in other areas related to graphs will act as a learning barrier in this area, and this is probably what has been observed here.

- The MBL technology used in this study had interpretive tools like the *tangent line gradient function*, the *examine data* function, the *integration function* and the *regression line function.* The learning activities in the learning programme required learners to use some of these features. However, use of these features requires a high level of familiarity with computers and knowledge of the MPLI programme itself. This could also have acted as a barrier working against the development of learner understanding in this area. More one-on-one interaction between learner and computer, obviously requiring in-depth knowledge of the software may help to overcome this barrier.

- Exposure to general MBL learning activities may not be enough to overcome all difficulties related to kinematics and kinematics graphs. MBL learning experiences should thus not be viewed as an easy cure-all for learner difficulties in this area. Attention has to be paid to the nature of the difficulty and activities designed to specifically target the difficulty (for example – the activity where two graphs capturing the motion of two objects can be simultaneously displayed for observation, analysis and interpretation). It may not be the case that learners achieve an overall understanding of kinematics and kinematics graphs through some type of 'osmotic' process as a result of their participation in MBL learning activities. Rather, specific activities have to be designed to target and develop understanding in specific areas.

- Attention may also need to be paid to the sequence of activities learners work through to ensure that misconceptions in a possibly more 'foundational' area, that may act as barriers to the development of understanding in another potentially more complex area, are dealt with first in order to facilitate learning in the more complex area. More attention is paid to this element in the recommendations made in the concluding chapter of this report.

This discussion illustrates that MBL technology can be an effective tool for enhancing learner understanding of kinematics and kinematic graphs, but there are potential barriers that can limit the success of its use. Minimizing these barriers will make the technology an even more effective teaching and learning tool.

8.7 Linking theories about the nature of learners' ideas and of concept learning to these observations

8.7.1 The nature of learner ideas

The observations made in this study and discussed in 8.4.2 above seem to agree with descriptions of the nature of learners' ideas made by various theorists, in particular:

- **that they are stable and can be very tenacious and resistant to change** (Driver *et al.*, 1985:3; Treagust, 1988:16; Hewson and Thorley, 1989:541). This study seems to indicate that some ideas in a particular area may be more resistant than others. For example, difficulties related to graphical interpretation (Area D) seemed more resistant than difficulties associated with graphical transformations and translations (Area C).

- **that they can appear to be incoherent** (Driver *et al.*, 1985:3). A learner may respond in a scientifically acceptable fashion in one situation, but in a similar context which may have an added dimension, reverts to a simplistic or contradictory explanation. In this study, this was observed when learners were able to come to suitable conclusions about the meaning of a negative s/t graph in one question, but when a similar question included the added dimension of the graph intersecting the x-axis, many learners reverted to a simplistic and erroneous response. These types of responses may be typical of learners who are at a particular stage in their understanding of a concept or idea. They may have a partial but not yet fully developed understanding of the idea, and so respond erratically in situations where this understanding needs to be used.

- **that they are universal** (Panse *et al.,*1994:64). The majority of learner ideas demonstrated here in response to questions on the test are similar to difficulties documented in other studies in this area, which were described in chapter 4 of this report.

In addition, the study seems to indicate that learner ideas may be:

- **Influential and interdependent** – difficulties in one area can create significant barriers to learning in another area.

- **Hierarchical in nature** – the development of understanding in a more complex area e.g. graphical interpretation, is dependent on learners having developed suitable levels of understanding in more foundational areas, e.g. a conceptual understanding of the various kinematic quantities.

8.7.2 Levels of development

Piaget's contention that development occurs in stages may provide a framework for explaining the observation that gains in understanding were clearly evident in Categories B and C, and to a smaller extent, Category A of the areas of difficulty, but Category D difficulties proved particularly resistant. This may be because learners were capable of operating at the 'concrete operations' stage, and ability at this level was sufficient for the challenges posed by Category A, B and C difficulties. Category D difficulties may require the ability to operate at a 'formal operations' level, which few of the learners were capable of doing.

Klausmeier's (1992) Concept Learning and Development theory uses a similar developmental approach. In his framework, learners at the 'classificatory level' can "recognize two items as being equivalent or not" – a key skill required for graph transformation and translation exercises. So learners who have developed understanding of kinematics and kinematics graphs at the 'classificatory level' may be able to overcome challenges associated with Category A, B and C difficulties. For Klausmeier, a key ability in order to develop understanding of concepts at the 'formal level' is the ability to carry out "a set of inductive processes that include hypothesizing, evaluating and inferring, or a set of meaningful reception operations that include processing and correctly using the given information". Learners may lack this ability and thus have difficulty overcoming the challenges posed by Category D difficulties.

CHAPTER 9

Results and analysis of data derived from the ethnographic exploration of learning during use of a TRAC PAC-based learning programme

This chapter reports on the analysis of data gained through observations made and information gathered as part of the ethnographic component of this project. As described previously, five learners of the group of twenty formed the focus group for this part of the study. Their learning progress (or lack thereof) made through the process was documented in detail using pre- and post-test questionnaires, pre- and post- learning programme group interviews, video and audio recordings, as well as observations I made as learners participated in the programme. Data in the form of test response sheets, interview transcripts, and a combined video, audio and observational transcript, were analyzed with a view to identifying behaviors and processes associated with learning (and non-learning), as learners participated in the MBL learning programme.

Firstly, what can be called a 'shifts in understanding' method of analysis was used to determine levels of understanding particular learners in the focus group reached, in relation to the eight conceptual difficulties chosen. The information gained here generated questions which were used to support, and in some ways, guide a 'verbal analysis' approach to analyzing the data. This, in turn, provided insight into the behaviors and processes associated with learning and non-learning as a result of learners participating in the microcomputer-based learning programme.

9.1 Analyzing 'shifts in understanding'

The test responses of the five learners in the focus group were analyzed individually, using what can be termed a 'shifts in understanding' method of analysis to identify the development (or non-development) of understanding of the learners in specific relation to the eight hypotheses or difficulties set up.

The following eight tables were generated to work out the levels of understanding individual learners reached in relation to the eight hypotheses set up, as a result of participation in the learning programme. As described earlier in this report:

- A judgment of 'substantial understanding' was made when the learner was able to select the appropriate answer and supporting reason for both questions related to that difficulty.
- A judgment of 'some understanding' was made when the learner was able to choose the appropriate answer and supporting reason for one of the two questions related to that difficulty.
- A judgment of 'little understanding' was made when the learner was unable to respond correctly to either of the two questions related to that difficulty.

Table 9.1: Levels of understanding demonstrated by learners in relation to difficulty A1.

	Pre-test			Post-test		
	Question A1.1	Question A1.2	Level of understanding demonstrated	Question A1.1	Question A1.2	Level of understanding demonstrated
Mondli	√	x	Some	√	x	Some
Craig	x	√	Some	√	√	Substantial
Thandeka	x	x	Little	√	x	Some
Nelisiwe	x	x	Little	x	√	Some
Kevin	√	√	Substantial	√	√	Substantial

Table 9.2: Levels of understanding demonstrated by learners in relation to difficulty A2.

	Pre-test			Post-test		
	Question A2.1	Question A2.2	Level of understanding demonstrated	Question A2.1	Question A2.2	Level of understanding demonstrated
Mondli	√	x	Some	√	x	Some
Craig	√	x	Some	√	√	Substantial
Thandeka	√	x	Some	√	√	Substantial
Nelisiwe	x	x	Little	x	x	Little
Kevin	x	x	Little	√	√	Substantial

Table 9.3: Levels of understanding demonstrated by learners in relation to difficulty B1.

	Pre-test			Post-test		
	Question B1.1	Question B1.2	Level of understanding demonstrated	Question B1.1	Question B1.2	Level of understanding demonstrated
Mondli	x	√	Some	x	√	Some
Craig	√	√	Substantial	√	√	Substantial
Thandeka	√	x	Some	√	x	Some
Nelisiwe	x	√	Some	x	x	Little
Kevin	x	x	Little	√	x	Some

Table 9.4: Levels of understanding demonstrated by learners in relation to difficulty B2.

	Pre-test			Post-test		
	Question B2.1	Question B2.2	Level of understanding demonstrated	Question B2.1	Question B2.2	Level of understanding demonstrated
Mondli	x	x	Little	√	√	Substantial
Craig	√	x	Some	√	√	Substantial
Thandeka	√	x	Some	√	√	Substantial
Nelisiwe	√	√	Substantial	√	√	Substantial
Kevin	√	x	Some	√	√	Substantial

Table 9.5: Levels of understanding demonstrated by learners in relation to difficulty C1.

	Pre-test			Post-test		
	Question C1.1	Question C1.2	Level of understanding demonstrated	Question C1.1	Question C1.2	Level of understanding demonstrated
Mondli	√	√	Substantial	√	√	Substantial
Craig	√	√	Substantial	√	√	Substantial
Thandeka	√	x	Some	√	√	Substantial
Nelisiwe	x	x	Little	√	x	Some
Kevin	√	x	Some	√	√	Substantial

Table 9.6: Levels of understanding demonstrated by learners in relation to difficulty C2.

	Pre-test			Post-test		
	Question C2.1	Question C2.2	Level of understanding demonstrated	Question C2.1	Question C2.2	Level of understanding demonstrated
Mondli	√	x	Some	√	√	Substantial
Craig	√	x	Some	√	√	Substantial
Thandeka	√	x	Some	√	√	Substantial
Nelisiwe	√	x	Some	x	√	Some
Kevin	x	x	Little	√	√	Substantial

Table 9.7: Levels of understanding demonstrated by learners in relation to difficulty D1.

	Pre-test			Post-test		
	Question D1.1	Question D1.2	Level of understanding demonstrated	Question D1.1	Question D1.2	Level of understanding demonstrated
Mondli	√	x	Some	√	x	Some
Craig	x	x	Little	√	√	Substantial
Thandeka	√	x	Some	√	√	Substantial
Nelisiwe	x	x	Little	√	x	Some
Kevin	√	x	Some	√	x	Some

Table 9.8: Levels of understanding demonstrated by learners in relation to difficulty D2.

	Pre-test			Post-test		
	Question D2.1	Question D2.2	Level of understanding demonstrated	Question D2.1	Question D2.2	Level of understanding demonstrated
Mondli	x	√	Some	√	x	Some
Craig	√	√	Substantial	√	√	Substantial
Thandeka	x	x	Little	√	√	Substantial
Nelisiwe	√	x	Some	x	x	Little
Kevin	√	x	Some	√	√	Substantial

The data represented on these tables was then used to construct the following pictures of 'shifts in learner understanding' for each of the five learners in the focus group, in relation to each of the eight difficulties identified.

The following key is applicable to the pictures:

● Level of understanding at start of programme.
■ Level of understanding at end of programme.
↑ Shift in understanding.

The fraction next to each learner's name represents the ratio of the number of positive shifts the learner actually made in relation to the number of positive shifts the learner was required to make, in order to reach a classification of 'substantial understanding' for all eight areas. Next to it is the fraction expressed as a percentage.

SU = Substantial Understanding
SO = Some Understanding
LU = Little Understanding

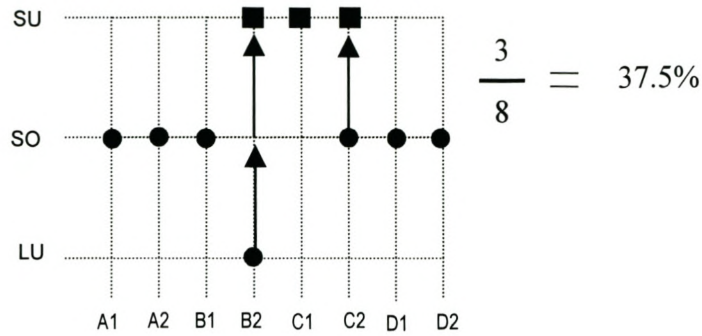


Figure 9.1: 'Shifts in understanding' for Mondli.

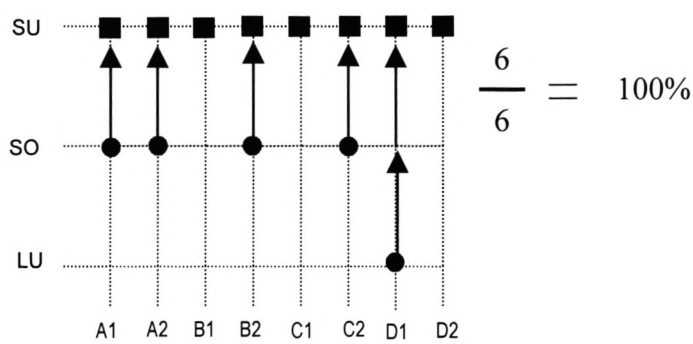


Figure 9.2: Shifts in understanding for Craig.

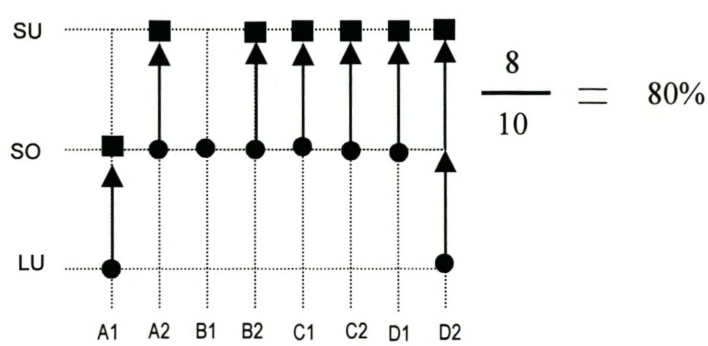


Figure 9.3: Shifts in understanding for Thandeka.

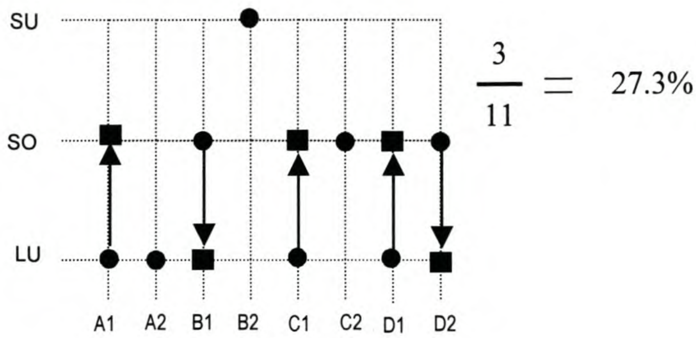


Figure 9.4: Shifts in understanding for Nelisiwe. (Note that this representation shows that she actually regressed in relation to two of the difficulties! This was the only case where this was observed.)

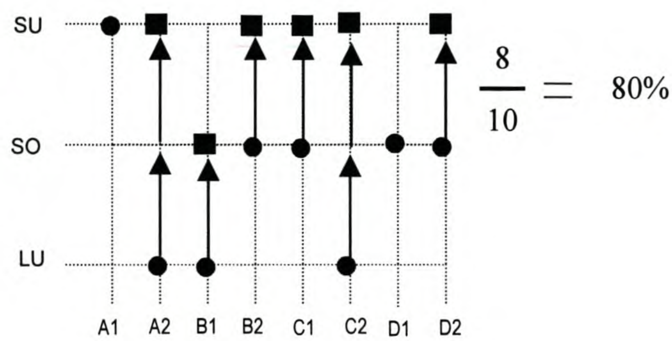


Figure 9.5: Shifts in understanding for Kevin.

These ways of representing the data allowed me to make the following observations and ask the following questions. These questions could then be used to guide further and more detailed analysis of the data:

- All the learners made some gains in understanding but some were more successful than others. The learning experience was most beneficial for Craig, Thandeka and Kevin, who respectively made 100%, 80% and 80% of the shifts required, and thus could be classified as 'successful learners' in this context. The learning experience was less beneficial for Mondli, who made 37.5% of the shifts required, and thus can be classified as a partly-successful learner in this context; and Nelisiwe, who made 27.3% of the shifts required and can thus be classified as an 'unsuccessful learner' in this context. What aspects of the learning experience could have contributed to this? What behaviours and processes can be associated with the learners who demonstrated differing gains in levels of understanding? Particularly, what, if any, were the differences in the behaviors demonstrated between learners who showed no improvement (the 'unsuccessful learner'), some improvement (the 'partly successful' learner), and those who showed significant improvement (the 'successful learners')?

The method of 'verbal analysis' was used in an attempt to answer these questions.

9.2 Verbal Analysis

'Verbal analysis', a method described by Chi (1997), was used as a basis for the analysis of data in this phase of the study. In keeping with the research approach taken in this study, this method of analysis "integrates elements of qualitative and quantitative analyses so that the interpretation of the results is less subjective" (Chi, 1997: 272). Learner utterances, verbalizations and gestures are the foundational units of analysis in this method, and are viewed as a reflection of the learners' thinking and learning processes, and existing knowledge structures. Thus, following a learner's verbalizations over time may provide a 'window' into if, how and why the learner's knowledge structures change over time.

The verbal analysis method has been described as follows:

> In verbal analysis, one tabulates, counts and draws relations between the occurrences of different kinds of utterances to reduce the subjectiveness of qualitative coding. Verbal analysis

> has been used, for example, to code explanations of what one understands as one reads a text sentence-by-sentence, to see whether an explanation is an inference, a monitoring statement, or some other irrelevant comment. (Chi, de Leeuw, Chiu, and LaVancher, 1994, described in Chi, 1997: 273.)

Eight functional steps make up the method, some of them optional.

1. Reducing or sampling the protocols.
2. Segmenting the reduced or sampled protocols (sometimes optional).
3. Developing or choosing a coding scheme or formalism.
4. Operationalising evidence in the coded protocols that constitutes a mapping to some chosen formalism.
5. Depicting the mapped formalism (optional).
6. Seeking patterns in the mapped formalism.
7. Interpreting the pattern(s).
8. Repeating the whole process, perhaps coding at a different grain size (optional).

(Chi, 1997: 283)

The paragraphs which follow describe the steps which have been used in this study and also describe how they have been used.

9.2.1 Reducing or sampling the protocols

Typically, the data collected in an ethnographic approach, such as the one embarked on in this project, tend to be quite voluminous. For example, the verbal, video and observational data collected in this project amounted to about 3 days (18 hours) worth of learning time which generated 135 pages of transcript data, plus learner artifacts in the form of questionnaires, written interview responses and workbook responses. It would have been very difficult if not impossible, to analyze all of this data at the level described by the method, and thus portions of the data have been selected for the analysis. Protocols for analysis were selected on the basis of the contribution they could make to the integrity of the findings related to the data being analyzed, and on the basis of the type of analysis being conducted. Data was analyzed at three 'grain' levels, which I have described as a '**Learner Involvement**' level of analysis, a '**Processes of Interaction'** level of analysis, and an '**Alternative Learner Ideas and Difficulties'** level of analysis. These provide insights from different perspectives on learning in the programme. Protocols were selected which would contribute most meaningfully to the grain level of analysis being conducted. The protocols used for each level of analysis are described in the section in this chapter which deals specifically with that level.

9.2.2 Segmenting the protocols

This involves breaking down, where necessary, the protocols that have been selected, into units of analysis that can be more easily manipulated. In this project, learners were involved in a learning programme comprising of 6 learning activities which themselves were comprised of several somewhat stand-alone tasks which the learners had to work through. For example, most activities contained an **introductory task** which was predictory in nature, followed by a **computer-based experiment task** which asked learners to conducts experiments and make observations, followed by an **analysis task** where students had to use the observations they made to respond to specific questions and to explain the observations they made, followed finally, in most cases, by an **application task**, where learners had to apply what they had learnt to solve problems. These stand-alone tasks formed appropriate units of analysis (called an analysis segment in the transcript). The analysis segments started when a particular task started, and ended when that task ended. This method of segmentation had the added advantage in that analysis segments tended to comprise of a complete task, and thus learner verbalizations, participation and action over a complete task could be analysed.

Segmentation of the protocols into units of analysis was most easily carried out on the basis of the analysis being done. For example, in the 'coarse' grained 'Learner Involvement' level of analysis, the entire transcript of the six learning activities formed the segment or unit of analysis.

Chi also raises the possibility that in some cases with verbal analysis, it may be more appropriate to search the data rather than segment it to determine suitable protocols for analysis. "Instead, one can simply search the protocols for occurrences of the desired activity." (Chi, 1997: 289.)

This method of obtaining suitable protocols for analysis was used in the finer-grained 'Processes of Interaction' analysis and 'Alternative Learner Ideas and Difficulties' analysis. For these levels of analysis, the 'desired activity' was identified as instances when the learners explored/exhibited 'alternative learner ideas' as they worked through the MBL activities. Segments of the transcripts where this happened were used as the protocols for these levels of analysis.

9.2.3 Choosing a coding scheme or formalism, and operationalizing evidence for coding

These steps of the method involves firstly deciding on categories or formalisms for coding of the data, and then deciding how a particular utterance or verbalization fits into a particular category or formalism. These steps were used in the 'Processes of Interaction' levels of analysis. Further information about the categories or formalisms used can be found when this level of analysis is discussed in Section 9.5 of this report.

Chi (1997: 291) identifies two potential problems that can arise regarding the coding of data:

- Ambiguity – How can one be certain that the classification ascribed to a particular verbalization is the correct one? This will always be an area of concern in studies like this. Measures taken to ensure consistency in categorization included using 'processes' as categories for coding which had fairly clearly-defined characteristics were being coded, categorizing a selection of segments several times to check if the same categorization was allocated, and requesting other people to categorise selections of segments, to compare the categorizations they allocated with my own.

- Context – How many lines of interaction before and after the verbalization being coded should be considered? In this study, this issue arose when the verbalization could not be coded with confidence by using it alone. I generally read as far up and as far down the protocol as was necessary to confidently code the verbalization. Where this happened, a general description of '5 lines up, 5 lines down' would cover most of the cases where clarification was needed. In cases where the verbalization could not be coded, it was classified as an 'unclassified utterance' (UU).

9.2.4 Depicting the mapped formalism

The analyses here used tables, graphs and interaction outlines as graphic organizers to depict the mapped formalisms.

9.2.5 Seeking patterns and coherence in the depicted data

The mapped formalisms in each case were scrutinized in an attempt to identify and document patterns and themes that possibly existed in them.

9.2.6 Interpreting patterns and their validity

The patterns demonstrated through the representation of the various formalisms were interpreted in relation to the research questions.

9.2.7 Repeating the whole process

In essence, the process was repeated three times, for each of the levels or 'grain sizes' of analysis. In the context of this study, 'Learner Involvement' was analyzed at a 'coarse' level of analysis, and 'Processes of Interaction' and 'Alternative Learner Ideas and Difficulties' were analyzed at a 'finer level' of analysis.

For each of these levels, the data that was analyzed in them and the findings that this led to, are described in the next three sections (Sections 9.3, 9.4 and 9.5) of this report.

9.3 'Learner Involvement'

It's a common perception that the degree of learner involvement in learning activities impacts directly on his/her learning in the activities. This analysis, at a very 'coarse' level, attempted to verify if this was the case for this small group of learners involved in an MBL learning programme. The entire transcript record over six activities (three days or approximately 18 hours of group work) was used as the protocol for this coarse grain level of analysis. The degree of learner verbalizations, as captured in the transcripts, was used as an indicator of learner involvement in the activity. It is my belief that this is a reliable indicator since much of the verbalizations and utterances recorded in the transcripts involved 'concept talk' – learners talking about the concepts being explored, or 'procedural talk' – learners talking about how the group or individuals should function in order to carry out the learning activity. A very small amount of learner talk unrelated to the learning activities was captured on the transcripts.

Key questions which guided this level of analysis included:

- What was the extent of learner involvement in the various activities?
- Are there any significant differences in the amount of learner involvement, as measured through verbal interactions, between successful and less successful learners?
- Can any patterns be identified regarding learner involvement over the course of the programme?

To start, the number of learner verbalizations was computed for each of the six activities over the three days of the learning programme. These are recorded on the table below.

Table 9.9: Learner involvement per activity, as measured by the number of verbalizations, for each of the six activities.

	Activity 1	Activity 2	Activity 3	Activity 4	Activity 5	Activity 6	
Mondli	130	67	82	41	64	30	414
Craig	173	81	92	118	125	71	660
Thandeka	147	67	93	184	160	73	724
Nelisiwe	80	55	51	97	95	23	401
Kevin	90	46	92	179	201	82	690
	620	316	410	619	645	279	**2889**

Using the figures in Table 9.9, the ratio of verbalizations per learner across the whole programme to the total verbalizations of all the learners across the six activities was computed. This is reflected as a percentage in Table 9.10. Figure 9.6 is a bar chart of the percentage interactions, and percentage 'shifts in understanding' for each learner.

	% interactions	% 'shift in understanding'
Mondli	14.3	37.5
Craig	23	100
Nelisiwe	13.8	27.2
Thandeka	25	80
Kevin	23.8	80

Table 9.10: % interactions and % 'shifts in understanding' for each learner.

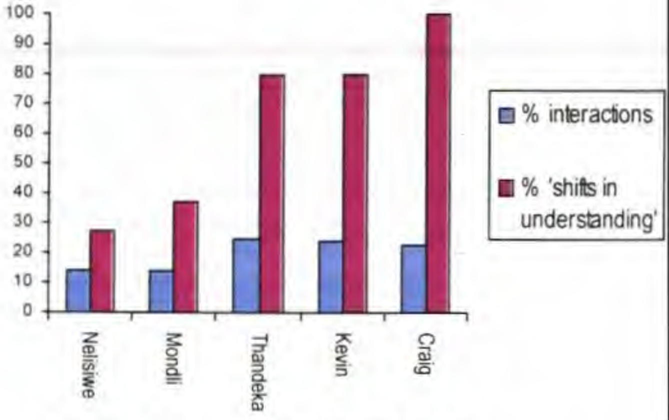


Figure 9.6: Bar chart of the % interactions and % 'shifts in understanding' for each learner.

An interesting pattern emerged. It appears that, for this small group, and in agreement with common perceptions, learners who enjoyed a higher degree of interactions in the small group setting also displayed greater learning success in the programme. Nelisiwe and Mondli, who were described as 'unsuccessful' and 'partly successful' learners respectively, each enjoyed less than 15% of the group's total interactions, while the 'successful' learners all enjoyed 23% or more of the group's interactions. The trends discussed here, are a result of a surface or coarse analysis of the data, and do not indicate anything about the quality of the interactions different learners were involved in. More insight into this can be gained from the 'Processes of Interaction' analysis which follows in the next section of this report.

When the learner involvement trends are subjected to deeper scrutiny, further interesting patterns are noted. Table 9.11 shows the learner involvement per activity, as measured by the amount of verbalizations, expressed as a percentage of the total verbalizations for the activity. Figure 9.7 is a bar chart representing these percentages.

Table 9.11: Learner involvement per activity, as measured by the amount of verbalizations, expressed as a percentage of the total for each activity.

	Activity 1	Activity 2	Activity 3	Activity 4	Activity 5	Activity 6
Mondli	20.9	21.2	20	6.6	9.9	10.8
Craig	27.9	25.6	22.4	19	19.4	25.4
Thandeka	23.7	21.2	22.7	29.7	24.8	26
Nelisiwe	12.9	17.4	12.4	15.7	14.7	8.2
Kevin	14.5	14.6	22.4	29	31.1	29.4

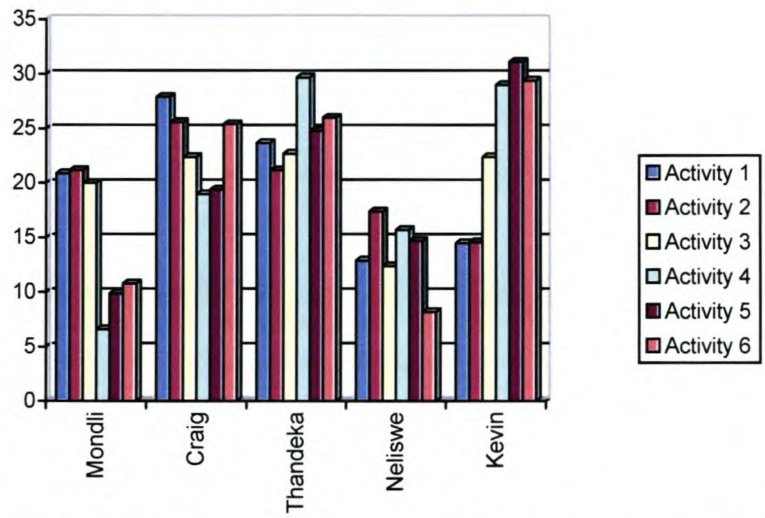


Figure 9.7: Bar chart of learner involvement per activity, as measured by the amount of verbalizations, represented as a percentage of the total amount of verbalizations for each activity.

Craig and Thandeka, who were successful learners in the context of this small group, demonstrated a consistently high amount of involvement in the interactions of the group over the duration of the learning programme. Nelisiwe, who was an unsuccessful learner, demonstrated a consistently low amount of involvement in the interactions of the group over the duration of the learning programme. Mondli and Kevin are two interesting cases. Mondli, a partly successful learner in this context, initially enjoyed a high degree of participation in the interactions of the group, but this decreased significantly as the learning programme progressed. Conversely, Kevin, a successful learner in this context, initially demonstrated a low degree of involvement, which increased significantly as the learning programme progressed.

For the five learners involved, there seems to be a correspondence between levels of involvement (as measured by the number of interactions), and learner success in the programme. Learners, who were more extensively involved, also showed greater learning gains in the programme.

I would like to propose the following hypotheses in an attempt to explain the patterns being observed here, based on observations made as a participant observer in the learning programme:

a. That Mondli's decrease in involvement in the interactions of the group were a result of the social dynamics that developed in this small group context. These social dynamics served to negate or limit his participation in the group, and that this had a negative impact on his learning development in the group.
b. That the social dynamics that developed in the context of this small group reinforced and supported Kevin's participation in the group, and this had a positive impact on his learning development.
c. That Nelisiwe was unable to demonstrate behaviors and processes required for effective participation and effective learning in the context of small group work in science. She was unable to identify with the 'discourses' of science and science learning operating in this group. This probably accounted, in part, for her lack of learning.
d. That Craig, Thandeka and Kevin were able to demonstrate the behaviors and processes required for effective participation, and were able to identify with the 'discourses' of science and science learning operating in the group, and that this had a positive impact on their learning.

Further exploration and investigation of hypotheses a and b described above is not possible in the context of this research project, given the nature of the data that was collected. Thus, these will be areas highlighted for further research in the concluding chapter of this report.

The 'Processes of Interaction' analysis which follows in Section 9.4 of this report will provide additional insight into hypotheses c and d.

A word of caution needs to be added here. It is often the case that successful learners might not demonstrate a high degree of involvement as measured by the verbalizations they make. Some learners are naturally quieter and still manage to learn successfully in a group context like this. So, it has to be emphasized that this is a coarse level grain of analysis which nevertheless has shown some interesting patterns for this group of learners. The validity of these patterns needed to be supported (and were) by observations made in the other levels of analysis in this study.

9.4 Processes of interaction

During study of the transcripts, it became obvious learners engaged in different ways with the tasks, leading to different outcomes in terms of learning. Some of the more common ways this happened are described below.

- **Consensus and common understanding:** The learners approached the set task and came to a solution through collaborative effort. No real difficulties or alternative ideas were encountered as the group completed the task, and at the end, there seemed to be common agreement on the solution reached.

- **Learning through argumentation:** One or more learners experienced and verbalized difficulties in relation to the concept, relationship or issue being discussed. Most often, these became 'visible' in the group interactions through ideas and views that the learners voiced. Other learners picked up on the verbalization and a debate developed around it, sometimes resulting in a shift in understanding for learners involved in the debate, towards **or** away from a more acceptable scientific conception. Examples of interactions like this can be found in Appendix 11, and they will be the subject of further analysis later in this chapter.

- **Learning through discussion and explanation:** A typical case of this was when a learner voiced a particular idea not synonymous with the typical 'scientific' understanding, or when a learner admitted to not being clear about a particular area, or asked a question about a particular difficulty. The idea, admission or question is picked up and explored further by the group. The interaction took the form of a discussion rather than an argument or debate. Examples of interactions like this can be found in Appendix 12, and they will be the subject of further analysis later in this chapter.

The 'learning through argumentation' and 'learning through discussion and explanation' interactions probably offer the most potential for learning and learner construction of understanding, since it is in these interactions that alternative views are voiced, explored, discussed, defended, attacked and perhaps changed. For this reason, all the 'learning through argumentation' interactions, and 'learning through discussion and explanation' interactions that could be clearly identified in the transcripts, and which clearly have an alternative learner idea or learner difficulty as the focus of the interaction, were used as the protocols for analysis in this 'Processes of Interaction' section. In addition, the following characteristics were helpful in identifying the segments.

'Learning through argumentation' segments were generally characterized by:

- The existence of a clear claim and counter-claim.
- Learners adopting positions and arguing for that position.
- Learners attempting to provide justifications for their positions.
- Swings in the interaction from one position to the other. Learners generally take turns to make points from their respective positions.

'Learning through discussion and explanation' segments were generally characterized by:

- The exploration of an alternative idea or difficulty that one learner has voiced.
- A sense that the learner recognized it as a difficulty tended to ask questions about it and was non-confrontational.
- Other learners offered explanations why the idea may be problematic.

The following question guided this level of analysis:

- Are there any differences in the extent to which unsuccessful, less successful and successful learners demonstrated processes or behaviours related to 'learning through argumentation' and 'learning through discussion and explanation'? Can 'processes of interaction' be identified for these learners in relation to their learning? The analysis which attempted to answer this question is described in Sections 9.4.1 and 9.4.2 of this report.

9.4.1 Learning through Argumentation

Argumentation is a central process in the activities of scientists, and yet is has not been seen as a central feature of science teaching and learning, and has been relatively ignored by science education researchers until recently. In making scientific claims, theories are open to challenge and progress is made through dispute, conflict and paradigm change." (Driver *et al.*, 2000: 288.)

Contrary to this, science in the majority of South African classrooms, and probably the world, has been presented as an unproblematic, uncontroversial body of facts, and the ability of learners to engage in processes of argumentation has not been viewed as an important facet of their learning, and as an ability which could actually enhance their learning experience. Our view is that in order to participate in a scientific community students/novices need to understand how to construct substantive arguments to support their positions." (Kelly *et al.*, 1998: 853)

If we consider the science classroom to be one of the first introductions that most learners have to a 'scientific community', then effective participation in this community requires that learners are able to develop the skills of argumentation and have the opportunity to practice them in the science classroom.

Several attempts at substantive, dialogical[1] arguments occurred as learners worked through the learning activities in the MBL programme. These have been captured on the transcripts and are analysed here. I have chosen to focus on the processes of argumentation, rather than the structure of the arguments themselves, as this will provide more insight

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[1] "An argument is considered substantive when knowledge of the actual content is requisite for understanding. " (Toulmin, 1958; Strike, 1982; quoted in Kelly *et al.*, 1998: 853.)
A dialogical or 'multivoiced' argument occurs when different perspectives are being examined and the purpose is to reach common agreement. (Driver *et al.*, 2000:291.)

into the differential learning experiences of the five learners involved in the small group interactions.

Kuhn's (1993) processes of argumentation have been adapted and used as the formalisms on which coding of the learners interactions as they participated in the arguments, was based. They are "describing and justifying theories, being able to present alternative theories, being able to present counter arguments, being able to provide rebuttals." (Driver et al., 2000; 294.)

The table which follows shows the codes that have been adapted from these:

Table 9.12: Codes for analysis of argument segments.

Category of behavior	**Code used in transcript**
Making a claim	Claim
Justifying the claim	JustClaim
Making an alternative claim	AltClaim
Justifying the alternative claim	JustAltClaim
Suggesting qualifications or rebuttals.[1]	QualRebut
Asking questions about a claim or alternative claim.	QuesClaim

The coded segments of transcripts used for this analysis can be found in Appendix 11.

A first level of analysis attempted to describe the level of participation and the extent to which learners engaged in the key processes of argumentation (claiming, justifying, questioning, qualifying and rebutting claims). Instances of learner's demonstrating these processes were counted on the transcripts, and the following table was generated.

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[1] Qualifiers are statements specifying conditions under which a claim can be taken to be true, and rebuttals are statements specifying conditions when a claim will not be true.

Table 9.13: Extent of learner engagement in processes of argumentation.

	Made claims	Justified claims	Questioned claims	Qualified or rebutted claims
Mondli (partly successful learner*)	28	6	0	1
Craig (successful learner*)	22	15	4	1
Nelisiwe (Unsuccessful learner*)	9	0	0	0
Thandeka (successful learner*)	20	9	1	0
Kevin (successful learner*)	26	12	1	0

*These categorizations were described at the beginning of this chapter.

The chart below displays these figures in a graphical fashion. Learners are arranged on the chart from least successful to most successful.

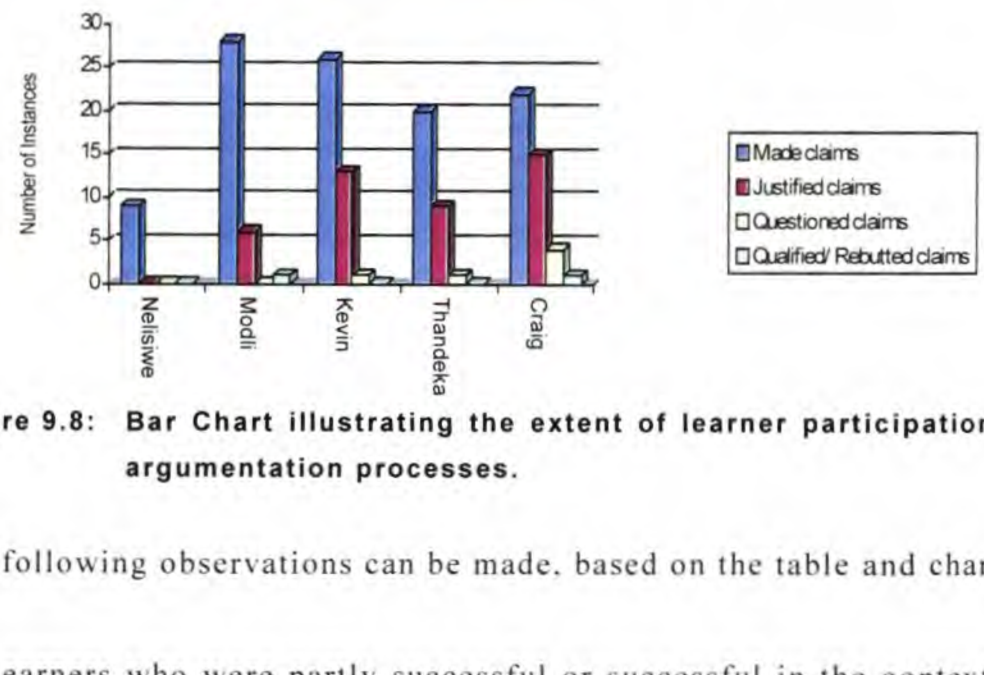


Figure 9.8: Bar Chart illustrating the extent of learner participation in argumentation processes.

The following observations can be made, based on the table and chart:

- Learners who were partly successful or successful in the context of the MBL learning programme were able to make more claims in the argumentation episodes.
- Learners who were successful in the context of the MBL learning programme were able to justify the claims they made to a greater extent.

- Questioning the claims that were made did not form a significant part of the argumentation episodes.
- Learners generally did not suggest qualifications or rebuttals to each other's claims.

It appears then, that the extent to which learners engage, and the ability they have to engage in processes of argumentation, may have a bearing on their learning success. Learners who engaged to a greater extent in terms of making claims, and justifying the claims they made also demonstrated greater learning success in the context of the learning programme. The general argumentation pattern consisted of claims and counter-claims, interspersed with justifications. Very rarely did learners question, qualify or rebut each other's claims, and were more likely to accept broad statements like, "Acceleration due to gravity is constant, 'cos gravity is constant. That's what I would say."

A second level of analysis attempted to explore the arguments in greater detail, to identify which learners were making what type of claims and to determine if learners showed shifts in their positions during the argumentation episodes.

The coded transcripts in Appendix 11 were used to generate the following table:

Table 9.14: Initial positions learners argued from, and shifts in positions.

	Originally argued from SI[1] perspective	Originally argued from AI[2] perspective	Changed from AI to SI	Changed from SI to AI
Mondli (partly successful learner*)	6	2	1	1
Craig (successful learner*)	6	1	1	1
Nelisiwe (Unsuccessful learner*)	2	3	0	0
Thandeka (successful learner*)	3	5	2	0
Kevin (successful learner*)	3	4	3	0

*These categorizations were described at the beginning of this chapter.
[1] SI - the position that is more in line with currently accepted scientific conceptions.
[2]AI – An 'alternative' learner idea that is contrary to currently accepted scientific conceptions.

Note that in almost all cases, learner entries in their workbooks suggest a movement from the 'alternative idea' to the 'scientific idea' for those learners who originally argued from an 'alternative idea' perspective. However, there is no way of knowing whether learners really adopted the 'scientific idea' or were simply 'going with the flow', and copied this information from other learners.

So, for the purpose of this analysis, a change is only recorded if the learner provided verbal evidence of it in a claim or justification for a claim, during the argumentation episode.

The information in Table 9.14 can be represented graphically as follows:

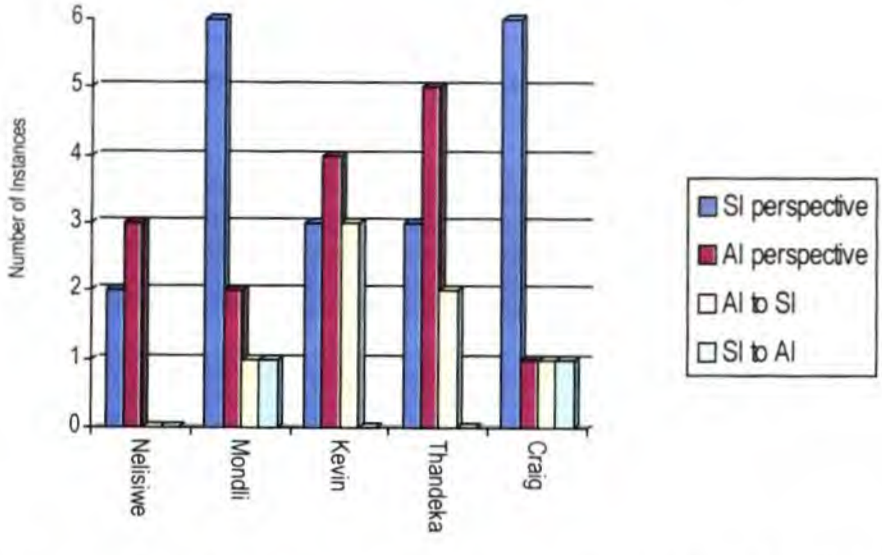


Figure 9.9: Bar Chart illustrating initial positions learners argued from, and shifts in positions.

The following observations can be made, based on the table and chart:

- Mondli and Craig argued from a 'scientific idea' perspective for 6 of the 8 argument episodes. These two learners had the highest scores in the group on the pre-test, indicating an initially greater level of understanding of kinematics and kinematic graphs than the other learners, and this could possibly explain their ability to adopt the 'scientific idea' perspective in these arguments. A key difference between Mondli and Craig, however, was the ability of Craig to provide justifications for the positions he adopted.

- Thandeka and Kevin, who were successful learners in the context of the programme, initially argued from the 'alternative idea' perspective more times than the other learners. It is possible that these argumentation episodes were fruitful for these learners as they allowed them to articulate their alternative ideas and make them visible to the other learners who could then challenge them and provide justification from the 'scientific idea' perspective, possibly leading to change and learning. This is indicated by the changes these two learners made from the 'alternative idea' perspective to the 'scientific idea' perspective, and possibly contributed to the learning gains they demonstrated.

- Nelisiwe, the unsuccessful learner, stands out again here. Although she took the 'alternative idea' position in some arguments, her participation was limited to just making the initial statement. She offered no justifications, and also showed no shifts in position.

- It was interesting to note that, although a specific learner first voiced an 'alternative idea', in most cases other learners also tended to have the same idea, supporting the view that particular 'alternative ideas', misconceptions or difficulties may be widespread amongst learners.

- Mondli and Craig seemed to shift in one of the arguments from a 'scientific idea' perspective to an 'alternative idea' perspective. This occurred in argumentation episode 5 (see Appendix 11), and resulted from a particularly forceful 'alternative idea' argument from Thandeka. Although both Mondli and Craig seemed to accept the 'alternative idea' position in the argumentation episode, Craig's written response in his workbook still indicated the 'scientific idea'. Mondli, on the other hand, recorded the 'alternative idea'. This indicates the possibility that small group collaborative work can also have negative effects, and lead to possible development of 'alternative' rather than 'scientific' ideas, particularly in areas where at least one learner in the interaction has not strongly established the 'scientific idea'.

Each of the difficulties or 'alternative ideas' that were verbalized in the argumentation episodes are explored further in Section 9.5 which follows.

9.4.2 Learning through Discussion and Explanation

The focus of this analysis was to identify the behaviors and processes learners demonstrated and/or engaged in as they participated in the discussion/explanation interactions, and to identify if there were any differences in the extent to which 'unsuccessful', 'partly-successful' and 'successful' learners engaged in these processes during the learning programme.

A similar study which surveyed the kinds of processes or behaviors which learners demonstrated as they participated in learning activities was conducted by Thornton (2004). Where possible, the observations made in that study are compared to the ones made here. The Thornton study was also carried out in an MBL context where groups of university students where involved in learning activities related to kinematics and dynamics. The Thornton study was a much larger study involving a larger sample of students but also carried out in a different context (an American context involving students at university level). It is interesting to see how the findings in the two studies compare.

The first step in the analysis involved selecting the protocols that would be used for the analysis. Segments of the transcripts where alternative learner ideas and/or difficulties were demonstrated and which were explored through discussion and explanation were identified for use. Nine of these segments were identified through learning activities 1 to 6. The next step in the analysis entailed settling on the categories of behavior or processes that would be surveyed.

A preliminary reading of the transcripts and of literature relating to learning, allowed for the identification of the processes and behaviors related to discussion and explanation, that learners were involved in, as they worked through the activities. These included:

- Making propositions, hypotheses and conclusions
- Asking questions
- Comparing and/or linking and/or using multiple representations
- Giving explanations

It should be noted that the final list of categories settled on here, resulted from starting with the initial list compiled as a result of an initial reading of the transcripts, and then refining this list as I became more familiar with the content of the transcripts. Chi (1997: 291) describes this as an interactive initially 'top-down' process and then 'bottom-up' to-and-fro process to settle on a final scheme. The categories selected for the analysis can be found in Table 9.15 below.

Table 9.15: Categories of behavior exhibited by learners in the discussion/explanation segments, together with an explanation of what each category means, and examples of utterances from the transcripts which fall into each category.

Category or formalism	Explanation and characteristics	Examples
Unclassified utterances	Verbalizations which do not fall into any other category or where learners were reading from a text, or which are unrelated to the task, or which could not be classified because they were incomplete.	*"Displacement..."* *(The learner begins this statement and there is nothing else in the context which suggests where he/she was going with it.)*
Proposing, Hypothesizing, Concluding (PHC)	This category included statements which were made as proposals or hypotheses for the group to consider, or predictions of what would happen in a particular scenario, or conclusions made. They were distinguished from explanations in that no reasons accompanied them. Characterizing indicators included phrases like, "I think...", "It will...", "It should...", "If we do this..."	*"See, it would probably be the inverse shape."* *"The shape will stay the same but the direction will change."* *(Predicting how a graph will change when the reference direction changes.)*
Comparing and/or linking and/or using multiple representations (CMR)	Making comparisons with what has been previously learnt, or with information presented elsewhere, e.g. in a different exercise or activity, in a different part/task in the same activity, in different places in the same task. For example, the learner may **compare** two parts of a graph, or one graph to another, or an observed motion to its graphical representation, or a written description to its graphical representation.	*"Well, that's what we discovered in the other... It was the mirror image.."* *(The 'other' here refers to a previous task. The learner is referring to what was learnt in that task.)* *"Okay, the first one is standing still."* *(Comparing a graph representation to the actual motion of an object.)*
Asking questions (AQ)	This included instances where learners asked conceptual questions related to the area being explored but excluded instances where questions of a technical or procedural nature were asked.	*"We didn't mix up the two all right? Reference point and reference direction?"* *Why is the acceleration negative for the whole motion?*

Explaining based on cause or principle. (EXP)	This included explanations based on cause or principle, and explanations which were attempts to support or challenge ideas. Reasons were implicitly or explicitly included in the verbalization.	*"That will be further away from the reference point... because it's above the axis."* *"If there's no gradient in a displacement-time graph, that means there's no velocity."* *(Clear reasons supplied to support the statements that were made.)*

Notes:

'Yes', 'Yah' utterances where they occurred on their own were not coded. This was because they could be ambiguous, e.g. they could be statements of agreement, they could be questions, they could be a simple utterance to encourage someone else to continue talking, etc. There had to be a phrase attached to them which provided more evidence of their nature, e.g. "Yes, I agree".

A complete record of the discussion/explanation segments used and coded for this section of the analysis can be found in Appendix 12. The number of instances each learner engaged in these processes in the discussion/explanation segments identified is shown in Table 9.16 below.

Table 9.16: Number of instances of learner engagement in behaviors/processes related to discussion/explanation.

	PHC	AQ	CMR[2]	EXP[2]	ALID[3]
Mondli (partly successful learner[1])	10	7	1	1	6
Craig (successful learner[1])	23	1	3	7	1
Nelisiwe (Unsuccessful learner[1])	4	1	0	1	0
Thandeka (successful learner[1])	31	5	4	8	4
Kevin (successful learner[1])	25	17	7	9	7

Notes:
[1]These categorizations were described at the beginning of this chapter.
[2]The CMR and EXP categories can be closely related. In many cases, learners compared multiple representations as a way of offering explanations.
[3]ALID = Alternative Learner Idea or Difficulty. In this column, the number of times specific learners ideas or difficulties were explored in the discussion/explanation segments is shown.
[4]When learners were interrupted and continued the same statement in their next turns; the combined utterances were treated as one.

The following sections highlight some of the relationships represented in this table.

9.4.2.1 Making propositions, hypotheses and conclusions

It may seem odd that these three processes are grouped together, as it can be argued that processes like making proposals or hypothesizing, and concluding possibly lie on opposite ends of the 'science processes' spectrum (Jordaan, F; personal communication, 2004).

The main reason for grouping them together here was a pragmatic one. It is difficult to distinguish between a proposal/prediction and conclusion simply based on a perusal of the transcript texts. For example, if a learner says, "It would change, it would have a negative velocity", it's hard to say if that is a conclusion the learner has come to, or a further proposal the learner is making in the context of the discussion. One clue could possibly be the stage of the discussion at which the utterance was made, but it can also be argued that learners may come to conclusions at any stage in the discussion. It is agreed that in a finer analysis it would be useful to be able to do this, but in the context of this analysis, simply knowing whether learners engaged in these collective processes will allow me to identify possible differences between successful and non-successful learners in relation to these important science processes.

Figure 9.10 below is a bar chart of the number of instances learners displayed these behaviors across the nine discussion/explanation segments surveyed.

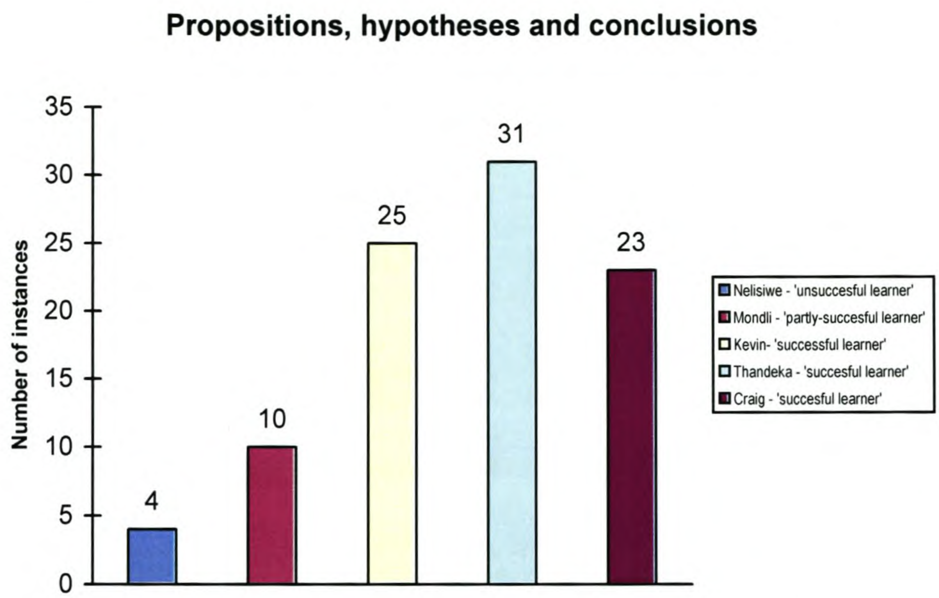


Figure 9.10: Number of instances of propositions, hypotheses and conclusions for each learner.

Learners who were most successful in the programme engaged in behavior involving proposing, hypothesizing and concluding more frequently. The 'unsuccessful' learner and 'partly successful' learner engaged in this behaviour far less frequently than the other learners.

Overall, utterances which can be classified as proposals, hypothesis and conclusions (PHCs) made up a high percentage of all the learners concept talk interactions.

These behaviors were not surveyed in the Thornton (2004) study so no direct comparison can be made here.

9.4.2.2 Asking questions

The charts below illustrate the frequencies at which different learners asked questions.

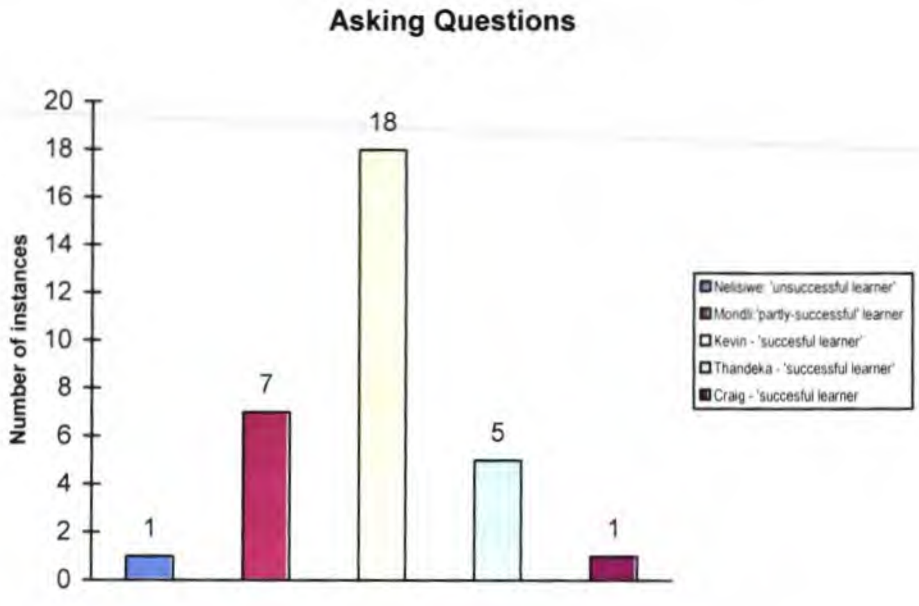


Figure 9.11: Number of questions asked by each learner.

Kevin stands out as being the most able to engage in the behavior of asking questions during the discussion/explanation interactions, followed by Mondli and Thandeka. Craig and Nelisiwe only asked one question each during the nine discussion/explanation interactions surveyed. A clear distinction between the different categories of learners is not evident here, and this led me to carry out the additional analysis which follows.

The questions were asked in the context of alternative ideas and difficulties that learners raised in the explanation/discussion segments, so it's useful to examine the rate at which learners engage in this behavior in relation to the difficulties and alternative ideas they exhibited in the discussion/explanation interactions. The chart which follows illustrates this relationship.

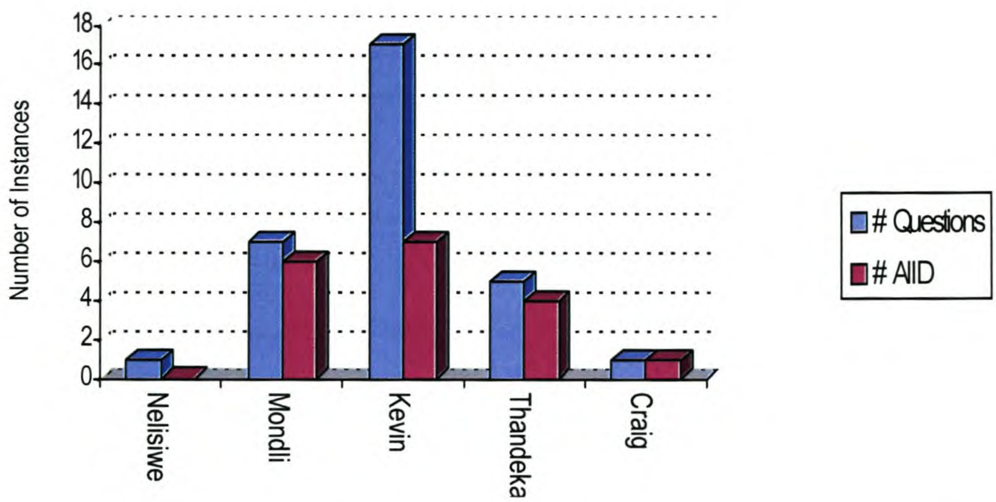


Figure 9.12 **Number of questions asked compared to the number of 'alternative ideas' or difficulties each learner demonstrated.**

Learners clearly asked questions in relation to the alternative ideas and/or difficulties they raised or encountered in the group interaction.

The 'alternative ideas' or difficulties that Kevin, Mondli and Thandeka raised formed the focus for most of the discussion/explanation interactions, and thus the questions that they were able to ask in relation to these 'alternative ideas' or difficulties account for their higher rate of questioning behaviour.

Nelisiwe's non-learning may be a result of her inability to articulate the difficulties she obviously had, and her not being able to ask questions about them.

In these interactions, Craig only demonstrated one 'alternative idea'. This was in discussion/explanation Episode 6 where he agreed with the 'alternative learner idea' suggested by Kevin, and tended to answer Kevin's questions about the idea. This was the only case in the discussion/explanation interactions where the 'alternative learner idea' remained as the one that the group seemed to accept.

So, rather than asking questions in these discussion/explanation interactions Craig was more likely to offer proposals, hypotheses, conclusions and explanations in response to the questions others raised.

Learning in the context of this small group engaged in MBL activities, seems to be related to the ability of learners to articulate or make visible the 'alternative ideas' or difficulties they have, and to their ability to ask questions about them.

Thornton's (2004) study differentiated between open and closed questions and generally found that closed questions were asked primarily by students who did not learn while open questions were asked most often by students who did. (Thornton, 2004: 7). This study did not differentiate between open and closed questions because it was observed that very few closed questions were asked. The learner who did not learn generally asked very few questions. The extent to which questions were asked seemed to be related to the alternative ideas that were made visible and explored. Learners who made their difficulties visible and participated in processes which explored them, including the asking of questions, also demonstrated learning success on the programme. In this sense, the findings here are congruent with those reported by Thornton (2004).

9.4.2.3 Comparing multiple representations

In this category of behavior, learners needed to make utterances or verbalizations in which they made comparisons with what has been previously learnt, or with information presented elsewhere, e.g. in a different exercise or activity, in a different part/task in the same activity, in different places in the same task.

Figure 9.13 is a bar chart of the instances different learners were able to do this in the nine discussion/explanation segments surveyed.

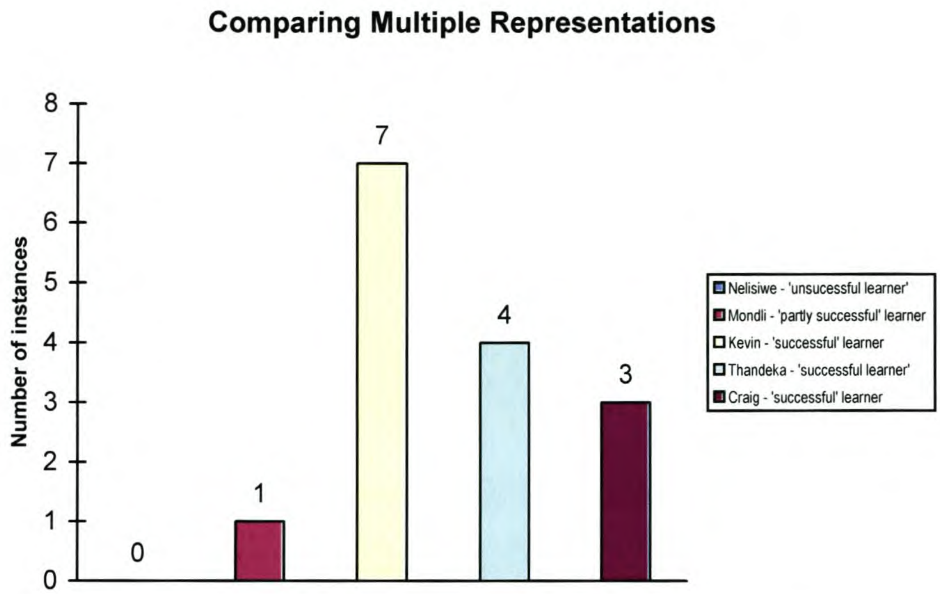


Figure 9.13: Number of instances where learners compared multiple representations in the nine interactions surveyed.

Kevin was particularly strong in this area. Many of the explanations he attempted involved getting other learners to consider graphs that they had encountered in previous exercises, in order to explain the features of current tasks that the group was working on. Generally, the successful learners were able to demonstrate the ability to compare multiple representations to a greater extent. Again, Nelisiwe, the 'unsuccessful' learner, stands out, this time through her inability to demonstrate this process.

The ability to engage in the process of comparing multiple representations, particularly, will impact significantly on learner difficulties in the area of graphical translations and transformation, and in the area of graph interpretation (Difficulty areas C and D in Appendix 5). It is expected that the learners who are able to engage in this process, will have shown development in relation to these two areas on the programme. Examination of the 'shifts in understanding' analysis diagrams in Figure 9.5 confirm that this is the case. All three 'successful' learners show positive shifts in understanding in relation to these two areas.

The same trend was reported in the Thornton (2004) study. That study found that 'successful learners are more likely to use and link multiple representations' (Thornton, 2004: 9).

9.4.2.4 Explaining

Figure 9.14 is a bar chart of the number of instances different learners made explanations in the nine segments analysed.

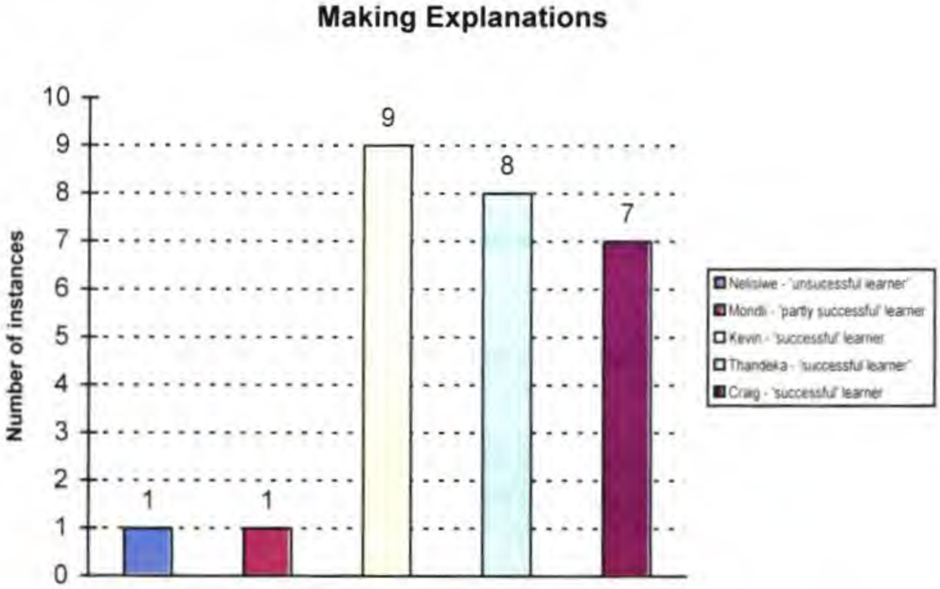


Figure 9.14: Number of instances where learners offered explanations in the nine discussion/explanation segments surveyed.

This chart illustrates that learners who were more successful in the learning programme were also able to participate in the key processes related to discussion/explanation interactions to a greater extent.

The Thornton (2004) study also found that successful learners in the MBL context were also able to provide more explanations than learners who were unsuccessful. An interesting observation made in that study, which was also the case here, and which may not be a common expectation of teachers, was that "students who do learn propose wrong and incorrect explanations" (Thornton, 2004: 8). This is highlighted as an important aspect of learner participation and learning in this context, and possibly contributes to learning in this context. This idea is explored further in the analysis which follows.

In conclusion, the fact that most of the trends in learner behavior observed here were also observed and reported in the Thornton (2004) study, lends some weight to these findings, and helps to negate a major limitation of this particular study, i.e. the small sample of learners that are the focus of this phase of the study.

9.5 Alternative learner ideas and difficulties

The analysis of the argumentation, explanation and discussion segments described in the previous section highlighted some alternative learner ideas which did not correspond with the accepted scientific view, or learner difficulties that were experienced in relation to kinematics and kinematic graphs. Arguments, debates and discussions developed as a result of some learners holding these views or displaying these difficulties.

In this section of the report, the learner ideas and difficulties demonstrated by learners in the argumentation episodes and explanation/discussion episodes are described and discussed. Interaction outlines are used to document the more important interactions in each episode. Where possible, probable sources of alternative learner ideas and difficulties are identified from the verbalizations the learners made. Finally, my observations regarding each of the interactions are described, and these are used at the end of this analysis to compile a summary of factors that seem to impact on learning for this group of learners in an MBL environment.

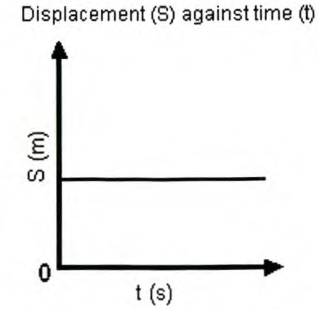
Key questions which guided this level of analysis included:

- What alternative ideas and/or difficulties did learners in the focus group demonstrate as they participated in the argumentation episodes and in the discussion/explanation episodes?
- Can probable sources of these ideas be identified from the verbalizations made by the learners?
- Can any insights about learning in the context of this small group working in an MBL environment be gained from learner interaction in these episodes?

9.5.1 Alternative learner ideas and difficulties visible in the argumentation episodes

- *Inability to recognize that the x-axis represents the reference point in an s/t graph.*

This difficulty was articulated by Mondli and is explored in argumentation episode 1 in Appendix 11. The group was attempting to interpret the graph alongside, and then describe the motion which this graph represents. For this graph, the reference point was 1.5m away from the sensor, and the direction away from the sensor was designated to be the positive direction.



Thandeka started the debate by suggesting:

81. Thandeka: Ok the first one is standing still.

Mondli agreed that it was standing still but suggested that this was because it was at the reference point.

82. Mondli: Yah, because it's....at the...
84. Mondli: ...at the reference point.

Craig disagreed with him:

85. Craig: That will be further away from the reference point... because it's above the axis.

Mondli was still not convinced:

86. Mondli: No ... stand still at the reference point...for a certain time... a certain amount of time.

Nelisiwe, Craig and Thandeka provided further justifications for their position:

88. Nelisiwe: ...move positively and then stand still at that point.

89. Craig: Yah .... Stand ahead of the reference point ... beyond the reference point.

93. Thandeka: Because at the reference point the displacement will be zero.

97. Craig: Beyond the reference point... because if you're at the reference point it will be zero.

Mondli argued:

99. Mondli: No, but that... that's the reference point.

Craig and Thandeka responded:

100. Craig: The reference point is the x-axis.

104. Thandeka: If you're standing at the reference point...

106. Thandeka: ...your displacement will be zero so...

107. Kevin: Your reference point is where they describing everything. That's where you take all your information from.

108. Thandeka: Yah, so in relation to the reference point you haven't moved so your displacement is zero - get what I'm saying?

Mondli eventually seems to accept the other learners' arguments:

109. Mondli: Oh? Ok. Stand still Ok ... I get it... beyond the reference point...

Observations from this interaction:

It's difficult to identify possible sources of Mondli's 'alternative learner idea' here, since he does not provide any justifications/explanations for his idea. All that is evident is that he seems to take a straight-line graph to indicate that the object is at the reference point.

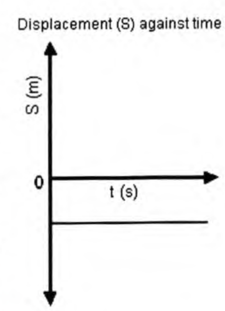
Mondli seemed to have learnt from the argumentation interaction because he provided verbal evidence of this in the interaction when he agreed with the other learners. In addition, he was able to correctly interpret similar graphs in later tasks. For example in a later task in

Activity 1, where the same graph was presented, but the reference direction was changed (towards the sensor was the positive direction), he was able to suggest:

408. Mondli: So, this is stand still between the sensor and the reference point.

The group seemed to find it quite difficult to convince Mondli. He tended to repeat himself several times without providing further justification for what he was claiming. This did not allow the other learners to gain insight into what he was thinking and thus their opposing arguments also tended to be repetitive. It was only when he indicated that he thought the line represented the reference point, that learners were able to show him otherwise, that in fact, the x-axis represented the reference point. This seemed to make a difference to his thinking.

- *Inability to use specified reference direction and sign convention to describe the displacement of an object.*



In Activity 1, the group needed to describe the motion an object would have if it was represented by the displacement-time graph alongside, given that a point 1.5m away from the sensor is the reference point, and the direction away from the sensor is positive. The interaction where this learner idea is displayed can be found in argumentation episode 2 of Appendix 11. Because it is a short interaction, it is reproduced in its entirety here:

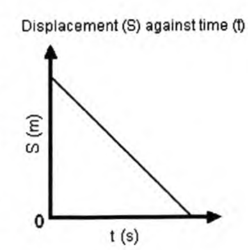
116. Thandeka: So for B...you'd have to stand still ... in front of the reference point.
117. Kevin: There's movement.
118. Thandeka: No, there's no movement.
119. Kevin: Oh, there's been no movement.
120. Nelisiwe: So you stand a few metres away...
121. Thandeka: Its only 1.5 metres.
122. Mondli: So you stand...
123. Nelisiwe: ...in front.
124. Mondli: No, you stand behind.
125. Thandeka: No you stand in front...
126. Kevin: You stand in front because it's negative as you move forward.

Observations from this interaction:

On the whole, the learners (except Kevin in this case) do not use the given sign convention to describe direction in the task i.e. that away from the sensor is positive. They use the reference point as a means of establishing direction, and use relative phrases like 'in front of the reference point', and 'behind the reference point' to describe the position of the object, rather than something more specific like 'beyond the reference point in a positive direction' or 'beyond the reference point in a negative direction'.

Another potential source of the error for Mondli is the 'graph as picture' problem. Because the straight-line graph is underneath the axis which represents the reference point, he may be reading that to mean that the object is behind the reference point.

- *Inability to distinguish between positive displacement and positive velocity (or negative displacement and negative velocity).*



This interaction occurred as learners worked through Activity 1. It is captured in its entirety in argumentation episode 3 in Appendix 11. The group was working to describe the motion of an object represented by the graph alongside. For this graph, movement away from the sensor was positive and the reference point was 1.5m away from the sensor. Initially, Kevin, Thandeka and Nelisiwe thought that the object was moving in a positive direction away from the sensor, while Mondli and Craig thought that it was moving toward the sensor.

Nelisiwe initiated the debate by asking the question:

138. Nelisiwe: Wouldn't you still be moving away but slowing down?

Thandeka and Kevin agreed with her:

139. Kevin: Still positive...
140. Thandeka: ...still positive.

Mondli and Craig thought otherwise:

141. Mondli: No move towards the reference point.
142. Craig: Yah, I agree.

In response to a 'why' question from Thandeka, Craig justified his position with the following statements:

144. Craig: 'Cos your displacement ...you're quite far away.
146. Craig: It is and you're moving towards the displacement of zero.

This convinced Thandeka to change her mind:

148. Thandeka: Oh yeah, but... So you're moving... towards the reference point...

Kevin, however remained unconvinced:

145. Kevin: It's not negative.
147. Kevin: But it's not negative...it's positive.
149. Kevin: No, you still have to move away from...
156. Kevin: Away, because it's positive. Away...

Thandeka was now able to argue from the other side to try to convince Kevin:

162. Thandeka: No look here. This is your reference point. You got to start here, and move there at a decelerating rate.

She was supported by Craig who used a sketch to support his explanation:

167. Craig: You start in the positive sector and move towards the reference point. Say then, here's your sensor ... here's your reference point. ...
169. Craig: That's your positive... that's the positive sector ...that's negative.
172. Craig: So you'd have to start here then move that way towards the reference.

This resulted in Kevin accepting their position:

174.Kevin: Move towards the sensor slowing down.

Observations from this interaction:

Kevin seemed to have a problem accepting that the object can have a positive displacement but be moving in the negative direction, thus having a negative velocity. He accepts that the positive direction is away from the reference point, and because this graph is only above the x-axis (in the positive area), he reasons that the object must be moving in a positive direction away from the reference point and thus have a positive velocity. So he links a positive displacement with a positive velocity. He does not use the negative slope of the graph as an indication that the object has a negative velocity, or the fact that the graph reaches the x-axis, indicating that the object reaches the reference point. He seems to be interpreting the s/t graph as if it were a v/t graph.

Note that there is another 'alternative learner idea' visible in this interaction – that the negative slope indicates that the object is slowing down (see Kevin's comment – speech turn 174 above). This idea is explored in more detail in the next discussion.

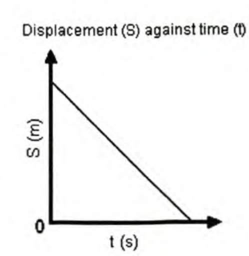
Craig seemed to recognise the source of Kevin's problem and was able to use a sketch to make a distinction between what he called 'negative and positive sectors' and direction of movement.

Nelisiwe's voice, beyond the initial question, is absent in the interaction.

It may be the case that learners can subscribe to 'alternative views' with varying degrees of commitment, or from different points in relation to initial understanding. This may make it easier for some learners to discard the 'alternative idea' more easily. This seemed to be the case with Thandeka and Kevin here.

- *A negative slope on an s/t graph means that the object is slowing down.*

Nelisiwe, Thandeka and Kevin exhibited this difficulty in Activity 1. It is captured in argumentation episode 4 in Appendix 11. Learners were working to describe the motion of an object represented by the displacement-time graph alongside.



138. Nelisiwe: Wouldn't you still be moving away **but slowing down**?
148. Thandeka: Oh yeah, but... So you're moving... towards the reference point.
150. Thandeka: (continuing from 148) ...at a **constant decelerating rate**...I'm sure that's it.
154. Kevin: **You decelerate**, moving away from... the thing.

Mondli and Craig argue that the object is not slowing down:

157. Mondli: No it's not necessarily...like... decelerating.
160. Craig: There's no acceleration or deceleration.
161. Mondli: Yah, cos it can just stop...like at a constant pace and then just stop.

Thandeka changes sides and agrees with Craig and Mondli:

175. Craig: No, it's at a constant speed.
176. Thandeka: Constant ...OK.

And Craig provides a justification for his claim:

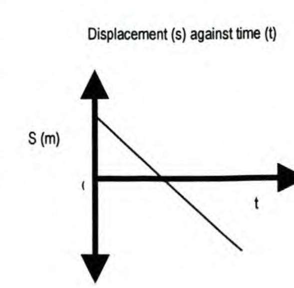
178. Craig: Yeah. This is a displacement-time graph so it's constant velocity. If it was accelerating it would be curved.

Observations from this interaction:

These learners may be confusing the graphical representations of velocity and displacement here. If this was a velocity-time graph, it would represent the motion of an object which was slowing down at a constant rate until is stopped. So, for these learners, a negative gradient is interpreted to mean that the object is slowing down, and the intersection with the t-axis probably means that the object comes to rest. It's again interesting to note that Craig seems to recognize the probable source of the other learners' confusion, and draws on it in his justification.

- *Crossing the t-axis in an s/t graph indicates that the object changes direction at that point.*

This difficulty was exhibited by Nelisiwe, Kevin and Thandeka in Activity 1. It is captured in argumentation episode 5 in Appendix 11. Learners were interpreting the motion an object would have if it was represented by the displacement-time graph alongside.



The difficulty was raised by Craig who asked a question about the direction of the object:

307. Craig: It's constant but would it be negative constant or positive constant?

Thandeka responded that the velocity:

308. Thandeka: Would change...

Mondli, on the other hand, argued that:

309. Mondli: No. It's the same velocity because the thing is...

Later in the interaction:

317. Mondli: No. It's the same direction.

Kevin and Nelisiwe agreed with Thandeka:

316. Kevin: So it would change. So it would be a negative velocity.

319. Nelisiwe: It can't be the same.

Craig tended to agree with Mondli:

324. Craig: So it will be negative...negative velocity. I think so.

But Thandeka was very forceful in her argument and suggested that:

333. Thandeka: OK guys. When you going to the reference point your velocity is positive. Once you have passed the reference point you have a negative velocity...cos you changed...direction.

and later,

342. Thandeka: (exasperated) No, see... While you walking towards the thing it's a positive velocity, and once you've gotten past you walking away from it so its changed direction so its a negative velocity.

Mondli was still not convinced and replied:

343. Mondli: But then you still going in the same direction.

Thandeka added:

344. Thandeka: No it's not the same direction. No. Listen to this... this way... you, when you're looking at the movement, with reference to you its the same direction, but reference to the reference point there's a change of direction cos its no longer moving towards, its moving away, so its changed direction... it's positive.

The argument episode ended at this point, with Thandeka's argument seemingly being accepted – one example of an argumentation episode where the 'alternative learner idea' seemed to be the one accepted by most learners at the conclusion of the episode.

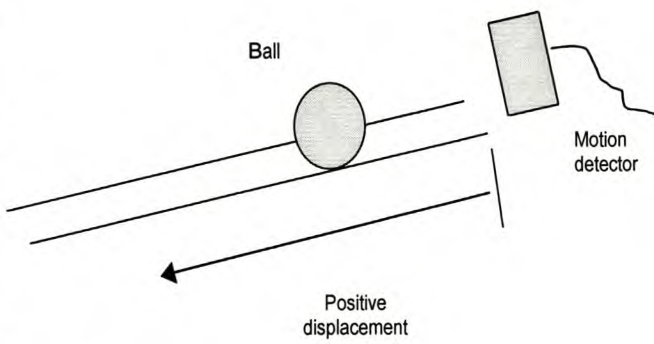
Observations from this interaction:

Thandeka seemed to give the reference point the status of a 'destination' in her argument and argued that the object travelled to the 'destination' from one direction and then away from the destination in the opposite direction. She used the reference point as a means of establishing the object's direction, not seeing the reference point as simply one arbitrary point on the straight line continuum along which the object is moving. Learners seem to expect that the reference point is essential for describing all aspects of the object's motion, and do not see its use limited to a description of the displacement of the object. They are thus inclined to want to use the reference point to describe the velocity of the object as well.

The 'alternative idea' seemed to be the generally accepted idea at the end of this particular interaction. This probably resulted from the ability of the learner (Thandeka) who was arguing for this viewpoint being able to provide forceful justification, and learners who were arguing differently (Mondli and Craig) not being able to justify their positions.

- *The acceleration of the object increases when its velocity increases and decreases when its velocity decreases.*

This 'alternative learner idea' was exhibited by Kevin in Activity 2 where the group was predicting the shape of the acceleration-time graph for an object rolling down a slope (or being dropped), given that the starting point of the ball was the reference point, and



the downward direction was positive. The interaction is recorded in its entirety in argumentation episode 6 of Appendix 11.

Mondli predicted that:

47. Mondli: Acceleration's constant so it's like a straight line.

Kevin did not agree with him and commented:

48. Kevin: But the acceleration is increasing.

Craig agreed with Mondli when he stated:

52. Craig: Constant acceleration. Gravity is always constant at ten metres per second, to the negative two that is.

Mondli reinforced his claim by stating:

53. Mondli: It's constant, yah. Even if it's a ... Even if the velocity is zero, the acceleration stays constant.

And Craig added:

54. Craig: We've only dealt with constant acceleration, so we won't get a confusing acceleration. Cos then all the other graphs would just be impossible.

This seems to be accepted by Kevin, and the group discussion continues. However, later in the interaction Kevin asks a question which indicated that he was still not convinced:

99. Kevin: Doesn't the acceleration increase?

Mondli responds:

101. Mondli: No, it's constant. It says there – constantly accelerated. It's the velocity that's like, that's like increasing.

And he is supported by Craig:

102. Craig: Yah, the velocity will be increasing due to the accelerating.
104. Craig: Acceleration due to gravity is constant, 'cos gravity is constant. That's what I would say.

Later in the activity the group are carrying out the computer-based task and generating the graphs for the motion. The a/t graph is not generated as an entirely straight line because of the loss of accuracy as the computer uses displacement to work out velocity, and then velocity to work out acceleration. This provides further 'evidence' for Kevin that his idea may be the correct one. He suggested that the graph that the group drew in their prediction exercise was wrong:

173. Kevin: Green? Green? Told you'll... I'm telling you'll the graph is wrong.

Craig and Thandeka admit to being confused by the representation as it was not what they expected:

174. Craig: It is confusing.
175. Thandeka: It is confusing.

Thandeka responds by suggesting:

177. Thandeka: Think of it this way Kevin. Once the ball is out of your hands there's only one force acting on it and that's gravity. And gravity is constant no matter where you are.

Kevin provides some insight into his thinking when he suggests:

178. Kevin: Is that acceleration or... velocity and time. If you increase velocity and the time stays the same... there will definitely be an increase in acceleration.

Later in the activity:

230. Kevin: But look here, right. Acceleration is equal to velocity over time. How can you tell me it stays the same when you increasing velocity? Then acceleration can't be... can't be staying constant. Acceleration is going to increase if the velocity increases.

Finally, Kevin seems to come to accept that the graph should be a straight line indicating a constant acceleration when he agrees with Thandeka, and with Craig who draws on the computer representation for support:

273. Thandeka: It's – it's a straight line parallel to the x-axis.
283. Craig: There it is. Above the x-axis. On the PC here.
284. Kevin: A straight line parallel to the...

Observations from this interaction:

Kevin clearly does not understand acceleration to be a measure of the rate of change of velocity, and is simply applying a learnt formula ($a = v/t$) to support his argument – perhaps an indication of his learning experience in the classroom. So, for him, if v changes then a must change as well. Thus, if velocity increases the acceleration must increase. This interaction has probably not done much for his conceptual understanding of the nature of acceleration, but may have provided him with a means to identify when acceleration should be constant, i.e. when the force causing it is constant. So he may have learnt how to use dynamic rather than kinematic reasoning for identifying the nature of the acceleration.

Other learners seem to recognize the source of Kevin's confusion – that he may be struggling with differentiating between the meanings of velocity and acceleration, and build this into their arguments to convince him. But they do not go far enough to show him that the velocity is increasing but increasing uniformly, and this is what makes the acceleration constant. Rather they argue from a causal force point of view and suggest that the acceleration is constant because the force causing it is constant, and so use a dynamics rather than a kinematics argument to convince him. A somewhat simplistic explanation is also provided which seemed to imply that all the accelerations learners will deal with will be uniform, and for this reason Kevin should accept that the acceleration is uniform.

The computer generated graph initially seemed to reinforce Kevin's misconception, as the perfect straight line that the group was expecting did not materialize. Later as the group was able to perfect their technique and obtain a more acceptable representation, the computer generated graph served as a means to convince as well.

Nelisiwe's 'voice' is absent from the dialogue.

- *The direction of acceleration is dependant on the direction in which the object is moving.*

This 'alternative learner idea' was demonstrated by Kevin as the group worked through Activity 3. It is captured in its entirety in argumentation episode 7 of Appendix 11.

The group was predicting the shape of the acceleration time graph for a ball that is rolled to and fro (from left to right) on the track shown alongside, given that the start is the reference point and forward along the track is the positive direction

Kevin was of the opinion that:

210. Kevin: But acceleration is a vector, so it should reach below the x-axis when there is a change in direction. Constant... down.
216. Kevin: First it has to be above the x-axis because it is moving in that direction...
218. Kevin: ...and then it's going to be below.... because it changes direction.

However Mondli felt:

212. Mondli: Yeah, it should be below.
219. Mondli: No. It's always below. 'Cos, look...

Craig supported Mondli when he suggested:

220. Craig: Yah. It will always be either...

Mondli provided support for his position:

221. Mondli: 'Cos it will be slowing down as it goes up and then it will be like, going faster in the opposite direction, so it's...it's still below. So it's just a straight line below.

Thandeka's idea was similar to Kevin's and she drew a sketch graph to demonstrate what she thought. Kevin agreed with the sketch.

228. Thandeka: No, guys, won't it look something like this? I'm not sure.

229. Kevin: Yah. That's what I'm trying to say it'll be.... because it changes direction.

Mondli argued:

231. Mondli: No, but then... it's accelerating in the opposite direction.
233. Mondli: ...so it can't be on top.

Kevin justified his position:

238. Kevin: But can you see over here, with the velocity – velocity is a vector. That's when you reached the x-axis...then below. So acceleration is a vector so...
240. Kevin: It changes direction.

Craig and Mondli argued:

248. Craig: But, now, it's going in the opposite direction so you gotta take that into account as well.
250. Craig: You're not increasing. You not accelerating in the same direction as you were originally. You're accelerating in the opposite direction, so it will stay below the graph.
252. Craig: It's a negative acceleration in a negative...
254. Craig: It's going faster and faster in a negative direction, not in a positive direction.
255. Mondli: If it was going slower and slower in the opposite direction, then it would be above. But it's going faster and faster.

Mondli introduced gravity as the causal force for the acceleration:

258. Mondli: So, if you're confused, just think of gravity. It's like, accelerating downwards.

This got Kevin thinking:

259. *Kevin:* But see here right...
261. *Kevin:* When you over here... over here there's no acceleration.
263. *Kevin*: And then once you reach the slope you going up, gravity is going down.
265. *Kevin:* So, won't your acceleration... ...Okay, okay, okay.

He seemed to realize that the acceleration should be negative after all, even when the ball is going up the slope, but also reserved his final judgment until the group's predicted graph was verified by the computer generated one:

268. *Kevin:* Well, we'll see if we right.
269. *Craig:* We'll see, we'll see.
270. *Mondli:* We'll see.
271. *Craig:* I reckon I am.
272. *Mondli:* Yah, me too.
276. *Craig:* And you need to give the computer a chance to be experimentally incorrect. Shall we go and do it?

Observations from this interaction:

Kevin clearly associates the direction of the acceleration with the direction of movement, rather than the direction of the force causing the acceleration, and argues that because acceleration, like velocity, is a vector quantity; its direction must change as the direction of movement changes. Initially, the arguments that Craig and Mondli made probably had no effect on Kevin because they were attempting to use direction of movement as well to justify their arguments. Craig's argument that "You're accelerating in the opposite direction..." (line 250) more likely served to support Kevin's ideas. When Mondli introduced gravity into the debate, this caused Kevin to think, and to question his idea, creating an opening for possible change.

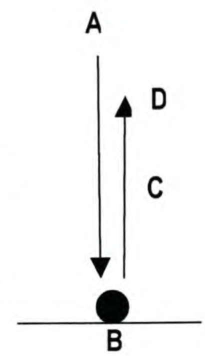
Verbal evidence from the interaction above seemed to indicate that Kevin recognized that the acceleration was a constant negative and that the force of gravity was responsible for this. His comment of "*Well, we'll see if we right*" indicated that he now grouped himself with the "we", the rest of the group, but also indicated that he was still not quite sure and wanted further information from the computer representation.

In this case, the justifications of other learners were not able to recognize and specifically target the underlying cause of the 'alternative learner idea' being challenged in the debate. Rather, the arguments they used were more likely to support the 'alternative learner idea'. It seemed as if Kevin reasoned on his own that he may be wrong, but was still not fully convinced until he saw the graphical evidence generated on the computer.

Again, Nelisiwe's 'voice' is absent from the dialogue.

- *The reference point is always the starting point of the motion.*

This 'learner idea' was demonstrated in Activity 5. It is captured in its entirety in argumentation episode 8 of Appendix 11. The group was describing the motion characteristics of a bouncing ball at various points in its motion. Here the group was considering the point B where the ball strikes the floor and describing the displacement of the ball at that point. The floor is the reference point and upwards is the positive direction.



Kevin starts off by suggesting:

457. *Kevin*: Okay, then what's it at B? Zero at that point?

Thandeka disagrees:

463. *Thandeka*: By the floor. And at B there is maximum displacement.

She is supported by Nelisiwe:

467. *Nelisiwe*: It hits the ... ground at 0.3... 0.3, that's what the displacement is.

Kevin justifies his position by referring to the graphical representation

472. *Kevin*: There's it... maximum displacement... no, no, no, no... displacement-time graph... this is your reference point... so there's no displacement.

Nelisiwe and Thandeka are not convinced:

473. *Nelisiwe*: Then Ghandi, this is not zero displacement, this is maximum displacement... maximum displacement.

476. Thandeka: Ghandi, maximum displacement.

Kevin responds:

477. Kevin: Hey now. It's on the ground.

Nelisiwe sticks to her position:

481. Nelisiwe: No, no, no, no. This is maximum displacement.

Thandeka reconsiders:

483. Thandeka: No, no... the floor is the reference

Chrstopher and Mondli agree:

484. Craig: Okay, minimum displacement...
487. Mondli: Displacement is zero.

Observations from this interaction:
Thandeka and Nelisiwe seem to argue from the point of view that the ball has traveled a maximum distance away from its starting point and thus has a maximum displacement. Implicit in their argument is the notion that the starting point is the reference point. They seem to be confusing the concepts of position and displacement. They do not provide any justification for the position they take. Kevin however is able to support his argument by drawing on a graph that the learners generated, and by pointing out where the actual reference point was. Thandeka appears to accept the argument, but there is no verbal indication from Nelisiwe. Her entry in her workbook still suggested the idea that the ball has a maximum displacement at point B.

The typical types of motion that learners encounter in their classroom experience, and the problems they are required to solve in kinematics almost always have the starting point of the motion as the reference point, creating the perception that this is always the case. This is probably a contributing cause for this 'alternative learner idea'.

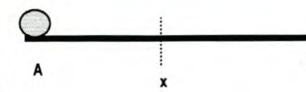
9.5.2 Alternative learner ideas and difficulties visible in the discussion/explanation episodes

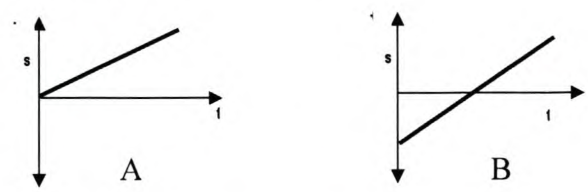
- *Inability to recognize that the x-axis represents the reference point in a displacement-time graph.*

This difficulty, experienced by Mondli, became evident as learners worked through the problem described alongside in Activity 1. The entire discussion is captured in discussion/ explanation episode 1 in Appendix 12. Extracts from the discussion here refer to Graph B.

<u>Task under discussion:</u>

Two displacement-time graphs for a ball rolling on a smooth horizontal surface with a uniform velocity between two points A and B are shown below:





Use your graphs to work out where the reference point for the motion is, and which direction has been chosen as positive. Give reasons for your answer.

Mondli thought that for Graph B, the reference point for the motion was Point B:

596. Mondli: (continuing)..Yah, and then the other one it's B.

Kevin, Thandeka and Craig did not agree with him:

600. Kevin: Uh, uh, it's x
601. Thandeka: (agreeing with Kevin) It's not. It's x.
604. Craig: The starting point is still A, but the reference point is x.

This led Mondli to ask why this was the case:

605. Mondli: No. But then how come it's x?

Kevin, Thandeka and Craig offered explanations

607. Kevin: Because there' negative to...
608. Thandeka: Because there's a change of direction now.
609. Kevin: (cont.) Yah

Mondli was still not satisfied with the response and prompted for additional explanations:

612. Mondli: So?

This prompted further explanation from Kevin:

612. Kevin: For these graphs here... (referring to the MBL graphs that they had to replicate) In order to get these graphs, you had to walk from behind the reference point towards the positive. So it has to be x because you moving from A to B, positive to negative.
616. Kevin: See. This part over here...
618. Kevin: (continuing)... you had to move from the positive through the reference point to the negative...(referring to previous example)

Mondli seems to be satisfied with the explanations and seems to accept that:

622. Mondli: X is the reference point.

Observations from this interaction:

It may be the case that Mondli believes that the reference point should be the start of the motion, and thus identifies A as the reference point in the first graph, and B as the reference in the second. The s/t representation in the second graph has a negative part, and he may be interpreting this to mean that the object is now moving in the opposite direction, from B to A.

Mondli was able to prompt further explanations from the others, and this may be an important skill that supports learning in this context.

Note Thandeka's comment of "there's a change of direction now" This is the same difficulty that was seen in argumentation episode 5, where Thandeka was able to convince the group that crossing the x-axis in an s/t graph meant a change in direction. So this was still a problem for the group at this point, as nobody challenged her statement here.

- *The acceleration of the object increases when its velocity increases and decreases when its velocity decreases.*

This 'alternative learner idea' was evident in Activity 4. The group was working on a task where they need to describe the acceleration of a ball that rolls up and down an incline, given that the starting point is the reference point and the upward direction is positive. They needed to describe the acceleration as the ball moves up the slope, at the turning point, and as it moves down the slope. The entire discussion is captured in discussion/explanation episode 2 in Appendix 12.

Kevin, who exhibited this difficulty earlier in the programme (see the discussion of the difficulties exhibited in argumentation episode 6), started the discussion with an open question:

41. Kevin: Acceleration. Increasing?

To which Thandeka replied:

42. Thandeka: Increasing. At the turning point zero. Acceleration – turning point non-zero, isn't it? As the ball comes down acceleration is increasing.

Kevin probed further:

43. Kevin: Acceleration decreasing? Okay, so why is the acceleration decreasing when it is going up?

Thandeka responded:

44. Thandeka: Cos it's slowing down.

Kevin now refers to the previous episode where this idea was explored (Argumentation Episode 6) and asks:

45. Kevin: But there... You showed the acceleration to be constant so why should it be decreasing, non-zero, increasing?

Thandeka changes her mind:

48. Thandeka: Constant, constant, constant.

Kevin needs an explanation/reason:

49. Kevin: Because?

Thandeka and Craig attempt to provide one:

51. Thandeka: Because it's free fall, it can only be $10 m.s^{-2}$. Yah.

53. Craig: Yah, acceleration should always be constant.

Kevin is still not satisfied and probes further:

54. Kevin: But at the turning point?

56. Kevin. No movement at the turning point.

Thandeka replies:

57. Thandeka: No. No it's... No matter where it is, it will still be under the influence of gravity.

Observations from this interaction:

In this discussion, Kevin is the one using open questions and other prompting devices to sustain the discussion.

Kevin also demonstrates an important ability here, the ability to transfer learning from one context to another. He recalls that a similar situation was explored in an earlier interaction and brings that learning into consideration here.

Even though Kevin was the one who held this 'alternative learner idea' when it was encountered in the earlier episode, he is the one questioning other learners' responses. This probably indicates that he has achieved a higher level of understanding in relation to this idea.

Kevin's question about the turning point may be an indication that he believed an object can only have an acceleration if it is moving. It could also be that he sees $a = \frac{v}{t}$ instead of Δv, so that $a = 0$ if $v = 0$.

Learners sometimes provide simplistic explanations as in this case with Craig when he suggests that, 'Yah, acceleration should always be constant', or with Thandeka who implies that gravitational acceleration is always $10 m.s^{-2}$. This may be an indication of learning experiences in the classroom, where explanations beyond the boundaries of what's needed or what will satisfy learners in an immediate context, or where cases in which a generally accepted principle may not apply, may seldom be explored.

- *The magnitude of the velocity of a ball at a point going up an incline is not the same as the magnitude of the velocity at that point on its way down the incline.*

This 'alternative learner idea' was evident when learners worked through a task in Activity 4. The group needed to describe and compare the velocity of a ball at the same point on a slope when it moves up and down the slope. The entire discussion is captured in discussion/explanation episode 3 in Appendix 12.

Kevin felt there may be different velocities for a particular point as the ball moved up and down the incline and gave an explanation why he thought so:

233. Kevin: When it's going up it's decreasing...so it's got less velocity.
235. Kevin: (continuing) ...when you're going down it's increasing...
237. Kevin: (continuing) ...so you might have a different reading.

Thandeka explained why this is not the case, drawing on the data that the group had collected to support her:

238. Thandeka: No, but if you have this point here...and this point here...and you take the readings, these points will be equal. Like here and here...zero point one eight (0.18)... and zero point one eight one (0.181). Except that it will be negative.

Kevin then agreed with her, also using the data to support him:

244. Kevin: Goes up with the same speed as it comes down... comes down with the same speed as it went up...
248. Kevin: That's what ... that's what the data says. Look here, zero comma one eight (0,18)... zero comma one eight (0,18).

Craig's summarizing statements captured what the group seemed to agree on:

271. Craig: Okay, you're watching? If you go up here...say we decide on that point. The ball is rolling up...Okay, I admit it's slowing down but at that point your velocity will say now be X. It's gonna go up there, turn around, come back down. When it reaches that point again it will be negative X. ...but it's still X, just going in the opposite direction.
284. Craig: Okay, I'll just read what I wrote: "The velocity of the ball at a particular point on the incline as it rolls up the incline is the same as that when it reaches the same point when it rolls back down the incline, just in the opposite direction."

Observations from this interaction:

Kevin's explanation provides insight into why he believes the two velocities may be different, in this case because the ball is slowing down as it goes up, and speeding up as it comes down. He probably expects the velocity on the way up to be smaller because the ball is slowing down, and on the way down to be bigger because the ball is speeding up.

Data collected and represented on the computer display played a role in resolving this difficulty for Kevin.

The learners tend not to use scientific relationships as the basis for their explanations. For example, conservation of energy, a concept they have encountered already in their normal classroom experience, would be an appropriate concept for the discussion above. Rather, they rely on visible evidence, what they can see as the motion occurs, or what the computer display has shown.

- *Assigning directional signs (+ or -) to a zero velocity.*

This idea was demonstrated by Kevin as the group worked through Activity 4. The entire discussion is captured in discussion/explanation episode 4 in Appendix 12. The group was working on a task where they had to compare the motion of a ball rolling up and down a slope for two cases, firstly where the upward direction is positive, and then when the upward direction is negative, and then construct a table of similarities and differences. In both cases the starting point at the bottom of the slope was the reference point. In this discussion, learners are comparing the velocity of the ball at the turning point for both cases.

Thandeka describes the velocity of the ball at the turning points:

412. Thandeka: At the turning point they're both zero...

Kevin wants the velocity to have a sign:

413. Kevin: Or positive.

Thandeka explains:

414. Thandeka: You cannot get a negative zero so can only be positive...

Her explanation also suggests that the zero velocity can have a sign attached to it, but that it can only be positive. Kevin uses a comparison with displacement to explain his reasoning:

417. Kevin: You have negative displacement...

419. Kevin: (continuing) Just as at this turning point, you have a positive displacement...

Thandeka reminds him that the group is discussing velocity. He accepts this but still insists:

424. Kevin: *It*... you can get a negative zero... you can get a negative zero but it doesn't mean negative... it just shows direction.

Thandeka explains:

425. Thandeka: Just zero's.

427. Thandeka: But there's no direction, because it just stops.

Kevin seems to accept this:

428. Kevin: Exactly... (group laughter)

Observations from this interaction:

Learner's ways of working with + and – signs in mathematics may be a possible source of the confusion here. Initially, Thandeka probably thought that since zero is often represented in mathematics with no sign, like other numbers where this is the case, the assumption is that it is positive.

For Kevin, his problem with differentiating between velocity and displacement, particularly the signs for these and what they mean, is a factor influencing his ideas here. We saw evidence of the same difficulty for Kevin when we discussed argumentation episode 3 earlier in this analysis.

- *A negative velocity means that the object is slowing down, and a positive velocity means that the object is speeding up.*

This 'alternative learner idea' became apparent in Activity 4 when the group was discussing the motion of a ball rolling up and down a slope, where the upward direction is negative, and the starting point at the bottom of the slope is the reference point. In this discussion, learners are discussing why the velocity of the ball decreases as the ball goes up the slope. The entire discussion is captured in discussion/episode 5 in Appendix 12.

Mondli asks a question:

560. Mondli: The velocity is decreasing... velocity... but then, why is it decreasing... Because the... because the upward movement...
562. Mondli: (continuing) ...is a negative direction?

Kevin replies:

561. Kevin: Because it's going up the slope.

Mondli still relates the magnitude of the velocity to its sign:

565. Mondli: Yah, that's why it's decreasing velocity. If it was positive it would be increasing.

Kevin attempts a more detailed explanation:

566. Kevin: No. That's what I'm trying to explain to you. Negative and positive doesn't ... like negative two and positive two, in physics it's the same thing, Like you know, in maths, negative two is smaller than two, but in physics, negative two and two is positive... just that it's in the opposite direction.

Mondli is still not convinced and asks a further question:

567. Mondli: So the reference direction, if it's up then it's negative, that's why it's decreasing...

569. Mondli: (continuing) ...if it was positive?

Kevin answers what he thinks Mondli wants to hear, then goes on to explain why it's not the case:

570. Kevin: Then it would be increasing?
572. Kevin: No, they just asking you below the turning point, that's below over here, so it would be decreasing. Look at your graph. (Reaches over to Mondli's book and pages back to his graph.)
574. Kevin: Below... Before you get to the turning point.

Mondli is still not satisfied and asks a further question:

575. Mondli: Yah, but then why... is it decreasing? Because it's negative?

Kevin introduces the idea of a force (gravity) causing the ball to slow down into his explanation:

576. Kevin: Because it's going down. Gravity is acting down the slope. The ball is going up the slope, so it will decrease.

Kevin and Mondli spent some time discussing this situation. As they were not interacting as part of the bigger group, they spoke softly, and so the conversation from here was not picked up on the tape recorder. However, Mondli's record in his workbook for this task read as follows:

"The velocity is decreasing because the upward movement has been used as the negative direction."

This seems to indicate that the difficulty was still unresolved for him at this point.

Observations from this interaction:

Kevin picked up on the probable source of Mondli's confusion, that he may be using ways of working with signs in mathematics, where + and – are indications of magnitude. He offered an explanation to show why this is incorrect for this scenario.

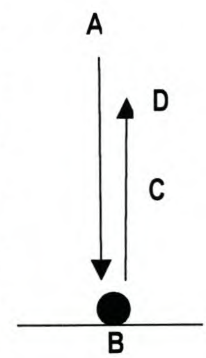
Kevin was also able to draw on a scientific relationship here, the relationship between the force acting and its effect on the velocity.

In spite of sustained and varied explanations from Kevin, Mondli still held on to his initial belief, indicating the tenacity of these beliefs for some learners. This probably indicates that elimination of a particular idea or difficulty is not instantaneous and may not result from one interaction like this. Mondli more likely needs to encounter this idea in a variety of learning experiences for it to be changed.

Mondli, in this case, was able to sustain the discussion/explanation interaction by asking questions.

- *The collision of a ball with the ground imparts a force on the ball which causes it to speed up over the first part of its upward motion, before it begins to slow down, as the effects of the force are no longer felt.*

This 'alternative learner idea' was evident in Activity 5 when learners worked on a task where they had to discus the motion of a bouncing ball, where the ball is dropped, strikes the ground and moves up again. In the discussion, A is the starting point of the ball, B is when it strikes the ground, C is midpoint on its way up again, and D is the high point it reaches on its upward movement. The entire discussion is recorded as explanation/ discussion episode 6 in Appendix 12.



Kevin asked:

616. Kevin: Wait, but... when it bounces... doesn't it speed up and then start slowing down?
619. Kevin: (repeating)Wait. See... uh... from... wait... from B to C... doesn't it speed up a little bit and then from C to D, slow down?

Thandeka responded:

620. Thandeka: C to D. It slows down.

Kevin repeated his question

622. Kevin: Okay, then... it... it doesn't start slowing down from here and ... it speeds up?

Thandeka and Craig also seemed to think this would be the case:

623. Thandeka: You have to accelerate after you stop... You know what I'm saying... you have to accel...
624. Craig: Yah, for a very short time. For a very short...

Kevin requested them to confirm what they were saying:

625. Kevin: Between B and C, doesn't the velocity increase?

Craig and Nelisiwe agreed:

626. Craig: Yah. Yah.

627. Nelisiwe: So it goes faster and faster, then it slows down.

Observations from this interaction:

The ground exerts a force on the ball initially causing it to speed up while it is in contact with the ground. However, these learners seem to have the idea that the effects of the force are felt over an extended time. In this case as the ball travels from B to C, they see it speeding up under the influence of this force. Then from C to D, they see the ball slowing down as the effects of the force get weaker and weaker. There are no real explanations offered by any of the learners here, so it is difficult to speculate on the source of this idea.

All the learners in this group seemed to agree with this idea, so it must be quite a common problem for learners. Their records in their workbooks in response to the task they were working on here record this idea (See activity transcripts). Because of this general agreement, and because this idea was not raised anywhere else in the group's interactions, it's probable that these learners still held this idea at the end of the learning programme.

- *Can a displacement-time graph go underneath the x-axis?*

This difficulty was evident for Kevin as the group worked on Activity 6. The learners were working on a task where they had to interpret the motion represented in a series of displacement-time graphs before attempting to replicate the graphs using the computer. This short interaction is captured in discussion/explanation episode 7 in Appendix 12.

Kevin asked:

47. Kevin: Craig, does the displacement-time graph ever go below the x-axis?
51. Kevin: (continuing) I mean, does it ever go... I mean... on one graph... top and bottom?

Craig explained:

52. *Craig*: Yah. Say that now here is your sensor, there's your reference point...Say now positive is going away... If you now...
54. Craig: (Continuing) (...few unclear words...) ... when you standing away from it...or you can go before it...so now you can go away and come back and go...

Kevin clarified and prompted further:

55. *Kevin*: So we going away from the sensor? We are not going...

Craig replied:

56. *Craig*: Correct... away from it.

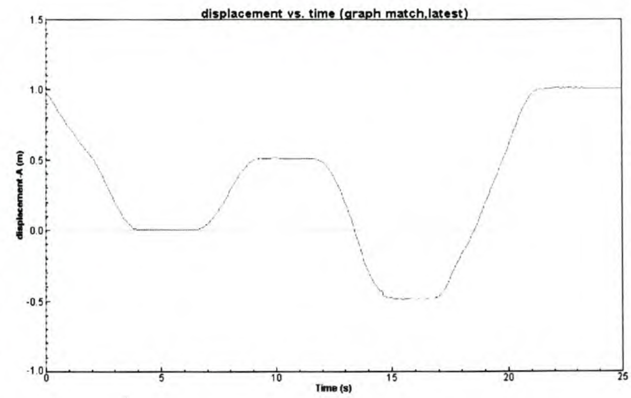
Observations from this interaction:

This difficulty probably arises because of the learners' lack of experience in working with negative displacements. Much of their experience in a traditional classroom is with motion in one direction, where the starting point of the motion is also the reference point. This leads to graphs which have positive gradients and which do not cross the x-axis. So learners find it difficult to interpret displacement-time graphs with negative gradients or which represent a negative displacement. Kevin exhibited a similar difficulty in argumentation episode 3 which was discussed earlier. In that case he had a problem interpreting the negative gradient of a displacement-time graph.

In the discussion, Craig's uses the word 'it' to refer to the reference point. His explanation to Kevin implies that portions of the graph above and below the x-axis represent displacements on either side of the reference point. Thus he seemed to pick up that Kevin's difficulty was based on his inability to recognize that portions above and below the x-axis represent displacements on either side of the reference point.

- *A negative gradient on an s/t graph means that the object is slowing down.*
- *The intersection of an s/t graph with the x-axis indicates a change in direction for the object.*

These two alternative learner ideas became evident as learners worked through a task in Activity 6. The learners were interpreting the motion represented in a series of displacement-time graphs before attempting to replicate the graphs using the computer. The graph that the learners are discussing is shown alongside. The entire discussion is captured in discussion/explanation episode 8 in Appendix 12.



Graph for Exercise 4 under discussion.

Thandeka asked a question and then answered it herself, referring to points on the graph where the direction of the slope changed:

65. *Thandeka*: Where does it change direction?
67. *Thandeka*: It changes direction here.

Mondli did not agree with her, and she repeated herself:

68. *Mondli*: No, that just means that it is slowing down.
69. *Thandeka*: No, it actually changes direction... and also changes direction here.

Mondli pointed out where he thought it changed direction, referring to the intersection points of the graph with the x-axis:

70. *Mondli*: No...it changes direction at... It's these two points.

Craig tried to explain why he was wrong:

71. *Craig*: No, you just going beyond the reference point. That's your reference point... Say now... here's your sensor...here's your reference point. It's going that way.
73. *Craig*: You not changing direction. You still going straight. Just that the displacements are positive and negative.

Mondli asked for further clarification:

75. Mondli: Okay, please explain the situation here.

Craig and Kevin jointly described the motion of the object:

76. Craig: Okay... standing away from the graph. Starting... you put your sensor... Here's your reference point. You starting here. You moving towards it till you get to it...
77. Kevin: Then you move away from it.
78. Craig: (continuing) ... then you stopping for a while. Then you moving away again.

Mondli then agreed with them:

79. Mondli: Yah, that's the change in direction.

Craig and Kevin completed their description:

80. Craig: (continuing) Yah, so you gonna accelerate away, stop.
81. Kevin: (continuing) Move back...
82. Craig: (continuing) Move back down that way... beyond it...back there...stands for two seconds... move way beyond it again to wait up here.

Observations from this interaction:

These two 'alternative learner ideas' were encountered in earlier activities the group was involved in. They are described in argumentation episodes 4 and 5.

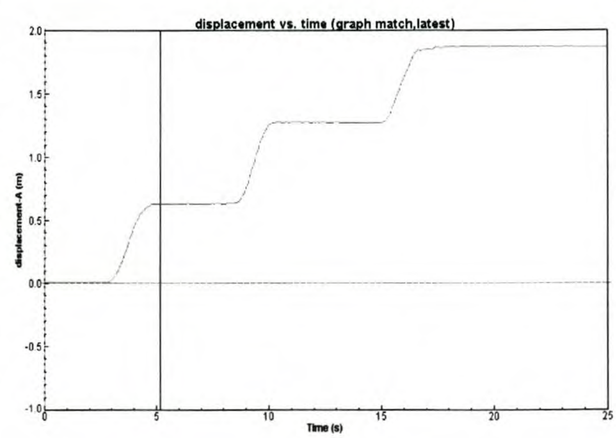
Although Mondli verbalized two 'alternative ideas' here, the one where he suggested the negative gradient meant the object was slowing down, was not noticed and explored further by the group here, possibly indicating that in a learning context like this, some difficulties can be overshadowed and thus ignored because the group focuses on more obvious ones.

It's interesting to note that in the earlier interaction where the learners explored what it meant when an s/t graph crossed the x-axis (argumentation episode 5), Mondli was the one who initially thought differently, but was convinced, together with the rest of the group, by Thandeka, that the intersection meant a change in direction. Here Thandeka, Craig and Kevin seem to have developed the correct idea while Mondli is still struggling with it. Nelisiwe's voice is absent. So

Thandeka, Craig and Kevin appear to have learnt as a result of their experiences from the time this difficulty was first encountered in Activity 1, but Mondli, up to this episode in Activity 6, still experienced problems with the idea. This suggests that a particular 'alternative learner idea' may need to be encountered in several different contexts before development occurs in relation to it, and that the extent this needs to happen differs for different learners.

- *Acceleration and deceleration do not apply to motion on a flat surface, only to inclines and to projectile motion.*
- *Difficulty translating and transforming graphs where there is mixed motion (i.e. a combination of stationary, uniform velocity and uniform acceleration).*

This 'alternative learner idea' and difficulty was evident in Activity 6 when learners were converting a series of displacement-time graphs into their corresponding velocity-time graphs and then checking their graphs using the computer equipment. In this interaction, they have started working on converting the graph shown alongside. The entire interaction is recorded in discussion/explanation episode 9 in Appendix 12.



Graph for exercise 1 under discussion.

Craig reminds the group that there are periods of deceleration that they should consider:

115. Craig: Don't forget you got deceleration in there.

Thandeka asked:

116. Thandeka: What deceleration?

Kevin suggested that acceleration only applied to inclines and to projectiles:

117. Kevin: No. That's for uphills and downhills. No, this is flat movement.

121. Kevin: That's for projectile motion.

Craig insists that there are periods of deceleration in the motion

122. Craig: You've still got to... you still gotta slow down.

Thandeka seems to agree and suggests that these periods will have to be represented by curves on the velocity-time graph.

123. Thandeka: So it mustn't be straight...it must be curved.

Kevin seems to think that the graph represents an object that is moving at a uniform velocity for a period, then stopping, then moving, then stopping, etc., but Craig points out that the s/t graph has curves indicating periods of acceleration and deceleration:

125. Craig: No. Let's just see. It's got a curve.

It appears as if the two difficulties being explored have overlapped and as a result become confused in the minds of the learners. Craig is interpreting the curves on the displacement-time graph to mean that there are periods of acceleration and deceleration. Thandeka initially suggested the use of curves on the velocity-time graph to show the periods of acceleration, and Kevin seems to follow this, even though he is still not convinced about the object accelerating and decelerating:

127. Kevin: Okay... so it will be a curve? And then dotted... curve... and then dotted.

He seems to accept that the object will accelerate, but his idea of a dotted line straight down to the x-axis to indicate that the object stops suddenly, indicates that he is not convinced that the object slows down to zero velocity.

A later comment he makes confirms this:

135. Kevin: But... wait, wait. Did you see when I done it? I never go fast then slow down. I went fast... and then I stopped.

Craig clarifies his ideas about the curves:

128. Craig: Okay. I'm not... no... it wouldn't be a curve. It wouldn't be curved.

Thandeka agrees with him:

130. Thandeka: Yes it... uh... actually velocity-time graphs don't have curves.

But she is still unsure and asks Craig whether the graphs should have curves. In response Craig explains:

148. Craig: No... I'm having no curves. I haven't put curves in the velocity-time graph...That wouldn't imply constant...um...constant acceleration.

Kevin still has a problem with the object slowing down and asks:

155. Kevin: Craig... But Craig, it doesn't slow down. Doesn't it just... the second line there... a dotted line.... This one coming down...Shouldn't it be a dotted line?

Craig explains:

156. Craig: No, because you don't just go...
159. Craig: (continuing) Look at the curve in here. They've all got a curve. You can see this has got a curve. So you have to assume that it slowed down.

Observations from this interaction:

This interaction illustrates that graph transformation is a particularly difficult area for learners, particularly when 'mixed' (at rest, uniform velocity, uniform acceleration) motion is involved.

Thandeka's response that '...velocity-time graphs don't have curves' is another example of a simplistic explanation or a learned response. It may be that she has learnt this in her traditional classroom learning experience with kinematics, but does not really understand the reasons why this may be so. Craig, on the other hand, demonstrates a deeper understanding when he explains that curves on a velocity time graph would imply a changing acceleration.

The group focuses on the graph translation exercise here, and the interaction centres mostly on whether their graph should have curves. Kevin's other 'alternative idea' about acceleration not applying to flat surfaces is not really explored further, a case of one 'alternative idea' being overshadowed by another.

This particular difficulty around transformation and translation of mixed motion graphs is probably a result of learners' experience of kinematic graphs in traditional classrooms, where most often, each 'type' of motion is dealt with separately. If learners are lucky enough to investigate motion in a practical way, they generally investigate uniform velocity first and learn how to draw graphs for this, and then move on to uniform accelerated motion. Very rarely will they investigate 'mixed motion' in a practical fashion and develop kinematic graphs which reflect this type of motion. Likewise, Kevin's idea about acceleration only applying to slopes and projectiles may be a carry-over of classroom experience, where acceleration may only be investigated in those contexts. It appears that this is an area where MBL activities can have a big impact. They allow for the easy investigation of mixed motion on a variety of surfaces including flat and sloped surfaces, and sustained exercises like the ones learners were involved in this programme, should have an impact on learner ability in this area.

9.6 Summary of themes, findings and tentative conclusions which emerged from the analyses

This section summarizes the themes, findings and tentative conclusions that seem to emerge from the analyses carried out in this chapter.

9.6.1 'Shifts in understanding' analysis

This analysis used learner performance on the questionnaires to identify any shifts in understanding that were made in relation to the specific 'alternative learner ideas' and difficulties. This analysis had two outcomes:

- It allowed me to separate the five learners in the small group which formed the focus of the study for this chapter into three categories:
  - 'unsuccessful learner' – Nelisiwe fell into this category. She made 27.3% of the number of shifts required.
  - 'partly successful learner' - Mondli fell into this category. He made 37.5% of the number of shifts required.
  - 'successful learner' – Kevin, Thandeka and Craig fell into this category. They made 80%, 80% and 100% respectively of the shifts required.
- It allowed me to formulate additional questions to guide further analyses.

9.6.2 'Level of Involvement' analysis

This analysis showed that:

- 'Successful learners' were each responsible for 23% or more of the total interactions of the group over the six learning activities surveyed, while the 'partly successful learner' and 'unsuccessful learner' were each responsible for less than 15% of the group's interactions. This led me to conclude that level of participation may impact on learning success in the context of this small group working through a series of MBL activities. Learners who demonstrated a higher degree of participation also showed greater learning gains, while learners who had lower levels of participation demonstrated smaller learning gains.

- Further analysis focusing on participation in each of the six learning activities showed that:

- Two of the successful learners (Thandeka and Craig) demonstrated consistently high participation over the duration of the programme.
- The participation of the other successful learner (Kevin) increased steadily over the duration of the programme.
- The participation of the partly-successful learner (Mondli) decreased over the duration of the programme.
- The participation of the unsuccessful learner was consistently low over the duration of the programme.

This led to speculation that there were factors operating within the group context which affirmed participation of some learners and negated participation of others, and that this impacted on their learning. These factors could be wide-ranging and include issues like language competence, gender, prior knowledge, issues of power and authority and inability to engage with the processes of learning operating in the group, etc. The type of data collected in the study prevented the investigation of the effects of most of these factors, and this will be highlighted as an area for further study in the concluding chapter of this report. However, the impact of learner ability to engage in the processes of learning operating in the group could be studied to some extent, and that formed the focus of the 'Processes of Interaction' analysis described in section 9.4 of this report, and summarized below.

9.6.3 'Processes of Interaction' analysis

The processes of interaction analysis focused on identifying the contexts in which alternative learner ideas and difficulties were made visible and explored, on identifying features of these contexts, and on identifying levels of learner participation in key behaviors related to these contexts. This analysis seemed to indicate that:

- Within the context of the MBL learning activities, collaborative small group interactions seemed to be the arena in which learner ideas and difficulties were made visible and explored.

- Learner ideas and difficulties seemed to be explored in two kinds of interactions, namely 'argumentation episodes' and 'discussion/ explanation episodes'.

- Argumentation episodes were characterized by:
  - The existence of clear claims and counter-claims.
  - Learners adopting positions and arguing for those positions.
  - Learners attempting to provide justifications for their positions.
  - Talk-turns in the interaction from one position then the other. Learners generally took turns to make points from their respective positions.
  - Continuation of the interaction until some form of resolution was reached. This may take the form of one side agreeing with the other and accepting the other's viewpoint or the two sides 'agreeing to disagree' until further input, e.g. through the use of the computer to collect further data.

- Discussion/explanation episodes were characterized by:
  - An exploration of an alternative idea or difficulty that one learner has voiced.
  - A sense that the learner recognizes the difficulty, tends to ask questions about it and is non-confrontational.
  - Other learners offer explanations why the idea may be problematic.
  - The learner who raises the issue sustains the interaction through further probing, prompting and questioning until he/she has reached some level of personal satisfaction with the explanations given.

- These characteristics, and a perusal of the literature on argumentation and explanation, allowed me to identify key processes, abilities or behaviors which learners needed to be able to demonstrate if they were to participate effectively in these learning episodes.

  For the argumentation episodes these included:
  - Making claims and counter-claims.
  - Justifying claims and counter-claims.
  - Qualifying and rebutting claims.
  - Questioning claims.

  For the discussion/explanation episodes these included:
  - Making propositions, hypotheses and conclusions.
  - Asking questions.
  - Comparing and/or linking and/or using multiple representations.
  - Giving explanations.

- The 'learning through argumentation' analysis seemed to show that:
  - Learners who engaged to a greater extent in terms of making claims, and justifying the claims they made also demonstrated greater learning success in the context of the learning programme.
  - Very rarely did learners question, qualify or rebut each other's claims.
  - Learners who started with a higher initial understanding of kinematics and kinematic graphs were able to argue more times from the 'scientific idea' perspective.
  - Two of the successful learners (Thandeka and Kevin) who benefited most from the programme initially argued from the 'alternative idea' perspective to greater extent, but also changed to a scientific perspective more times than other learners. It may be that these learners' participation in the argumentation

episodes allowed their 'alternative ideas' to be made visible and to be challenged in ways that facilitated their learning.

- A case was also observed of learners changing from the scientific perspective to the 'alternative learner idea' perspective. This indicates the possibility that small group collaborative work can also lead to possible development of 'alternative' rather than 'scientific' ideas, particularly in areas where at least one learner in the interaction has not strongly established the 'scientific idea'.
- The unsuccessful learner in this context (Nelisiwe) was unable to effectively demonstrate and/or participate in the processes of making and justifying claims which were central to the argumentation episodes. This may have contributed to her lack of learning.

- The 'learning through discussion and explanation' analysis seemed to show that:
  - Learners who demonstrated learning success engaged in behavior involving proposing, hypothesizing and concluding, comparing multiple representations, and explaining more frequently than the partly successful or unsuccessful learners. It seems that, within the context of the small group discussions in this learning programme, the ability to engage in these processes may enhance the learning experience of these learners, and thus enhance learning for these learners.
  - The questioning category was an interesting one, in that a distinction between the different categories of learners could not be easily made. However, a further analysis which matched the degree to which learners asked questions with the frequency they exhibited 'alternative learner ideas' seemed to show that learners who raised or aired the 'alternative learner ideas' or difficulties that formed the focus of the discussion/explanation episodes also asked questions in relation to these. It seems as if, within the

discussion/explanation interactions of this small group working on MBL activities, that learning may be related to the ability of learners to raise or make visible the 'alternative ideas' or difficulties they have, and to the ability to ask questions about them.

9.6.4 'Alternative Learner Ideas and Difficulties' analysis

This analysis focused on a description of the 'alternative learner ideas' and/or difficulties that became evident as learners participated in the argumentation interactions, and in the discussion/explanation interactions.

These ideas or difficulties are summarized in the table which follows. They are categorized into one of the four areas described earlier in this report.

Table 9.17: Alternative learner ideas and difficulties exhibited by learners in the argumentation interactions and in the discussion/explanation interactions.

Area of difficulty	'Alternative learner ideas' or difficulties exhibited as learners worked through learning activities in the learning programme
A: **Problems associated with conceptual understanding of kinematic quantities.**	The acceleration of the object increases when its velocity increases and decreases when its velocity decreases.
	The magnitude of the velocity of a ball at a point going up an incline is not the same as the magnitude of the velocity at that point on its way down the incline.
	The collision of a ball with the ground imparts a force on the ball which causes it to speed up over the first part of its upward motion, before it begins to slow down, as the effects of the force are no longer felt.
	Acceleration and deceleration do not apply to motion on a flat surface, only to inclines and to projectile motion.

B: **Problems associated with reference points, sign convention and negative kinematic quantities.**	Inability to use specified reference direction and sign convention to describe the displacement of an object.
	Inability to distinguish between positive displacement and positive velocity (or negative displacement and negative velocity).
	The reference point is always the starting point of the motion.
	Assigning directional signs (+ or -) to a zero velocity.
	A negative velocity means that the object is slowing down, and a positive velocity means that the object is speeding up.
	Can a displacement-time graph go underneath the x-axis?
	The sign allocated to describe the direction of the acceleration is always the same as the sign allocated to the direction in which the object is moving.
C: **Graph translation and transformation difficulties.**	Difficulty translating and transforming graphs where there is mixed motion (i.e. a combination of stationary, uniform velocity and uniform acceleration).
D: **Graph interpretation difficulties.**	Inability to recognize that the x-axis represents the reference point in an s/t graph.
	A negative slope on a s/t graph means that the object is slowing down.
	Crossing the x-axis in a s/t graph indicates that the object changes direction at that point.

The following common themes and/or findings seemed to emerge when the argumentation interactions and the discussion/explanation interactions were examined and explored:

In relation to the argumentation episodes:

- The ability of learners who have an 'alternative understanding' to articulate this understanding, and their ability to give reasons why they hold this view, the ability of other learners to recognize what may be an 'incorrect' learner idea or difficulty and their ability to present an alternative view and to provide justification for it, are probably key factors contributing to any shifts in understanding that are experienced. The inability of Nelisiwe to engage in any of these processes is probably a key factor in her lack of learning in the programme.

- In some cases, other learners recognize the underlying cause of the 'alternative learner idea' or difficulty, and use it in their arguments or explanations to learners who demonstrate these, in this way undermining the alternative idea or difficulty. This probably acts as a strong driving force for conceptual change or the alleviation of the difficulty being experienced. So, the ability of learners to provide justifications for the positions they adopted was important for learning for two reasons:
    - A justification provided by a learner who adopted the 'alternative learner idea' provided insight for the other learners into the underlying cause or reasons why the learner held this idea.
    - Justifications by learners who adopted the 'scientific' position provided opportunities for these learners to challenge and/or undermine the causes or reasons used to support the 'alternative learner idea' position.

- When learner arguments and justifications were not able to specifically target the underlying causes or reasons for an 'alternative learner idea' being held, it appeared more difficult for the learner who held the 'alternative learner idea' to recognize the need to change it.

- When a learner was able to provide justification of an 'alternative learner idea' in the absence of justification from learners who held the more 'scientific' view, the 'alternative view' was dominant, and it appeared as if weaker learners in the group adopted this view.

- Computer-generated graphs were used in learners' justifications or explanations to support particular positions, to provide evidence for other learners and to resolve debates which were deadlocked.

- Learners seemed to hold 'alternative learner ideas' with varying degrees of commitment. This made it easier for some learners to change their ideas and move more easily to the 'scientific idea'.

- Learner's classroom experiences of kinematics can be a contributing factor to the development of alternative learner ideas and their level of engagement in MBL activities. For example, a tendency of learners to revert to simplistic explanations was observed, for example:

  54. *Craig:* We've only dealt with constant acceleration, so we won't get a confusing acceleration. Cos then all the other graphs would just be impossible.

  This may be an indication of learners experiences at school level, where a learner, in response to a question about non-uniform acceleration, may receive the reply, "That's not in the syllabus" or "You will deal with that at university level", or "You will not be asked about that in any test or examination". It may be the case that learners' experiences are limited to what authorities deem to be the bare minimum for them to pass examinations or tests – particularly the final and 'all-important' matriculation examination. The following unsolicited comments, made by learners as they participated in the learning activities, seem to bear this out:

  566. *Thandeka:* And constant acceleration…I hope we get all this stuff for the exam.
  [Extract from transcript for Activity 5.]

  and,

  445. *Kevin:* You know, I never learnt about these principles in school.

  446. *Thandeka:* Neither did we.

  447. *Craig:* Nor did I.

  448. *Nelisiwe:* We didn't…

449. Thandeka: I didn't know about reference direction.

450. Kevin: ...I didn't know about reference points.

451. Craig: We weren't taught about this.

452. Thandeka: Yah, we weren't taught about this.

453. Kevin: We were just given a graph... describe the motion...from the shape...

454. Craig: Yah.
[Extract from transcript for Activity 4.]

In relation to the discussion/explanation episodes:

- Where learner justification of an 'alternative idea' or difficulty provided insight into the source or reasons why the learner held that idea, in the discussion/explanation episodes it is the learner's questions and/or explanations that provide this insight.

- Similarly, it is the other learners' explanation responses in relation to the 'alternative idea' or difficulty that serve as the stimuli for change in these interactions.

- The ability of learners to use open questions and other prompting devices to sustain explanation and discussion of a particular difficulty or 'alternative learner idea' until they are clearer about it may be an important skill that impacts on learning in this context.

- In many cases, learners do not use scientific relationships as the basis for their explanations and/or justifications. Rather they rely on visible evidence, what they can see as the motion occurs, or what the computer display has shown, or even simplistic 'learned responses' like "the acceleration should always be constant", or 'velocity-time graphs don't have curves".

- It probably does not mean that because a particular 'alternative learner idea' or difficulty is explored in an argumentation or discussion/explanation interaction, that its elimination is instantaneous. Rather, it may be more realistic to state that for many of the ideas or difficulties explored, these interactions have created opportunities for 'cognitive conflict' in the learners exhibiting them, and thus possibly set these learners on the path to changing their ideas or overcoming the difficulties they have displayed. So, a more holistic view is that a combination of varied and sustained learning experiences together will have a significant and lasting impact on these ideas or difficulties.

- It's possible that the entire group can hold a particular 'alternative idea' and thus agree with each other on it. In this case, no 'cognitive conflict' is experienced and probably no learning in relation to this idea begins. This seemed to be the case in discussion/explanation episode 6.

- Sometimes more than one difficulty can be exhibited in a 'learning episode' but learners latch onto and attempt to resolve one of them, ignoring the others. So, the creation of learning opportunities for learners who have 'alternative learner ideas' or difficulties, in the context of collaborative small groups, probably depends on:
  - whether the design of the activity itself, e.g. the kinds of questions asked allow these difficulties to be made visible;
  - the ability of other learners in the group to recognize these ideas or difficulties;
  - their ability to respond meaningfully to them in ways that challenge the learner's existing ideas.

9.7 Interpretations and Explanations

This section of the report is an attempt to interpret and explain the observations and findings presented, using the theoretical frameworks of learning theory and conceptual change. A number of learning theories and theories of conceptual change were described in Chapter 3 of this report. These were used to design features of this study, including the overall approach, the data collection tools and the learning programme component of the study. However, they were also described in anticipation that some may be useful in developing explanations for the broad findings in this component of the study. Of these, constructivist theory, particularly Piagetian and Vygotskian theory, seems to provide useful lenses through which the observations and findings in this phase of the study can be explained.

9.7.1 A Piagetian constructivist interpretation

Several features of Piagetian theory seem to be useful in attempting to interpret and explain some of the observations and findings made in this component of the research project. These are described in the discussion which follows.

9.7.1.1 Subject – object relations, assimilation-accommodation and success-failure

A starting point for possible learning in the Piagetain framework is the application of a learner's existing cognitive structures to make sense of and analyze current experiences in the environment. These experiences can be analysed in terms of subject-object relations that develop in the current context. The MBL collaborative group work provides the context in which multiple subject-object relations are possible. For example, in the context of this study, relations develop between ideas that the learner (subject) possesses and ideas from the MBL context in which the learner is operating, including the ideas of other learners and the ideas presented in the curriculum materials, including those made available through the computer representations. These relations develop through the processes of assimilation and accommodation, and result in a (possibly momentarily modified) cognitive structure which allows the learner to make meaning (develop an understanding) of the present experience, and as a result experience a degree of success or failure in it. In the context of this study, where a small group worked collaboratively on a set of MBL learning activities, degrees of success/failure and understanding achieved by individual learners was visible in the applications and interpretations they made in response to tasks and problems and their verbalizations about these.

9.7.1.2 Perturbations and equilibration

Individual learners in this context got feedback about their success/failure or degree of understanding achieved, mostly through the response of other learners in the group, and in some cases through the representations made available in the curriculum materials, including the computer representations. Feedback from the context in this study resulted in two possible scenarios:

- Learners possibly experiencing **perturbations** (dissonance in their cognitive structure as a result of other meanings available in the context –cognitive conflict).

- For more of the time, perturbations seemed not to be experienced, and the task/idea/problem that the group worked with could be resolved through the application of existing cognitive structures. In those cases, individuals in the group seemed to be in agreement about a common meaning, possibly indicating a congruency in the cognitive structures of individuals in the group, in relation to the ideas being explored. This was referred to as 'consensus and common understanding' in the analysis in Section 9.4 of this report.

Those cases where perturbations were experienced, were important to this study because they indicated times when the cognitive structure of the learner was in conflict with ideas available in the context, because the learner held 'alternative ideas' that conflicted with the 'scientific ideas' in the context. These perturbations were resolved (**compensated for**) through learners becoming involved in **regulatory behavior** in a number of ways:

- The perturbations were ignored or simply avoided by the learner, resulting in no meaningful change to the cognitive structure of the learner. For example, no attempt was made by the learner to engage more deeply with the perturbation and its cause, or the learner accepted a simplistic explanation for the perturbation. The unsuccessful learner (Nelisiwe) in this study engaged in this behavior quite extensively. She obviously experienced perturbations and sometimes verbalized them at the beginning of an interaction, but her involvement in the interaction seemed to end at that point.

- The perturbation is experienced by the learner as an **'obstacle'** resulting in failure and negative feedback from the environment, including fellow learners. These were visible in the context of this study in the argumentation episodes. Deeper engagement and possible steps towards resolution of the perturbation here involved the learner being able to participate effectively in the argumentation process – an ability which the more successful learners in the study exhibited.

- The perturbation is experienced as a **'lacunae'** or gap in understanding and is characterized by positive feedback from the environment. It arises through recognition by the learner that existing cognitive structures are not sufficient to explain current experiences. In the context of this study, this type of perturbation was visible in the discussion/explanation episodes. These were typically characterized by learners recognizing that they were not understanding something sufficiently, and then asking questions about it, and continuing to lead the engagement and interaction until they were satisfied. So, deeper engagement and possible steps towards resolution of this type of perturbation, in the context of this study, required that learners were able to participate effectively in the processes of explanation/discussion – an ability which the more successful learners in the study demonstrated.

In summary then, the process of equilibration is an internal process mediating between the internal world of the learner and the external environment. It is the process through which perturbations are resolved, and which drives cognitive restructuring. What are outward signs that the learner is engaging in this process? In other words, what are the visible regulatory behaviors that learners can be involved in as they attempt to resolve the perturbations? In the context of this small group working collaboratively on MBL activities, it seems as if the extent to which the learner participates in the processes of argumentation and discussion/explanation are visible regulatory behaviors which indicate that the learner is attempting to resolve perturbations through equilibration, and thus move towards a new cognitive structure. Thus, learners who demonstrate that they are more able to engage in these processes should demonstrate a greater extent of cognitive restructuring. In this study, if findings in the 'shifts in understanding' analysis are accepted as an indicator of the extent of cognitive restructuring that took place for different learners, then this does seem to be the case. Learners who were more successful also demonstrated that they were able to engage in the processes of argumentation and discussion/explanation to a greater extent.

So, if this interpretation is accepted, it seems as if the processes of argumentation and discussion/explanation, and their related sub-processes including the ability to make proposals, hypotheses, conclusions, claims, counter-claims, justifications, questions and explanations, are key indicators of possible cognitive restructuring and are key processes which impact on it.

The diagram which follows on the next page is a reproduction of the one providing an overview of Piaget's theory which can be found in Chapter 3 where this theory was discussed. Some of the applications/interpretations relating to this study are shown on the diagram.

So, in the context of this study, and using this framework as an explanatory tool, successful learners are those learners who are able to develop subject-object relations between the ideas they have and the ideas available in the context, they are able to apply these relations to the context, and from the feedback they receive, they are able to recognize dissonance between their ideas and others. Furthermore, they are capable of using regulatory mechanisms to resolve the perturbations arising, if the context provides the opportunity to do so.

So two factors seem to impact on learner resolution of perturbations, and thus cognitive restructuring here:

- The ability of individual learners to participate in regulatory processes to resolve the perturbations. Successful learners in the context of this study demonstrated that they were able to participate in these processes.
- An opportunity provided in the context for the perturbations to be resolved. For some learners it may be that the context limits the ways in which they can resolve the perturbations, for example in cases where a perturbation is experienced and made visible by the learner involved, but ignored by other learners, or where the learner experiences a perturbation, but does not feel validated in the group situation and comfortable enough to participate in processes which may help to resolve the perturbation. Scenarios like this are highlighted as an area that needs further research in the last chapter of this report.

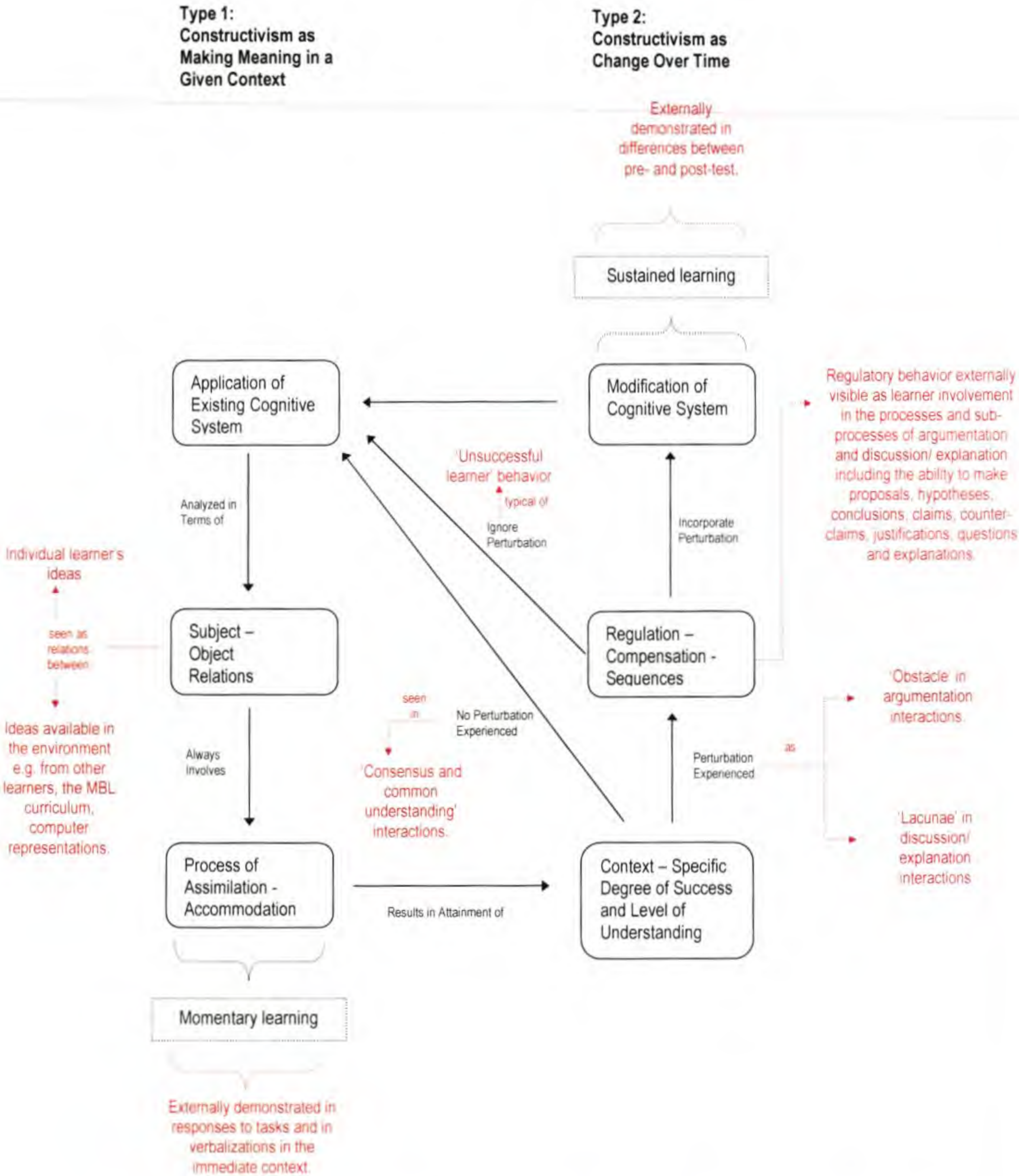


Figure 9.15: An overview of elements in Piaget's Theory (slightly adapted from De Lisi and Goldbeck, 1999: 6). The entire diagram is reflective of the process of equilibration. The additions in red are applications to, and interpretations made in this study.

9.7.2 A Vygotskian social constructivist interpretation

A key theme underpinning social constructivist theory is the notion that learners reconstruct ideas in collaboration with others in the social environment, in order to make meaning for themselves. The social setting provides the context in which ideas can be made visible, explored, tested, challenged and perhaps changed. Small group collaborative work in an MBL context like the one described in this report, provides such a setting, and it is my contention that this setting is a key component and contributing factor to the learning that has taken place. In particular, the argumentation interactions and the discussion/explanations interactions can be viewed as the sites at which reconstruction of ideas begin to take place. It is at these sites that the alternative ideas and difficulties are made visible and open to interrogation and scrutiny.

9.7.2.1 The Zone of Proximal Development (ZPD)

Vygotsky's notion of the Zone of Proximal Development (ZPD) provides a useful theoretical lens to interpret what seems to be happening at these learning sites.

Vygotsky describes the ZPD as:

> The distance between the actual developmental level as determined by individual problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers. (Vygotsky, 1978, quoted in Tharp and Gallimore, 1988:30.)

If the 'alternative learner idea' or difficulty made visible in the interaction is perceived as the level of understanding the learner is currently at, and a higher level (the level of understanding the learner is able to reach when assisted) is the 'scientific idea' as understood by the group, then learning and conceptual change involves movement from the 'alternative learner idea' to an idea or understanding which more closely matches the 'scientific idea'. Mediation by others in the social environment is the mechanism through which change takes place.

Several things need to take place so that this can occur:

- The learner's ideas or present understanding need to be made visible in a problem-solving setting.

- Others in the social setting need to recognize it, and to recognize the problems, flaws or shortcomings it may have.

- There needs to be an understanding available in the social setting which represents advancement on the idea the learner currently displays. The difference between this understanding and that demonstrated in the 'alternative learner idea' or difficulty, represents the ZPD within that social setting.

- There needs to be mediatory mechanisms which facilitate, stimulate or encourage the movement from one idea to another.

Within the context of this learning programme where a small group worked collaboratively on a series of MBL activities, the argumentation and explanation/discussion learning sites seem to provide opportunities for these conditions to be satisfied:

- The argumentation interactions and the discussion/explanation interactions all occurred as the group worked on a problem-based task, so it was in the context of a problem-solving setting that the alternative learner ideas and difficulties were made visible. These needed to be resolved if the learner and the group was to reach an acceptable solution to the problem.

- The existence of more advanced ideas held by other learners in the group allowed for the recognition and challenging of 'alternative learner ideas'.

- Ideas were made visible and challenged through the use of mediatory mechanisms involving the making of proposals, hypotheses, conclusions, claims, counter-claims, justifications, questions and explanations. So these mediatory mechanisms also provided the stimuli for change.

- The computer-based tasks and the representations they produced (the MBL activities) also provided an important mediatory mechanism which allowed for the representation, investigation, testing and/or questioning of ideas.

These interpretations are captured on the diagram which follows.

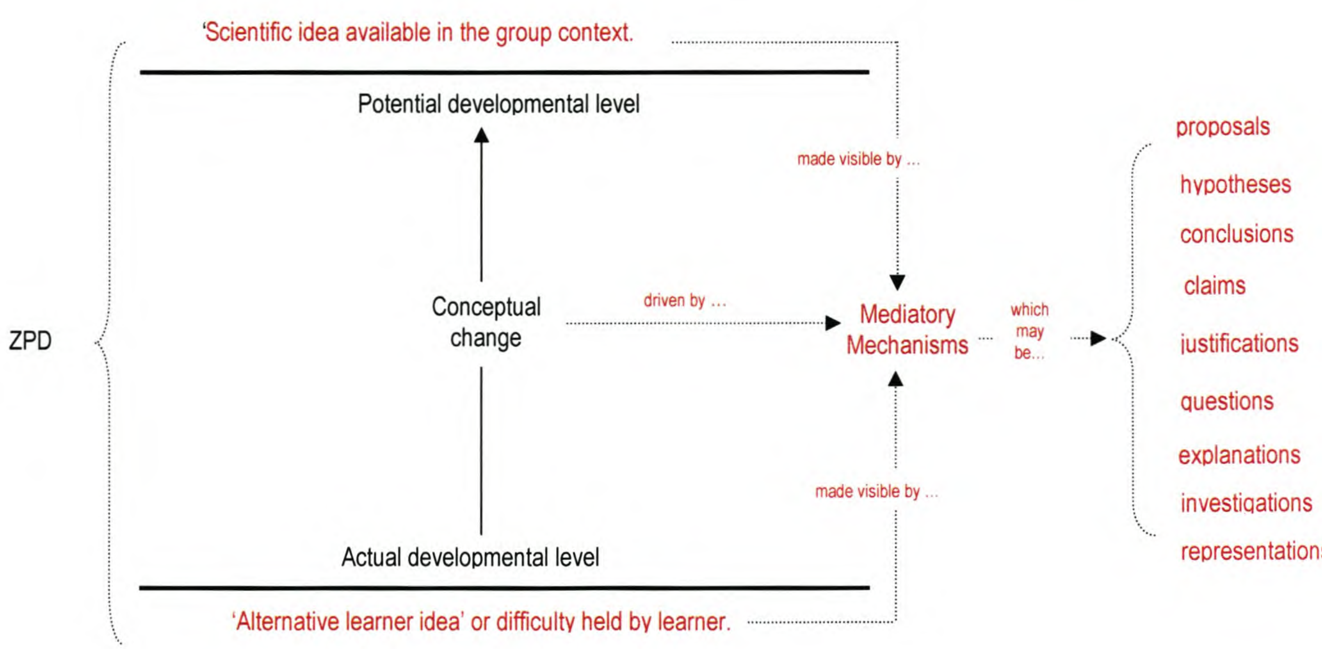


Figure 9.16: Using Vygotsky's ZPD to explain possible learning in the context of MBL small group collaborative work (the red components relate to observations and findings in this research).

Thus, using this diagram as a framework or as an explanatory tool, it is possible that learners will be more successful within the context of MBL small group collaborative work if:

- They are able to verbalise the 'alternative ideas' or difficulties they have.
- One or more learners in the group hold a more advanced idea and are able to recognize the 'alternative idea' or difficulty when it is verbalized.
- The learners are able to participate effectively and extensively in mediatory mechanisms which drive change in ideas.

Conversely, barriers to learning, in the context of this framework can arise when:

- Learners are unable to verbalize the alternative ideas or difficulties they have.
- Other learners in the collaborative setting fail to recognize the alternative ideas or difficulties when they are raised.
- Learners are unable or unwilling to participate in the mediatory processes which may facilitate learning.

In the context of the small group which formed the focus of this study, successful learners were the ones who were able to verbalise their ideas and who were able to participate in the mediatory processes which challenged these ideas.

The following questions arise:

- What allows learners who are able to verbalise their ideas, to participate effectively in the mediatory processes?
- What makes groups able to recognize alternative ideas and difficulties and also willing to explore them further?

These are key questions for further research which will be highlighted in the next and concluding chapter.

CHAPTER 10

Summary, Limitations and Suggestions for Further Research

This first part of this chapter (Section 10.1) provides a concluding overview of the study. A detailed description of the findings and explanations in relation to each of the research questions will not be repeated here. Instead, a brief description of how the question was tackled, and possible overarching findings will be described. The reader is directed to relevant parts in the report for more detailed descriptions.

Section 10.2 elaborates on 'dialogical learning' as an overarching theory which seems to emerge from this study.

Limitations of the teaching/learning context, including limitations related to the TRAC-PAC as an example of MBL technology, and limitations of the research project itself are explored in Section 10.3.

Finally, suggestions for further research, which arise from the study, are described in Section 10.4 of the chapter.

10.1 Summary of the study

Three research questions determined the shape and direction of this study, and the structure of this report. They were:

1 What conceptual difficulties do learners experience in the area of kinematic graphs?

2 Does use of the TRAC PAC (as a microcomputer-based laboratory tool) contribute to learner understanding of graphs of motion and related concepts?

3 If learning is enhanced using the TRAC PAC, how does this occur?

A discussion of the South African science education context, and a content analysis of kinematics and kinematic graphs and the experience of South African learners in relation to this, provided the foundation in which the study was embedded. This is captured in Chapter 1 and Chapter 2 of this report.

Theories of learning, theories of conceptual change and understanding provided the theoretical framework for the study. These theories impacted on the design of the study, the design of the research instruments and the intervention programme, and on the interpretation of findings and observations made in the study. This theoretical framework was described in Chapter 3 of this report.

10.1.1 Answering Research Question 1

Research Question 1 was answered in three ways:

- A review of the literature of international and South African studies on learner understanding of kinematics and kinematic graphs was conducted. This highlighted a variety of 'alternative learner ideas' and difficulties exhibited by learners in this area. The 'alternative learner ideas' and difficulties were categorized into four broad areas:

A: Problems related to conceptual understanding of kinematic quantities.

B: Problems associated with reference points, sign convention difficulties and difficulties dealing with negative kinematic quantities.

C: Graph translation and transformation difficulties.

D: Graph interpretation difficulties.

The 'alternative learner ideas' and difficulties identified from a review of the literature can be found in Chapter 4 of this report. These difficulties were used in the design of the pre- and post–questionnaires that, in turn, were used to identify if learning occurred as a result of learner participation in the MBL programme, and in the design of the learning activities which made up the learning programme. A description of the approach used to develop the questionnaire can be found in Chapter 6 of this report. A description of the design of the learning programme used in this study can be found in Chapter 7 of this report.

- An item and matrix analysis of learner responses to the questions on the questionnaires highlighted a variety of 'alternative learner ideas' and difficulties which this particular group of South African learners exhibited, many of them similar to those reported in the international and South African studies which were reviewed. These were described in Chapter 8 (Section 8.4.2) of this report.

- Transcripts of the learners' interactions as they participated in the six learning activities also highlighted a number of 'alternative learner ideas' and difficulties, again many of them similar to those reported in Chapter 4 and in Chapter 8 of this report. These can be found in Chapter 9 (Section 9.6.4) of this report.

10.1.2 Answering Research Question 2

This question formed the focus of the largely quantitative phase of this study, which was described in Chapter 8 of this report. Eight examples of specific 'alternative learner ideas' or difficulties, two from each of the four categories of difficulties described earlier were identified for tracking in this phase of the study. Eight hypotheses were set up for these eight difficulties, and a diagnostic, two-tier 16-item questionnaire (2 questions for each hypothesis) was used to identify any changes in learner understanding in relation to eight hypotheses. Items on this questionnaire made up the pre-test and post-test, and were randomly ordered on these tests.

Pre- and post-test results were analyzed in two ways:

- Absolute scores that learners achieved on the pre- and post-test were computed and represented in the form of a table, bar chart and scatter graph. Analysis of these through the patterns that were visible on them and through computations of average percentage increases, means for the two tests and a t-test between the two sets of scores, was carried out. This allowed the researcher to come to the conclusion that the MBL learning experience generally enhanced the understanding of kinematics and kinematic graphs for learners. A detailed description of the analysis and findings in relation to the absolute scores can be found in Section 8.1 of this report.

- Learner responses to each of the items was analyzed in greater depth using an item and matrix analysis approach described by Svec (1999). This analysis had two main outcomes:

- It allowed for the identification and description of common 'alternative learner ideas' and difficulties that were evident in this group of learners. These can be found in section 8.4.2 of this report.
- It allowed for the identification of changes in learner understanding in relation to each of the eight hypotheses set up. This analysis showed that the MBL experience had a varied impact on the development of understanding of learners in relation to the eight hypotheses and thus, four areas of difficulty identified. A detailed description of these findings can be found in Section 8.4.3 of this report.

10.1.3 Answering Research Question 3

The qualitative aspect of the study, which was described in Chapter 9 of this report, attempted to answer this question. In general, the analysis here showed that, for this small group of learners working in an MBL context:

- Group discussions were the sites at which alternative learner ideas and difficulties were explored.
- Learning seemed to be related to the level of involvement of the learners in the interactions of the group.
- Alternative learner ideas' and difficulties were explored in two types of interactions, namely argumentation interactions and discussion/ explanation interactions.
- The ability of learners to demonstrate and participate in the processes of argumentation and discussion/explanation seemed to be related to the level of success they demonstrated in the programme.

A detailed summary of my observations and findings in relation to Research Question 3 can be found in Chapter 9 (section 9.6) of this report.

10.2 An emerging theory of 'dialogical learning' in the context of collaborative microcomputer-based learning activities.

The most important contribution of this study, in relation to microcomputer-based learning scenarios in science, has been the identification of the collaborative group, and the interactions and processes which occur in these groups, as a possible vehicle through which alternative learner ideas can be explored, and where changes in understanding in relation to these ideas may begin to happen.

A constructivist epistemology underpinned the design and implementation of the learning programme, and was also used to explain the findings that were made in relation to possible learning and non-learning that took place. This included the use of perspectives from:

- Piagetian theory, which locates cognitive restructuring primarily within the cognitive structures of the individual, but which also shows how it is possible that interaction with the physical and social environment impacts on the restructuring that takes place; and
- Vygotsian theory, which locates the construction of meaning in the social domain, and which shows how participation in mediatory processes within this environment can possibly lead to learning.

'Dialogical learning' is a useful summarising concept to capture the different observations that were made and the explanations offered in relation to the observations, and in the inductive ethnographic tradition in which part of the study was located, is the overarching theory which seems to emerge.

In the context that was studied here, dialogical learning involves, through dialogue (multi-voiced interactions), the creation of a 'text', which becomes available for learners to work with and make meaning of in the learning context. The 'text' can probably best be described as an interplay between the ideas that are being explored i.e. as the interplay between the scientific ideas and the alternative ideas 'voiced' for example, in the argumentation or discussion/explanation interactions. Various participants in the context contribute to the creation of the 'text', including:

- The teacher, who in the context of this study, played an essential but implicit rather than explicit role. Because of the 'units of analysis' on which much of the ethnographic component of the study was based, i.e. the collaborative group interactions, the teacher's 'voice' appears to be absent from the process. However, the teacher contributes substantially to the creation of the text through the design of the learning experiences, including the protocols which guided the activities of the learners as they engaged in the computer-based investigations and through the facilitation of the learning activities as they occurred. Facilitation in this context, as the groups worked on learning activities, involved responding to learner queries, 'listening in' on group discussion and offering comments or questions pointing in particular directions, and engaging in debriefing activities on conclusion of the activities. It should be mentioned here that the teacher's role was intentionally downplayed to allow more scope for assessing the impact of the technology on whether and how learning took place.

- The learners who contributed to varying degrees in the construction of the 'text' and in the meanings they derived from it. We can think of learner construction of the 'text' as involvement in outward-orientated and inward-orientated processes. Outward-orientated process are those which allow conceptions to be made visible and contested as the 'text' that emerges, and inward-orientated processes are those which involve learners working with the emerging 'text' to create meaning for themselves. In the context of this study these processes included those related to argumentation and discussion-explanation.

The varying degrees in which learners participated in these processes perhaps, in part, explains the varying degrees of success learners experienced in the programme.

Learning success also relates to the kind of resolution or closure learners reached in relation to the 'text' being explored, which was not the same for all learners. In the case of these learners working in a collaborative group in a microcomputer-based context, mutual agreement on the form of the text, and its incorporation in this form by all learners, was not always the outcome of the dialogical interaction. Closure for learners could happen through simple rejection of the 'text', postponement of engagement to a later time, or a more permanent accommodation of the 'text' in the learner's cognitive structures – the last possibility being the one most fruitful for learning.

- The computer representation is another contributor to the creation of the 'text' that is explored. As a physical entity, its contribution is probably in one direction, towards the construction of the 'text'. However, its involvement becomes dialogical through the manipulations and interpretations afforded it by the human participants in the interaction.

These ideas, applied for the focus group of learners in this study, are captured in the diagram which follows:

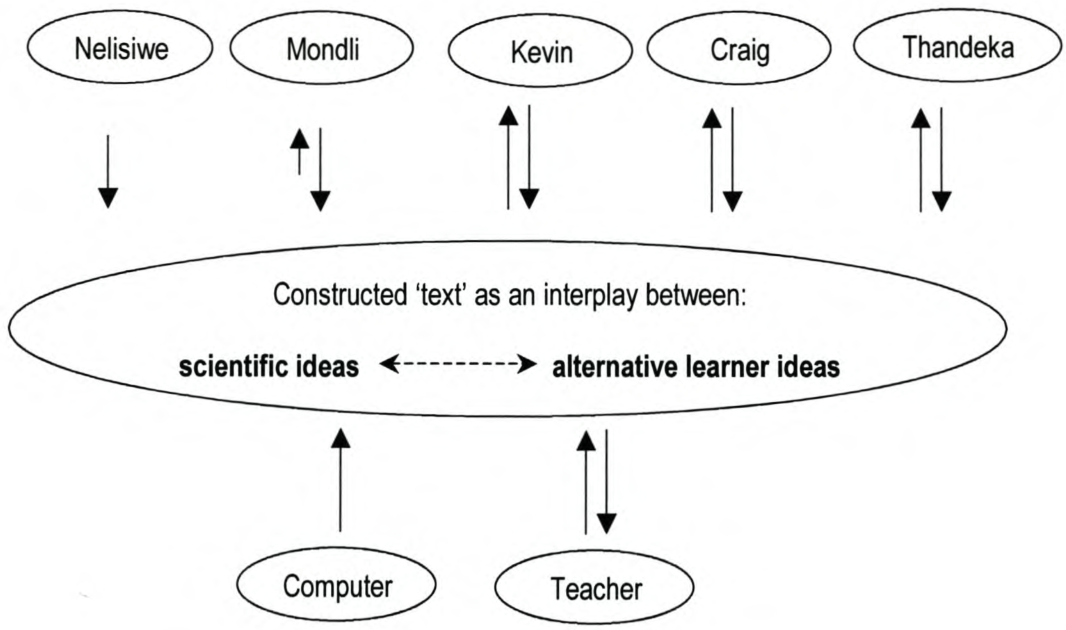


Figure 10.1 'Dialogical learning' in the context of collaborative groups working on mbl activities.

The arrows represent inward and outward processes contributing to the construction and interpretation of the emergent 'text'. For the computer I have represented this as uni-directional, with the computer contributing to the construction of the 'text'. Note that it's possible for the teacher's interaction in the dialogue to be bi-directional, implying the teacher as 'learner' in the context as well – perhaps in this case learning about the conceptions particular learners hold in relation to scientific concepts, and manipulating the learning context to respond to these conceptions. This study did not show how this could occur, and this could perhaps be the focus for another study in this area. In relation to the learners, I have used the direction and length of the arrows to indicate their involvement in these processes. Thus, Nelisiwe, the 'unsuccessful' learner in this context, involved herself primarily in outward processes contributing to the construction of the ‘text’, and even here, only to a small extent. Mondli, the ‘partly-successful’ learner was involved to a greater extent, but perhaps with more emphasis still on the outward processes of ‘text’ construction. Kevin, Thandeka and Craig, the ‘successful’ learners in the context seemed to involve themselves extensively in both the outward processes of ‘text’ construction and the inward processes of ‘text’ interpretation and meaning-making.

These explanations define learner interaction in the context of collaborative groups as interaction with an emerging ‘text, and learning in this context with the extent to which individual learners contribute to the construction and interpretation of this ‘text’ in order to make meaning, both for themselves and for each other.

10.3 A critique – limitations experienced in this project.

The discussion which follows describes limitations of the teaching/learning context, including limitations related to the TRAC-PAC as an example of MBL technology, and limitations of the research project itself.

10.3.1 Limitations of the technology and teaching-learning context.

A number of limitations of the teaching-learning context and the technology have been identified at various stages of this dissertation, and these are pulled together here.

The structure of the learning programme itself, and the choices made about the nature of the learning activities, may be a contributing factor to the differential impact on learner understanding in relation to the four areas of difficulty which was observed in the study. For example, it may be that learner understanding of kinematic concepts (Area of difficulty A) did not improve significantly because there were not enough opportunities within the programme for learners to explore these concepts in a manner that contributed to their understanding of them. Thus, exposure to general MBL activities may not be enough to overcome all difficulties related to kinematic and kinematic graphs. Attention has to be paid to identifying the nature of the difficulties learners experience and activities designed to provide opportunities for learners to explore these difficulties.

Use of the technology requires a degree of expertise in relation to the use of computers and other hardware, for example the appropriate sensors, and use of appropriate software, in this case the MPLI programme. This can be a significant barrier to learners using the technology to its full potential.

Use of the technology in contexts like the one used in this project (which was modelled on the typical manner that learners use the TRAC PAC in the South African context), means that the teacher has to carry out a multiplicity of roles. These include technical assistant and trouble-shooter, computer software expert, interpreter of data, classroom manager, in addition to the teaching/supporting learning role, often in a large class context. It can happen that the important teaching role is overshadowed and undermined by the other roles that the teacher has to carry out.

Learners often view the ideas presented in traditional textbooks and other print-based communications as being completely authoritative and immune to challenge. This danger also exists for computer representations like those made available through the use of MBL technology. For example, learners can accept without question, flawed representations that can occur as a result of the experimental setting or incorrect use of the apparatus. The ability of learners to engage expertly with the processes of argumentation, and to use these processes to respond critically to all ideas, not just those 'voiced' by fellow-learners, can possibly contribute to the reduction of this problem.

All this points to the fact that viewing the use of this technology as an easy 'cure-all' for the difficulties learners can experience with kinematics and kinematic graphs is hugely problematic. Teachers, who want to implement this technology in their classrooms, need to do so in a manner which recognises its limitations and to attempt to minimise these in the design of the learning activities they use.

10.3.2 Limitations of the research project

Several possible weaknesses of the study exist. They include validity of the research tools, validity of the findings and fragmentation in the research approach. These are discussed in more detail in the paragraphs that follow.

Specific examples of alternative learner ideas and difficulties were chosen as the focus for the quantitative phase of this study. They were selected from a variety of difficulties in this area reported in the literature, and on the basis of difficulties that learners in a pilot study demonstrated. There was no guarantee that the particular group of learners, who were the subjects for this study, would hold these alternative ideas or exhibit these difficulties. This raises questions about the validity of the research instruments used; since the two vital tools designed for the study – the questionnaire and the learning programme – were based on selected alternative ideas and difficulties. However, if these selected learner ideas and difficulties (see Table 4.1) are compared with the alternative learner ideas and difficulties actually exhibited by this group of learners in their responses to the questionnaire (see Table 8.4) and in the argumentation and discussion/explanation interactions as they participated in the learning programme (see table 9.17), it can be observed that there is a good match between them, thus decreasing the potential impact of this weakness on the findings of the study.

Another possible area of concern is the use of the same questions in the pre-test and post-test, and thus the possibility of a 'test effect', where learning on the test itself, influenced the results that were observed. This possibility was taken into account in the design of the project and techniques were used to minimise this effect, including:

- Random mixing of the test questions in the post-test.
- Learners not being aware that they would write a post-test, nor being aware that the same questions would be used.
- Use of two-tier multiple-choice questions which required learners to match reasons with choices. This reduced the effect of guessing, and also meant that for learners to do this correctly consistently, they had to have some degree of understanding in relation to the idea that the question was based on.
- Use of more than one hypothesis in relation to a particular area of difficulty, and more than one question in relation to each hypothesis.

Through implementation of these measures, it was felt that the benefits of comparing performance on the same items outweighed the possible limitations of the 'test effect' influencing the data that was collected.

Subjectivity of analysis and interpretation of data is another area of concern for any study. This was not a major concern in the quantitative phase of this study, since data here was represented, analysed and interpreted in a largely statistical fashion, thus reducing subjective influences. Care was taken to employ statistical tools, for example the Stuart-Maxwell Test and the McNemar Test, which were suitable for small sample sizes. In this study, this concern related more to the qualitative phase described in Chapter 9 of this report. The method of analysis used here helped to minimise this weakness. Verbal analysis, as an analytic approach, combines qualitative and quantitative methodologies in an attempt to minimise subjectivity. However, coding of verbalisations into categories is still very much dependent on the interpretation of the person doing the categorization. Subjectivity of interpretation in this regard was minimised through setting up clearly defined categories for coding, and getting several people to code segments of data to achieve some form of standardization. The combination of quantitative and qualitative approaches in the study generated findings which supported and complemented rather than conflicted with each other, and this probably adds to their validity.

Hogan and Tudge (1999:40) write that:

> The application of Vygotsky's theory to collaborative problem solving (as to anything else) requires more than pairing a child with a competent other and focussing simply on the interactions between them (or for that matter, on the results of these interactions). Rather, it requires an interweaving of different aspects of development, including the individual and the cultural-historical as well as the interpersonal. (Hogan and Tudge, 1999: 40.)

This description encapsulates another possible limitation of this particular study, i.e. a fragmented rather than holistic approach. The study focuses on interactions of learners as they construct and interpret 'texts', and the results of these interactions on learning (one aspect of the complex learning web that develops), but does not capture the impact of other personal, interpersonal and social factors and the interplay between these factors and learning. For example, the role of the teacher as an important influence on learning in this context was not explored here. In defence of the study, contextual constraints (time, human and physical resources, etc.) have limited its scope. While the study does provide important insights into the aspect that has been focussed on, it is recognised that in order to gain an overall understanding of learning in this context, other factors have to be explored. These have been identified as important areas for further research.

10.4 Suggestions for further research

This research project has raised many questions in relation to learning in an MBL context, and some of these are identified below as possible directions for further research in this area:

- Learner pre-knowledge seemed to be an important variable that affected the potential for learning in this context. Research needs to be conducted into the minimum pre-knowledge required for learners to have a greater chance of success in this setting. For example, for learners who were over the 'threshold' level of 30% in the pre-test as observed in this study, what did they possess in terms of prior knowledge and skills that allowed them to be successful in this context?

- It was also observed that alternative learner ideas related to kinematics and kinematic graphs were inter-dependant and hierarchical in that the sense that overcoming difficulties in one, perhaps more advanced area, was dependent on understanding achieved in other areas. Thus, research needs to be conducted into an approach which allows learners to encounter these ideas in a developmental and scaffolded fashion, so that the impact of difficulties experienced in one area on the development of understanding in another, is minimised.

- The roles that different learners played in the collaborative group interactions seemed to be important for learning. For example, it was important that there were people in the group who held ideas that were 'in competition' with the alternative learner ideas proposed by others, if these ideas were to be challenged. Besides simply holding ideas which could challenge alternative ideas, learners needed to be willing and able to do so. In effect, learners needed to be willing to take responsibility for each other's learning. Thus, research into the composition of groups, the roles that learners needed to play, and the skills that are needed for them to carry out these roles effectively, needs to be conducted. Possible questions that arise are:
    - What are the essential skills required for effective participation in collaborative group interactions in an MBL context?
    - When, where and how should learners be given opportunities to develop these?

  In this regard, and in relation to this study of learners participating in MBL activities, skills and processes related to argumentation and discussion/explanation seemed to be particularly important.

- Mention has been made of the absence of the teacher's voice in this study, and thus the lack of exploration of the roles of the teacher in this learning context, and reasons for this in relation to this particular study have been suggested. However, it is realised that the teacher plays important roles in learning in this context, and research needs to be conducted into the nature of these roles and their impact on the kind of learning that takes place.

- It was noted in this study, that learner involvement in the programme overall, and in specific parts of the programme, varied quite extensively. Variation in participation patterns may be due to learners simply not being able to participate because of personal factors like lack of prior knowledge, and lack of skills needed to participate effectively in the group interactions. Besides personal factors, group dynamic factors also seemed to impact on learner involvement and participation. The kind of data collected in this study did not allow for an exploration of these factors. However, much more research needs to be conducted into the influence of both personal and social factors on learner involvement and learning in this context. The MBL collaborative group context provides excellent opportunities for research into small group dynamics, and into the intersection between science education and issues of social justice (this term is used very broadly to incorporate factors like language, differential ability, race, gender, issues of power etc), an intersection which is vital given the current South African education context.

An overarching question to guide the various research suggestions here could be: "What features, characteristics and factors (personal and social) impact on the learning experiences of learners in the collaborative group context, and how do these factors operate to facilitate the participation and thus potential success of some learners, but exclude others?

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List of Appendices

Appendix 1

Workshop invitation flyer

TRAC
South Africa

invites

Grade 11 and 12 Physical Science learners

to participate
in a

3-day research workshop

on

Kinematics and Kinematic Graphs (Graphs of Motion)

- **Did you know that examination questions which require understanding of kinematics and kinematics graphs usually make up a significant portion of the final matric higher grade Physical Science examination paper?**
- **Do you have difficulty understanding kinematics and kinematics graphs and answering examination-type questions in this area?**

THEN THIS WORKSHOP IS FOR YOU!

What's it all about?

TRAC SA is an organisation based at the University of Stellenbosch, but operating in various provinces in South Africa, including Kwazulu-Natal. One of its aims is to make learners aware of career opportunities in Engineering, Science and Technology and to help learners prepare for further study in these fields. One of the ways it does this is to support science teaching and learning through the provision and placement of TRAC PAC's in schools and in TRAC LABs set up at tertiary institutions.
The TRAC PAC is a micro-computer based laboratory which uses sensors connected to a computer to collect data, which the computer is able to display graphically.
We are looking for twenty grade 11 or grade 12 learners to participate in a 3 - day research workshop where they will participate in hands-on motion experiments using the TRAC-PAC.

What will be expected of you?

- Complete a questionnaire and possibly participate in a short interview before and after the workshop so that we can determine how your understanding of kinematics and kinematic graphs has grown.
- Participate fully in the workshops over three days.

N.B. you must have already worked through this section of the syllabus with your teacher. This workshop is designed to extend your understanding.

Details of the workshop.

Venue: School of Education, Training and Development, University of Natal, Pietermaritzburg.

Dates: 1st, 2nd and 3rd April 2003.

Cost: Free on a first-come, first serve basis. Lunch will also be provided.

Closing date: Application forms must reach Mr W. Green at the School of Education, Training and Development, University of Natal, before 7 March 2003.

Interested? Then fill in the form overleaf and return ASAP to your teacher

Appendix 2

Workshop reply form

Graphs of Motion Workshop Reply Form

Yes, I want to participate in the TRAC SA Graphs of Motion workshop to be held at the University of Natal from 1st - 3rd April 2003.

My details are:

Name: ....

Grade: ....

School: ....

Residential address:
....
....
....

Learners participating in motion experiments using the TRAC PAC.

Postal address:
....
....
....

Telephone number(s):

.... (h) .... (cell)

I agree that in accepting a place on the workshop, I will attend for the full three days and participate fully in all the activities during the workshop.

....
Learner signature

Parental Permission

I, ...,
parent/guardian of ....
hereby agree to my son/daughter/ward's participation in this workshop.

....
Parent signature

If you require more information about this workshop, please contact:

Mr WJ Green
School of Education, Training and Development
University of Natal
Private Bag X01
Scottsville
3209
South Africa

Tel: (033) 260 5912 (w)

Fax: (033) 260 5080

Cell: 082 322 9065

greenw@nu.ac.za

Appendix 3
Pre-Questionnaire

Dear Learner

Welcome to the Kinematics/graphs of motion workshop. Thanks for participating. I am sure that you will learn much from it. Please provide me with the following details.

1. Name: ……………………………………………………………………

2. Present School: ……………………………………………………………………

3. Grade: (tick one) Grade 11: ☐ Grade 12: ☐

4. Gender: (tick one) Male: ☐ Female: ☐

5. First Language: ……………………………………………………………………

6. Language in which Physical Science is taught to you at school:

   ……………………………………………………………………

7. Grade on which you are studying Physical Science: HG ☐ SG ☐

8. My Physical Science result at the end of my last grade was:

☐ less than 40% ☐ between 40 and 49% ☐ between 50 and 59%

☐ between 60 and 69% ☐ between 70 and 79% ☐ greater than 80%

9. Have you received any formal teaching in motion and graphs of motion?

   ☐ YES ☐ NO

   If yes, when did this take place?

   ……………………………………………………………………

   ……………………………………………………………………

10. Please tick the options which describes your experience with computers. Note that you can tick more than 1 box.

    I am computer literate. ☐ YES ☐ NO

    I have access to a computer at home which I use often. ☐ YES ☐ NO

    I have access to computers at school which I use often. ☐ YES ☐ NO

Pre-Questionnaire
Multiple Choice with reasons

Instructions:

This test is made up of 16 multiple-choice questions. There are four options to choose from for each question (A, B, C and D), and three possible reasons to support the choice of an option (i, ii and iii). Circle or tick the option that you think is most correct, and the reason which best supports your choice.

You will be given a response sheet with blocks on it like the one shown below for each of the questions that you have to answer. Mark your choices in the boxes. For example, if you think that the correct answer to question 1 is option A, and the correct reason to support this choice is option ii, then you should mark those in the boxes as shown:

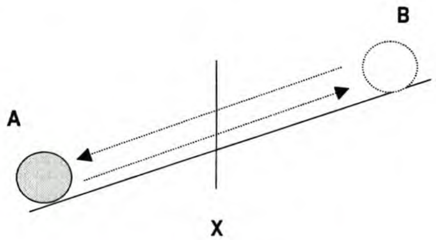
Question 1	A	B	C	D	i	ii	iii	iv

Hand in both the question paper, and the response sheet when you have answered all the questions.

Relax, and remember that the main aim here is to help you develop a better understanding of this important area of physical science.

Question 1

A ball is pushed and rolls up and then down a slope. It starts at position A, through the midpoint X, to position B where it stops momentarily and changes direction, rolling back down to A.
Consider X to be the reference point of the motion and movement up the slope to be positive.



Which one of the following options fit the motion described here?

A: The magnitude and direction of the acceleration of the ball at A, B and X is the same.

B: The acceleration of the ball is greatest at A, smaller at X and zero at B.

C: The magnitude of the acceleration is the same at A, B and X, but its direction changes as it moves up and then down the slope.

D: The acceleration is positive as the ball moves up the slope, and negative as the ball comes down.

because...

i. the ball goes slower and slower as it moves up the slope, so its acceleration is decreasing, and faster and faster as it comes down, so its acceleration is increasing. It stops for a short time at the top, so its acceleration has to be zero there.

ii. the ball is moving in the positive direction as it goes up the slope, so its acceleration must be positive then. As it comes down, it's moving in the negative direction, so its acceleration must be negative.

iii. the acceleration of the ball does not change as it goes up and down the slope because the force causing the acceleration does not change as it moves up and down the slope.

iv. I guessed the answer / this answer just seems most correct.

Question 2

When an object that is traveling in a straight line covers greater consecutive (one after the other) distances in the same period of time, it means that:

A: its velocity is increasing.

B: its acceleration is increasing.

C: it has a positive acceleration.

D: it has a positive velocity.

because...

i. when the speed of an object increases, it has a positive acceleration, and when its speed decreases it has a negative acceleration.

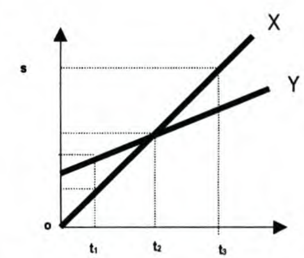
ii. a positive velocity means that the object is going faster and faster, and a negative velocity means that the object is going slower and slower.

iii. if one distance is greater than another, and the object takes equal time to cover the greater distance, it must have been moving faster.

iv. I guessed the answer / this answer just seems most correct.

Question 3

The motion of two objects, X and Y, are represented in the displacement-time graph drawn alongside:



A: At time = t_1 ,object Y is moving faster than object X.

B: At time = t_1, object X is moving faster than object Y.

C: At time = t_2, object X and Y are moving at the same speed.

D: At time = t_3, object Y is moving faster than object X.

because...

i. the objects have the same speed at t_2 because their graphs meet at this point.

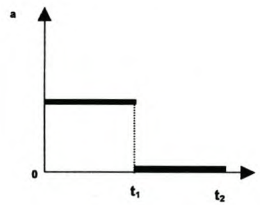
ii. graph Y is higher than graph X at t_1.

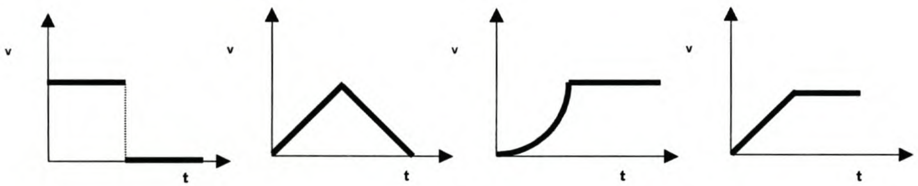
iii. the gradient of graph X is greater than that of graph Y.

iv. I guessed the answer / this answer just seems most correct.

Question 4

The acceleration-time graph alongside refers to the movement of a lift that moves upwards from rest. The velocity-time graph for the movement of the lift is best represented by:





A B C D

because...

i. the lift travels at a constant velocity between 0 and t_1 where it stops. It does not move between t_1 and t_2.

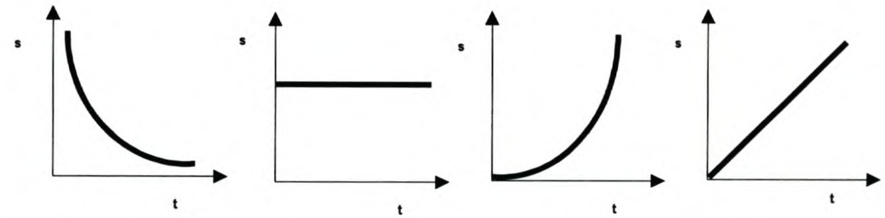
ii. the speed of the lift increases uniformly between 0 and t_1. It moves with a uniform velocity between t_1 and t_2.

iii. the lift goes up at a constant velocity, stops and then comes down with the same constant velocity.

iv. I guessed the answer / this answer just seems most correct.

Question 5

A ball-bearing (small steel ball) is released and falls to the ground. Consider friction to be negligible. Which one of the following graphs best represents the relationship between its displacement(s) and the time (t)?



A B C D

because...

i. the ball-bearing's velocity increases uniformly under the influence of gravity.

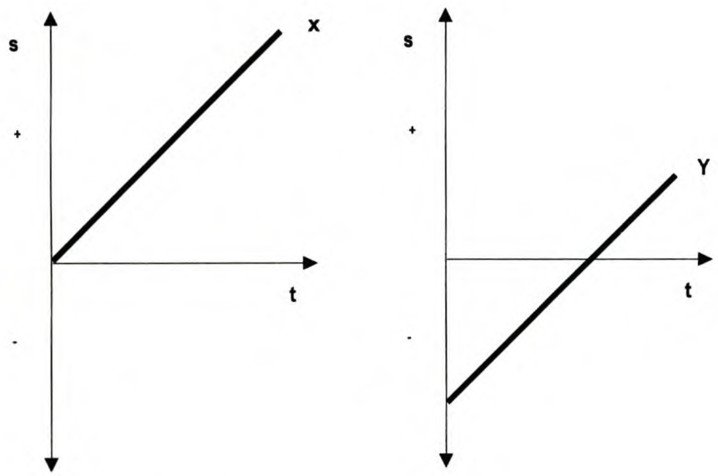
ii. the velocity is constant because the acceleration is constant.

iii. the acceleration of the ball-bearing increases because it is moving faster and faster.

iv. I guessed the answer / this answer just seems most correct.

Question 6

Consider the displacement-time graphs represented by X and Y below:



A: The object in X is moving only in a positive direction while the object in Y is moving in a negative and then in a positive direction.
B: It is not possible that X and Y can be graphs representing the motion of the same object.
C: It is possible that X and Y can be graphs representing the motion of the same object.
D: The object in X is moving at the same speed whereas the object in Y is moving slowly at first, and then faster.

because...

i. the motion of one object cannot be represented by two different displacement-time graphs.

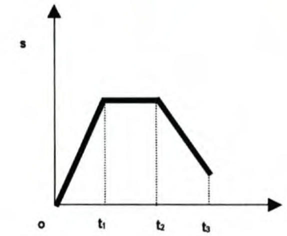
ii. graph X and graph Y represent the motion of the same object, but represented from different reference points.

iii. graph Y crosses the x-axis and this indicates that it has changed direction.

iv. I guessed the answer / this answer just seems most correct.

Question 7

The displacement–time graph for part of the motion of an object is shown alongside. Consider the part of the graph from t_2 to t_3. This part of the graph indicates that:



A: The object was moving in a negative direction at a constant velocity.

B: The object was slowing down and will eventually stop.

C: The object was going downhill.

D: The object was moving in a negative direction, and was slowing down.

because...

i. the object's speed increases, reaches a constant and then decreases.

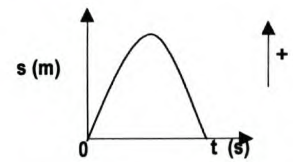
ii. the object's speed is decreasing and it will stop once the graph reaches the x-axis.

iii. the object is moving in the opposite direction to the initial motion since the gradient of the graph is negative.

iv. I guessed the answer / this answer just seems most correct.

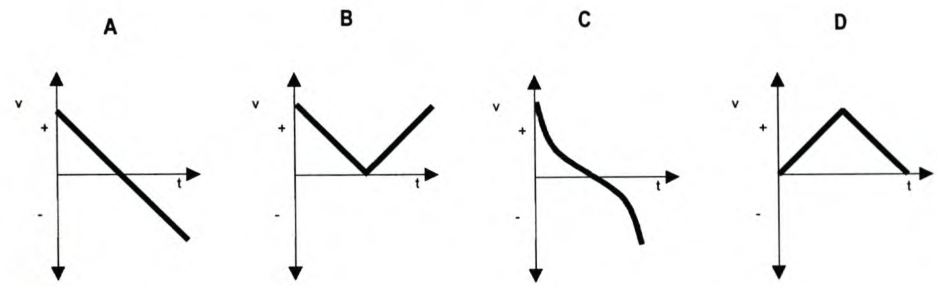
Questions 8 and 9 refer to the scenario described below:

The graph alongside is a displacement-time graph representing the motion of a ball as it is thrown upwards and then caught. Displacement upward is positive.



Question 8

The correct velocity-time sketch graph for the motion of the ball is:



because...

i. the ball has a uniformly decreasing positive velocity as it goes up, and a uniformly increasing negative velocity as it comes down.

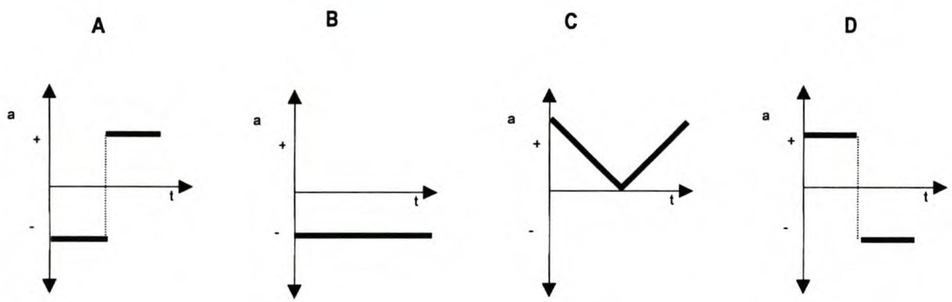
ii. the ball's velocity becomes more negative as it slows down and becomes more positive as it speeds up.

iii. the velocity is positive at first because the ball is moving in the positive direction, and negative when it is moving in the negative direction.

iv. I guessed the answer / this answer just seems most correct.

Question 9

The correct acceleration-time sketch graph for the motion of the ball is:



because...

i. the acceleration is negative as the ball goes up because it is slowing down, and positive as the ball comes down because it is speeding up.

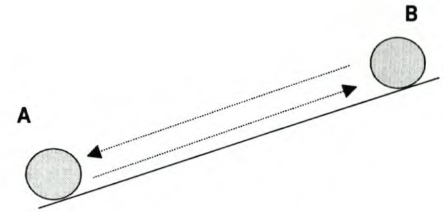
ii. the acceleration is negative throughout the motion of the ball because this is dependent on the direction of the force causing the acceleration.

iii. the acceleration is positive as the ball goes up, because it is moving in the positive direction, and negative as it comes down, because it is moving in the negative direction.

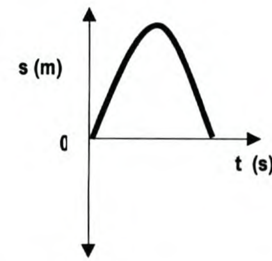
iv. I guessed the answer / this answer just seems most correct.

Question 10

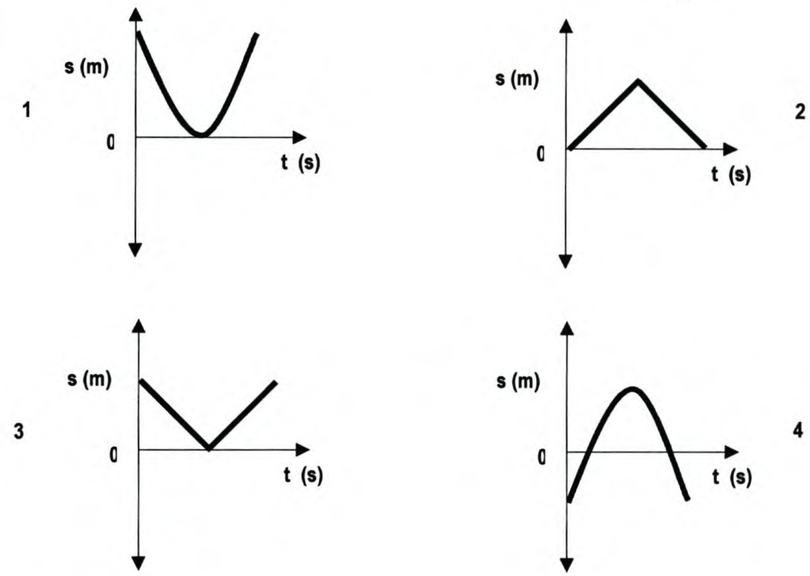
The diagram alongside shows a ball rolling up and down a slope. The ball starts at position A, moves to position B where it stops and changes direction. It then rolls down the slope to A.



A sketch of the displacement-time graph for this motion is shown alongside.



The following displacement-time graphs can also be drawn to represent this motion:



A: 1 and 2

B: 1 and 4

C: 2 and 3

D: 2 and 4

because...

ii. in the two new graphs chosen, only the reference directions of both the graphs have been changed.

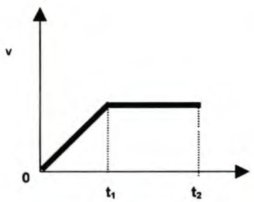
ii. in the two new graphs chosen, only the reference points of both graphs have been changed.

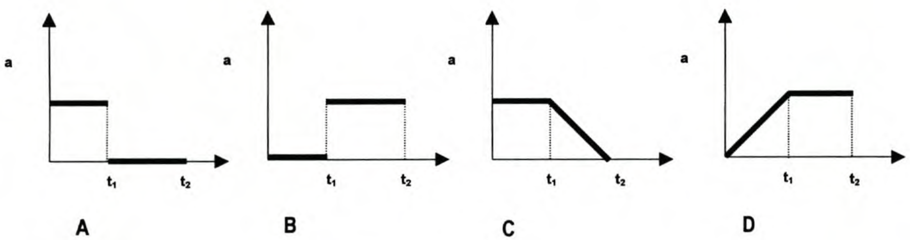
iii. in the two new graphs chosen, different reference points were chosen for both graphs and the reference direction of one of the graphs was changed.

iv. I guessed the answer / this answer just seems most correct.

Question 11

Consider the velocity-time graph of an object moving in a straight line alongside. The corresponding acceleration-time graph for this motion will be:





because...

i. the object moves with a constant velocity and then slows down and stops.

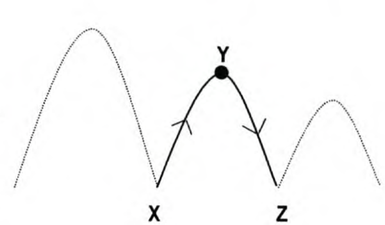
ii. the acceleration first increases because the object is speeding up and then the acceleration remains constant because the object is moving at a uniform velocity.

iii. the object accelerates uniformly and then moves with a constant velocity.

iv. I guessed the answer / this answer just seems most correct.

Question 12

The picture alongside shows a ball bouncing. Consider the middle bounce. X indicates a point where it leaves the surface, Y indicates the highest point it reaches and Z indicates a point where it hits the surface again.



Choose one of the options below to describe the displacement (s), velocity (v) and acceleration (a) of the ball **at point Y** during the middle bounce.

	s	v	a
A	zero	maximum	maximum
B	maximum	zero	maximum
C	maximum	zero	zero
D	zero	zero	zero

because...

i it is at rest, furthest away from it's starting point X, and so cannot be accelerating.

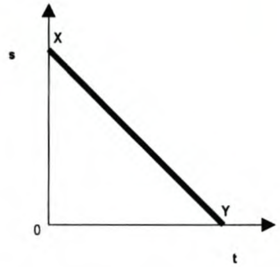
ii. it is at rest, furthest away from its starting point Y, but its acceleration does not change through the entire motion.

iii. an object that is not moving cannot be accelerating.

iv. I guessed the answer / this answer just seems most correct.

Question 13

The displacement-time graph for part of the motion of a rolling ball is shown alongside.



A: The ball is rolling down an incline away from its starting point.

B: The ball stops at point Y.

C: The ball is moving in a negative direction.

D: The ball is slowing down.

because...

i. the negative gradient indicates that the object is moving in a negative direction.

ii the negative gradient means that the object is slowing down.

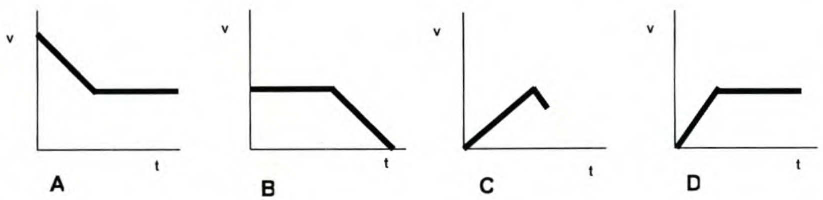
iii. the graph touches the x-axis at point Y, so the object is not moving at this point.

iv. I guessed the answer / this answer just seems most correct.

Question 14

A frictionless trolley starts from rest and runs down a sloping runway then over a frictionless horizontal plane.

Which one of the following graphs of velocity versus time best represents the motion of the trolley.



because...

i. the velocity will increase as the trolley rolls down the slope and become constant as it moves across the horizontal plane.

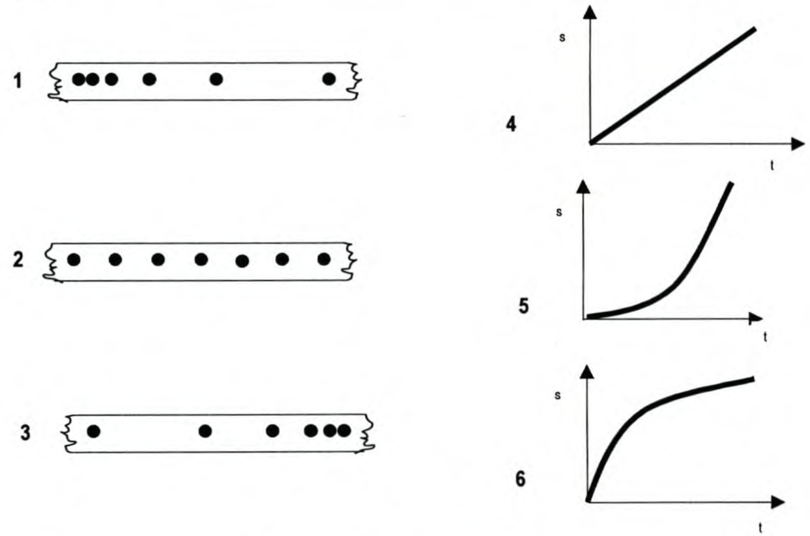
ii. the velocity increases as it rolls down the slope. It then slows down and eventually stops as it moves along the horizontal plane.

iii. the acceleration increases as the trolley moves down the slope and then it moves with a constant acceleration over the horizontal plane.

iv. I guessed the answer / this answer just seems most correct.

Question 15

The following are sketches of three ticker timer tapes of the same length that were pulled through the same ticker timer. In each case the tape was attached to a moving trolley which pulled the tape through the timer, and in each case, the left-hand side of the tape was attached to the trolley. Displacement-time graphs that were generated using the ticker tapes are also shown.



Choose the combination below which is a correct match of the ticker tapes and graphs:

A: 1 with 4, 2 with 5 and 3 with 6.
B: 1 with 6, 2 with 4 and 3 with 5.
C: 1 with 5, 2 with 6 and 3 with 4.
D: 1 with 5, 2 with 4 and 3 with 6.

because...

i. 1 is moving with a uniform velocity, 2 is moving faster and faster and 3 is moving slower and slower.

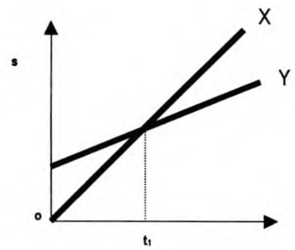
ii. 1 is moving faster and faster, 2 is moving with a uniform velocity and 3 is moving slower and slower.

iii. 1 is moving slower and slower, 2 is moving with a uniform velocity and 3 is moving faster and faster.

iv. I guessed the answer / this answer just seems most correct.

Question 16

The motion of two objects, X and Y, are represented in the displacement-time graph drawn alongside:



For the time period $t = 0$ to $t = t_1$:

A: Object X has covered approximately half the distance that object Y has.

B: Object X has covered a greater distance than object Y.

C: Object Y has covered a greater distance than object X.

D: The objects have covered equal distances.

because...

i. the change in height of graph X is greater than that of graph Y between $t = 0$ to $t = t_1$.

ii. the area under graph X is greater than the area under graph Y between $t = 0$ to $t = t_1$.

iii. object X and Y are at the same position at t_1.

iv. I guessed the answer / this answer just seems most correct.

Pre-Questionnaire Response Sheet

Name: ....

Question 1	**A**	B	C	D	i	ii	**iii**	iv
Question 2	**A**	B	C	D	i	ii	**iii**	iv
Question 3	A	**B**	C	D	i	ii	**iii**	iv
Question 4	A	B	C	**D**	i	ii	**iii**	iv
Question 5	A	B	**C**	D	**i**	ii	iii	iv
Question 6	A	B	**C**	D	i	**ii**	iii	iv
Question 7	**A**	B	C	D	i	ii	**iii**	iv
Question 8	**A**	B	C	D	**i**	ii	**iii**	iv
Question 9	A	**B**	C	D	i	**ii**	iii	iv
Question 10	A	**B**	C	D	i	ii	iii	iv
Question 11	**A**	B	C	D	i	ii	**iii**	iv
Question 12	A	**B**	C	D	i	**ii**	iii	iv
Question 13	A	B	**C**	D	**i**	ii	iii	iv
Question 14	A	B	C	**D**	**i**	ii	iii	iv
Question 15	A	B	C	**D**	i	**ii**	iii	iv
Question 16	A	**B**	C	D	i	ii	**iii**	iv

Appendix 4
Post-Questionnaire

Post-Questionnaire
Multiple Choice with reasons

Your name

Instructions:

This test is made up of 16 multiple-choice questions. There are four options to choose from for each question (A, B, C and D), and three possible reasons to support the choice of an option (i, ii and iii). Circle or tick the option that you think is most correct, and the reason which best supports your choice.

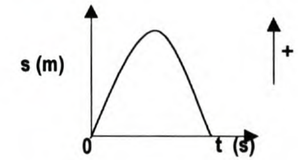
You will be given a response sheet with blocks on it like the one shown below for each of the questions that you have to answer. Mark your choices in the boxes. For example, if you think that the correct answer to question 16 is option A, and the correct reason to support this choice is option ii, then you should mark those in the boxes as shown:

Question 16	A	B	C	D	i	ii	iii	iv

Hand in both the question paper, and the response sheet when you have answered all the questions.

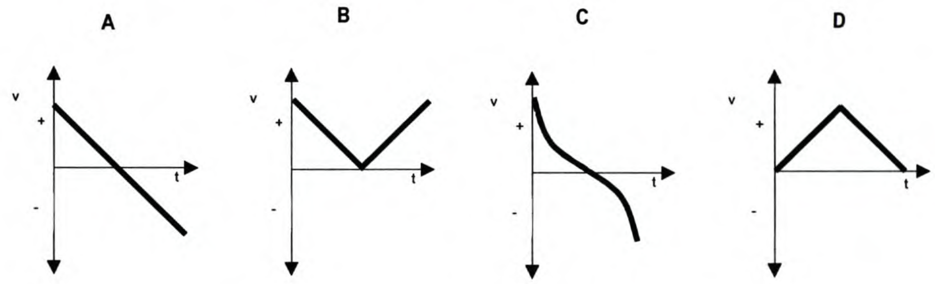
Questions 1 and 2 refer to the scenario described below:

The graph alongside is a displacement-time graph representing the motion of a ball as it is thrown upwards and then caught. Displacement upward is positive.



Question 1

The correct velocity-time sketch graph for the motion of the ball is:



because...

i. the ball has a uniformly decreasing positive velocity as it goes up, and a uniformly increasing negative velocity as it comes down.

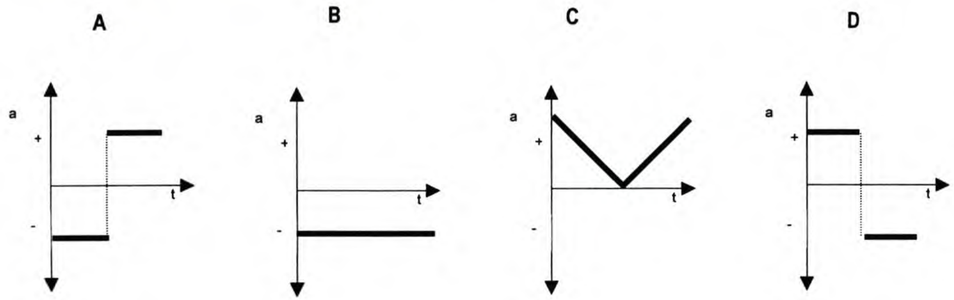
ii. the ball's velocity becomes more negative as it slows down and becomes more positive as it speeds up.

iii. the velocity is positive at first because the ball is moving in the positive direction, and negative when it is moving in the negative direction.

iv. I guessed the answer / this answer just seems most correct.

Question 2

The correct acceleration-time sketch graph for the motion of the ball is:



because...

i. the acceleration is negative as the ball goes up because it is slowing down, and positive as the ball comes down because it is speeding up.

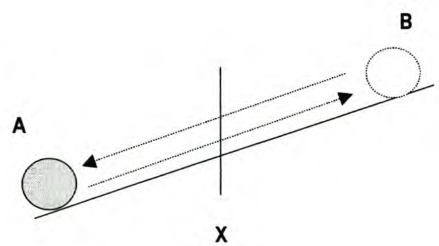
ii. the acceleration is negative throughout the motion of the ball because this is dependent on the direction of the force causing the acceleration.

iii. the acceleration is positive as the ball goes up, because it is moving in the positive direction, and negative as it comes down, because it is moving in the negative direction.

iv. I guessed the answer / this answer just seems most correct.

Question 3

A ball is pushed and rolls up and then down a slope. It starts at position A, through the midpoint X, to position B where it stops momentarily and changes direction, rolling back down to A.
Consider X to be the reference point of the motion and movement up the slope to be positive.



Which one of the following options fit the motion described here?

A: The magnitude and direction of the acceleration of the ball at A, B and X is the same.

B: The acceleration of the ball is greatest at A, smaller at X and zero at B.

C: The magnitude of the acceleration is the same at A, B and X, but its direction changes as it moves up and then down the slope.

D: The acceleration is positive as the ball moves up the slope, and negative as the ball comes down.

because...

i. the ball goes slower and slower as it moves up the slope, so its acceleration is decreasing, and faster and faster as it comes down, so its acceleration is increasing. It stops for a short time at the top, so its acceleration has to be zero there.

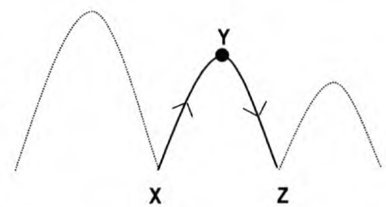
ii. the ball is moving in the positive direction as it goes up the slope, so its acceleration must be positive then. As it comes down, it's moving in the negative direction, so its acceleration must be negative.

iii. the acceleration of the ball does not change as it goes up and down the slope because the force causing the acceleration does not change as it moves up and down the slope.

iv. I guessed the answer / this answer just seems most correct.

Question 4

The picture alongside shows a ball bouncing. Consider the middle bounce. X indicates a point where it leaves the surface, Y indicates the highest point it reaches and Z indicates a point where it hits the surface again.



Choose one of the options below to describe the displacement (s), velocity (v) and acceleration (a) of the ball **at point Y** during the middle bounce, given that the floor is the reference level, and up is positive.

	s	v	a
A	zero	maximum	maximum
B	maximum	zero	maximum
C	maximum	zero	zero
D	zero	zero	zero

because...

i it is at rest, furthest away from it's starting point X, and so cannot be accelerating.

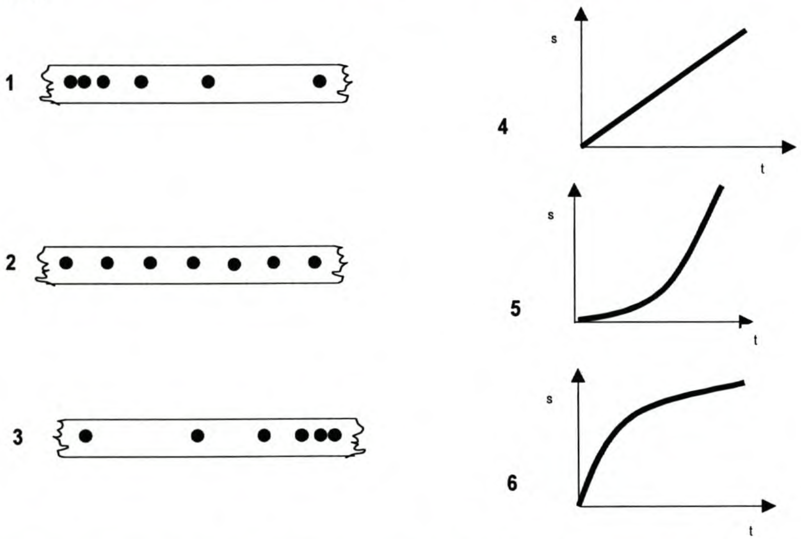
ii. it is at rest, furthest away from its starting point Y, but its acceleration does not change through the entire motion.

iii. an object that is not moving cannot be accelerating.

iv. I guessed the answer / this answer just seems most correct.

Question 5

The following are sketches of three ticker timer tapes of the same length that were pulled through the same ticker timer. In each case the tape was attached to a moving trolley which pulled the tape through the timer, and in each case, the left-hand side of the tape was attached to the trolley. Displacement-time graphs that were generated using the ticker tapes are also shown.



Choose the combination below which is a correct match of the ticker tapes and graphs:

A: 1 with 4, 2 with 5 and 3 with 6.
B: 1 with 6, 2 with 4 and 3 with 5.
C: 1 with 5, 2 with 6 and 3 with 4.
D: 1 with 5, 2 with 4 and 3 with 6.

because...

i. 1 is moving with a uniform velocity, 2 is moving faster and faster and 3 is moving slower and slower.

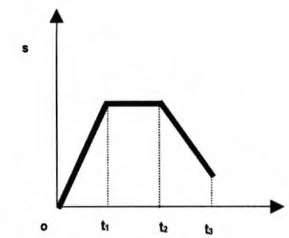
ii. 1 is moving faster and faster, 2 is moving with a uniform velocity and 3 is moving slower and slower.

iii. 1 is moving slower and slower, 2 is moving with a uniform velocity and 3 is moving faster and faster.

iv. I guessed the answer / this answer just seems most correct.

Question 6

The displacement–time graph for part of the motion of an object is shown alongside. Consider the part of the graph from t_2 to t_3. This part of the graph indicates that:



A: The object was moving in a negative direction at a constant velocity.

B: The object was slowing down and will eventually stop.

C: The object was going downhill.

D: The object was moving in a negative direction, and was slowing down.

because...

i. the object's speed increases, reaches a constant and then decreases.

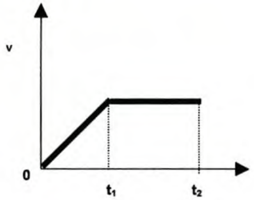
ii. the object's speed is decreasing and it will stop once the graph reaches the x-axis.

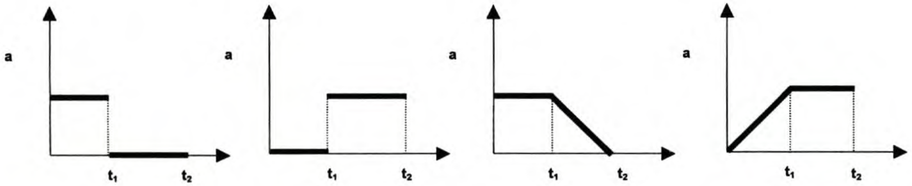
iii. the object is moving in the opposite direction to the initial motion since the gradient of the graph is negative.

iv. I guessed the answer / this answer just seems most correct.

Question 7

Consider the velocity-time graph of an object moving in a straight line alongside. The corresponding acceleration-time graph for this motion will be:





A **B** **C** **D**

because...

i. the object moves with a constant velocity and then slows down and stops.

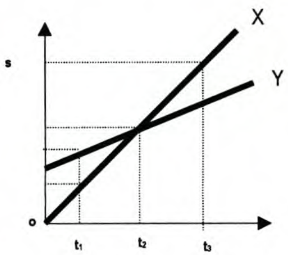
ii. the acceleration first increases because the object is speeding up and then the acceleration remains constant because the object is moving at a uniform velocity.

iii. the object accelerates uniformly and then moves with a constant velocity.

iv. I guessed the answer / this answer just seems most correct.

Question 8

The motion of two objects, X and Y, are represented in the displacement-time graph drawn alongside:



A: At time = t_1, object Y is moving faster than object X.

B: At time = t_1, object X is moving faster than object Y.

C: At time = t_2, object X and Y are moving at the same speed.

D: At time = t_3, object Y is moving faster than object X.

because...

i. the objects have the same speed at t_2 because their graphs meet at this point.

ii. graph Y is higher than graph X at t_1.

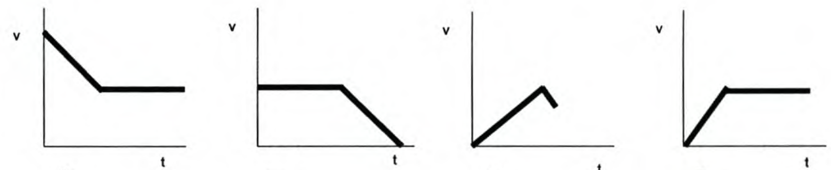
iii. the gradient of graph X is greater than that of graph Y.

iv. I guessed the answer / this answer just seems most correct.

Question 9

A frictionless trolley starts from rest and runs down a sloping runway then over a frictionless horizontal plane.

Which one of the following graphs of velocity versus time best represents the motion of the trolley.



A **B** **C** **D**

because...

i. the velocity will increase as the trolley rolls down the slope and become constant as it moves across the horizontal plane.

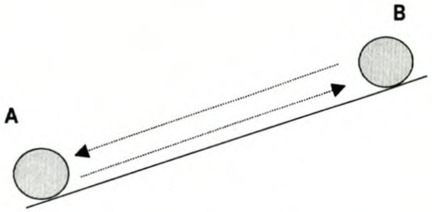
ii. the velocity increases as it rolls down the slope. It then slows down and eventually stops as it moves along the horizontal plane.

iii. the acceleration increases as the trolley moves down the slope and then it moves with a constant acceleration over the horizontal plane.

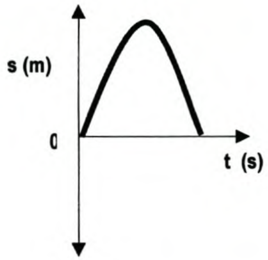
iv. I guessed the answer / this answer just seems most correct.

Question 10

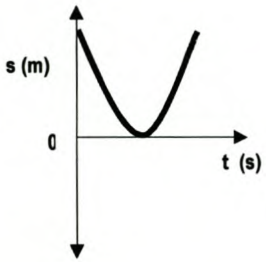
The diagram alongside shows a ball rolling up and down a slope. The ball starts at position A, moves to position B where it stops and changes direction. It then rolls down the slope to A.

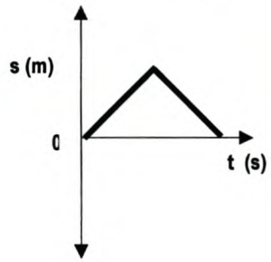


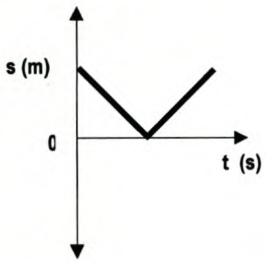
A sketch of the displacement-time graph for this motion is shown alongside.

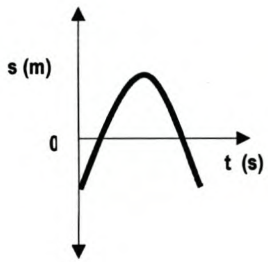


The following displacement-time graphs can also be drawn to represent this motion:

1


2


3


4


A: 1 and 2

B: 1 and 4

C: 2 and 3

D: 2 and 4

because...

ii. in the two new graphs chosen, only the reference directions of both the graphs have been changed.

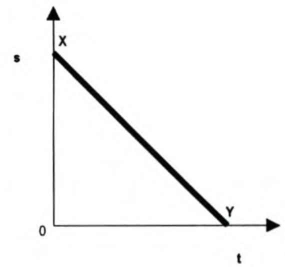
ii. in the two new graphs chosen, only the reference points of both graphs have been changed.

iii. in the two new graphs chosen, different reference points were chosen for both graphs and the reference direction of one of the graphs was changed.

iv. I guessed the answer / this answer just seems most correct.

Question 11

The displacement-time graph for part of the motion of a rolling ball is shown alongside.



A: The ball is rolling down an incline away from its starting point.

B: The ball stops at point Y.

C: The ball is moving in a negative direction.

D: The ball is slowing down.

because...

i. the negative gradient indicates that the object is moving in a negative direction.

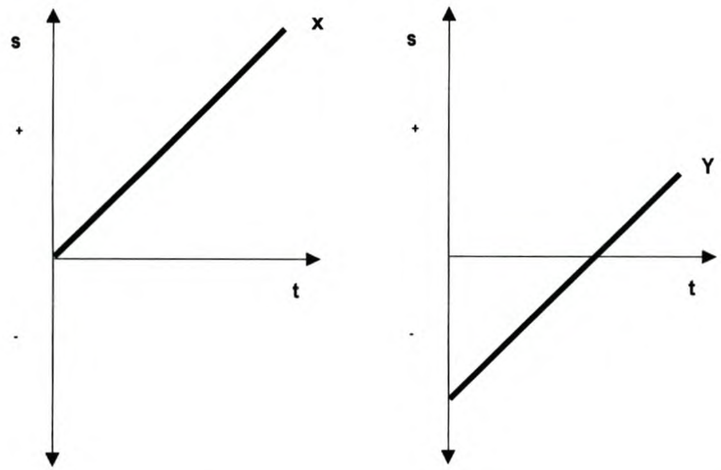
ii the negative gradient means that the object is slowing down.

iii. the graph touches the x-axis at point Y, so the object is not moving at this point.

iv. I guessed the answer / this answer just seems most correct.

Question 12

Consider the displacement-time graphs represented by X and Y below:



A: The object in X is moving only in a positive direction while the object in Y is moving in a negative and then in a positive direction.
B: It is not possible that X and Y can be graphs representing the motion of the same object.
C: It is possible that X and Y can be graphs representing the motion of the same object.
D: The object in X is moving at the same speed whereas the object in Y is moving slowly at first, and then faster.

because...

i. the motion of one object cannot be represented by two different displacement-time graphs.

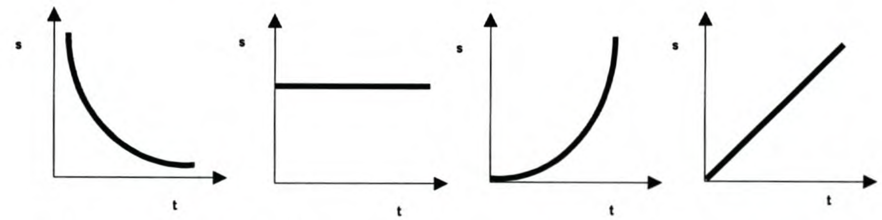
ii. graph X and graph Y represent the motion of the same object, but represented from different reference points.

iii. graph Y crosses the x-axis and this indicates that it has changed direction.

iv. I guessed the answer / this answer just seems most correct.

Question 13

A ball-bearing (small steel ball) is released and falls to the ground. Consider friction to be negligible. Which one of the following graphs best represents the relationship between its displacement(s) and the time (t)?



A B C D

because...

i. the ball-bearing's velocity increases uniformly under the influence of gravity.

ii. the velocity is constant because the acceleration is constant.

iii. the acceleration of the ball-bearing increases because it is moving faster and faster.

iv. I guessed the answer / this answer just seems most correct.

Question 14

When an object that is traveling in a straight line covers greater consecutive (one after the other) distances in the same period of time, it means that:

A: its velocity is increasing.

B: its acceleration is increasing.

C: it has a positive acceleration.

D: it has a positive velocity.

because...

i. when the speed of an object increases, it has a positive acceleration, and when its speed decreases it has a negative acceleration.

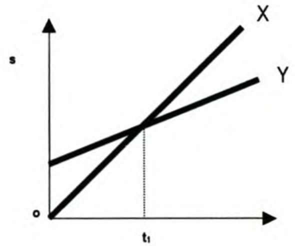
ii. a positive velocity means that the object is going faster and faster, and a negative velocity means that the object is going slower and slower.

iii. if one distance is greater than another, and the object takes equal time to cover the greater distance, it must have been moving faster.

iv. I guessed the answer / this answer just seems most correct.

Question 15

The motion of two objects, X and Y, are represented in the displacement-time graph drawn alongside:



For the time period $t = 0$ to $t = t_1$:

A: Object X has covered approximately half the distance that object Y has.

B: Object X has covered a greater distance than object Y.

C: Object Y has covered a greater distance than object X.

D: The objects have covered equal distances.

because...

i. the change in height of graph X is greater than that of graph Y between $t = 0$ to $t = t_1$.

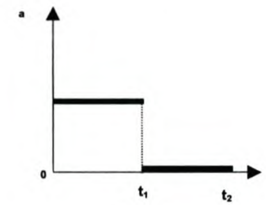
ii. the area under graph X is greater than the area under graph Y between $t = 0$ to $t = t_1$.

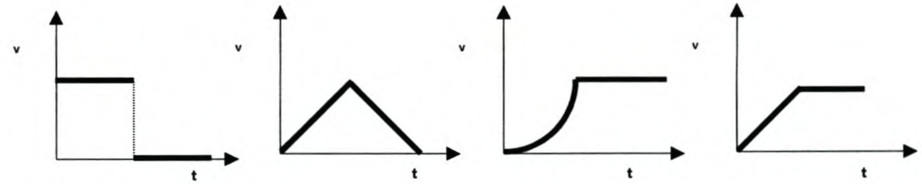
iii. object X and Y are at the same position at t_1.

iv. I guessed the answer / this answer just seems most correct.

Question 16

The acceleration-time graph alongside refers to the movement of a lift that moves upwards from rest. The velocity-time graph for the movement of the lift is best represented by:





A B C D

because...

i. the lift travels at a constant velocity between 0 and t_1 where it stops. It does not move between t_1 and t_2.

ii. the speed of the lift increases uniformly between 0 and t_1. It moves with a uniform velocity between t_1 and t_2.

iii. the lift goes up at a constant velocity, stops and then comes down with the same constant velocity.

iv. I guessed the answer / this answer just seems most correct.

Post-Questionnaire Response Sheet

Name: ....

Question 1	**A**	B	C	D	**i**	ii	**iii**	iv
Question 2	A	**B**	C	D	i	**ii**	iii	iv
Question 3	**A**	B	C	D	i	ii	**iii**	iv
Question 4	A	**B**	C	D	i	**ii**	iii	iv
Question 5	A	B	C	**D**	i	ii	**iii**	iv
Question 6	**A**	B	C	D	i	ii	**iii**	iv
Question 7	**A**	B	C	D	i	ii	**iii**	iv
Question 8	A	**B**	C	D	i	ii	**iii**	iv
Question 9	A	B	C	**D**	**i**	ii	iii	iv
Question 10	A	**B**	C	D	i	ii	**iii**	iv
Question 11	A	B	**C**	D	**i**	ii	iii	iv
Question 12	A	B	**C**	D	i	**ii**	iii	iv
Question 13	A	B	**C**	D	**i**	ii	iii	iv
Question 14	**A**	B	C	D	i	ii	**iii**	iv
Question 15	A	**B**	C	D	**i**	ii	iii	iv
Question 16	A	B	C	**D**	i	**ii**	iii	iv

Appendix 5
Questionnaires Specification Grid

The table below shows the four main areas in kinematics and kinematics graphs that learners have difficulty in. A **selection** of specific difficulties is used as an indicator in this research to determine the effect of the use of MBL technology on learner understanding in the four areas. Two questions are included for each difficulty, so four questions focus on one particular area. Each question is given a code for analysis purposes, and the final two columns show the actual number for each question in the pre- and post-questionnaire, given that the same questions are used in both.

Area of difficulty	Two examples of specific difficulties that learners experience in this area	Question code for analysis purposes	Question number	
			In pre-test	In post-test
A: Problems associated with conceptual understanding of kinematic quantities.	1.The learner has a weak understanding of different kinematic concepts and thus experiences difficulty differentiating between kinematic quantities.	A1.1	2	14
		A1.2	15	5
	2. The learner has difficulty accepting that an object at rest (e.g. a bouncing ball at the top of its path) can still be accelerating, and that the acceleration remains constant throughout the motion.	A2.1	12	4
		A2.2	1	3
B: Problems associated with reference points, sign convention and negative kinematic quantities.	1. The learner does not recognise that reference points and positive and negative signs to represent direction of the motion are arbitrarily allocated.	B1.1	6	12
		B1.2	10	10
	2. The learner associates the sign of velocity and/or acceleration with the magnitude of these quantities rather than with the direction of movement (in the case of velocity) and the direction of the resultant force (in the case of acceleration).	B2.1	8	1
		B2.2	9	2

C: Graph translation and transformation difficulties.	1. The learner draws/chooses a graph which closely resembles the shape of the path that the object takes.	C1.1	14	9
		C1.2	5	13
	2. The learner cannot distinguish between different kinematic graphs representing the same motion. Draws/chooses graphs that resemble each other.	C2.1	11	7
		C2.2	4	16
D: Graph interpretation difficulties.	1. The learner focuses on an incorrect aspect of the graph when describing features of the motion.	D1.1	3	8
		D1.2	16	15
	2. The learner interprets negative slopes in a s/t graph to mean that the object is slowing down rather than moving in a negative direction.	D2.1	7	6
		D2.2	13	11

Appendix 6
Pre-Instruction Interview Protocol

A group interview was conducted with the five learners who made up the focus group for this research.

This interview was conducted before learners participated in the TRAC PAC-based learning programme (directly after they answered the pre-questionnaire), and was based on the following scenarios, using the TRAC PAC and TRAC activities as research tools:

Scenario 1

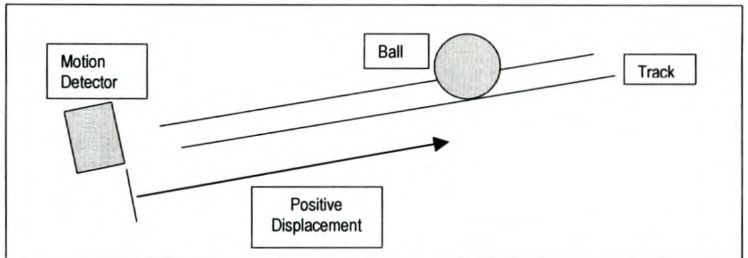


Figure 1: Ball rolling up and down an incline (motion detector is reference point and up is positive)

Scenario 2

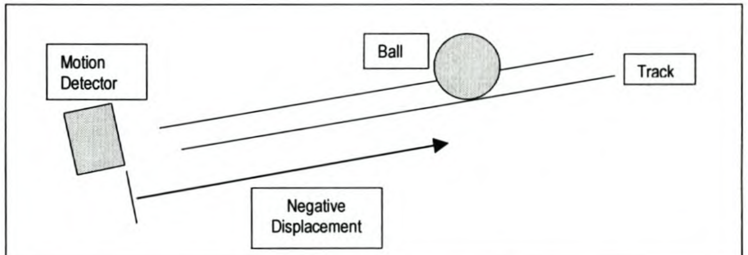


Figure 2: Ball rolling up and down an incline (motion detector is reference point and up is negative)

Scenario 3

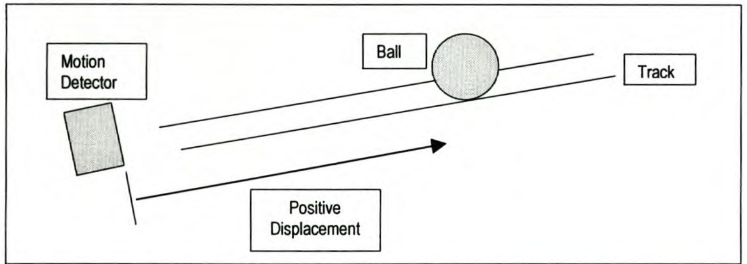


Figure 3: Ball rolling up and down an incline (midpoint of track is reference point and up is positive)

Interview process:

- Learners were asked to carefully observe the motion of the ball in each scenario.
- They were then asked to describe the motion in their own words (they had to write their descriptions).
- They were then asked to draw sketch graphs (s/t, v/t and a/t) for the motion.
- The TRAC PAC was then used to generate motion graphs for the motion of the ball.
- Learners were asked to compare their graphs to the graphs generated by the computer, to correct their graphs using a different colour marker, and to attempt to explain (again in writing) any differences between their graphs and the computer-generated ones.

Appendix 7
Post-Instruction Interview Protocol

A group interview was conducted with the five learners who made up the focus group for this research.

This interview was conducted after learners participated in the TRAC PAC-based learning programme (directly after they answered the post-questionnaire), and was based on the following scenarios:

Scenario 1

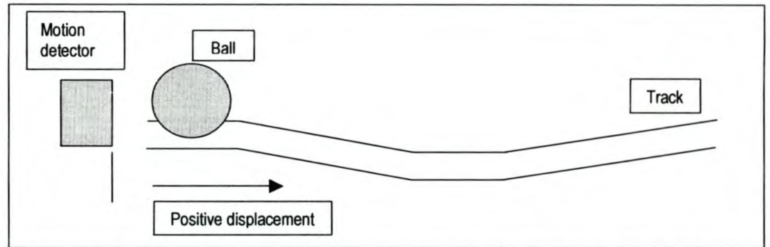


Figure 1: Ball rolling on level and sloped track (motion detector is reference point and motion to the right is positive)

Scenario 2

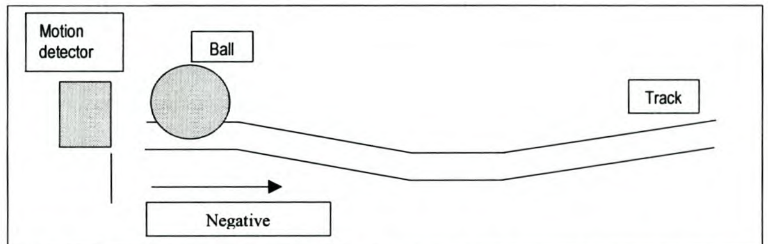


Figure 2: Ball rolling on level and sloped track (motion detector is reference point and motion to the right is negative)

Scenario 3

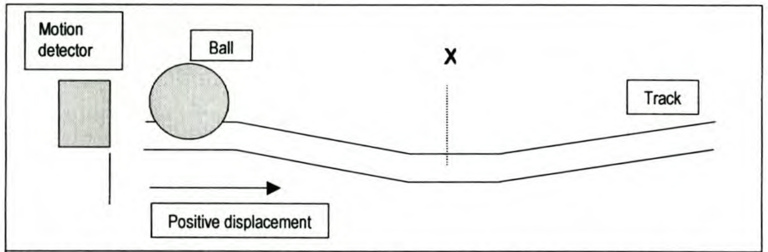


Figure 3: Ball rolling on level and sloped track (X is the reference point and motion to the right is positive)

Interview process:

- Learners were asked to carefully observe the motion of the ball in each scenario.
- They were then asked to describe the motion in their own words (they had to write their descriptions).
- They were then asked to draw sketch graphs (s/t, v/t and a/t) for the motion.

Appendix 8

Hypotheses to test the effectiveness of MBL technology on learner understanding of kinematic graphs.

Area of difficulty	**Two examples of specific difficulties that learners experience in this area**	**Hypotheses for each area** (As a result of working through a series of MBL learning activities, learners...	**Question code for analysis purposes**
A: Problems associated with conceptual understanding of kinematic quantities.	1.The learner has a weak understanding of different kinematic concepts and thus experiences difficulty differentiating between kinematic quantities.	Hypothesis A1 ...demonstrate an improved understanding of, and ability to differentiate between velocity and acceleration.	A1.1 A1.2
	2. The learner has difficulty accepting that an object at rest (e.g. a bouncing ball at the top of its path) can still be accelerating, and that the acceleration remains constant throughout the motion.	Hypothesis A2 ... are more likely to accept that, in the case of projectile motion, the acceleration of the object is unchanged through the motion.	A2.1 A2.2
B: Problems associated with reference points, sign convention and negative kinematic quantities.	1. The learner does not recognise that reference points and positive and negative signs to represent direction of the motion are arbitrarily allocated.	Hypothesis B1 ...are more able to recognise that reference points and reference directions to describe a particular motion are arbitrarily chosen.	B1.1 B1.2
	2. The learner associates the sign of velocity and/or acceleration with the magnitude of these quantities rather than with the direction of movement (in the case of velocity) and the direction of the resultant force (in the case of acceleration).	Hypothesis B2 ...show improved ability to associate the sign of a kinematic quantity with its direction rather that its magnitude.	B2.1 B2.2

C: Graph translation and transformation difficulties.	1. The learner draws/chooses a graph which closely resembles the shape of the path that the object takes.	<u>Hypothesis C1</u> ...learners are more able to choose graphs which describe the variation over time in the kinematic quantity, rather than graphs which resemble the shape of the path that the object takes.	C1.1 C1.2
	2. The learner cannot distinguish between different kinematic graphs representing the same motion. Draws/chooses graphs that resemble each other.	<u>Hypothesis C2</u> ... learners are more able to choose graphs which describe the variation over time in the kinematic quantity, rather than graphs which resemble each other.	C2.1 C2.2
D: Graph interpretation difficulties	The learner focuses on an incorrect aspect of the graph when describing features of the motion.	<u>Hypothesis D1</u> ...are more able to use appropriate features to interpret the graph, rather than attempting to use more obvious and perhaps inappropriate features of the graph.	D1.1 D1.2
	The learner interprets negative slopes in a s/t graph are interpreted to mean that the object is slowing down rather than moving in a negative direction.	<u>Hypothesis D2</u> ...are more able to identify that a negative slope in an s/t graph means that the object is moving in a negative direction rather than meaning that the object is slowing down.	D2.1 D2.2

Appendix 9
Learning Activities Specification Grid

The table below shows the four main areas in kinematics and kinematics graphs that learners have difficulty in. A **selection** of specific difficulties is used as an indicator in this research to determine the effect of the use of MBL technology on learner understanding in the four areas. The table shows the activities in the learning programme in which learners have an opportunity to work through, and thus hopefully improve their understanding and ability to deal effectively with the difficulties listed.

Area of difficulty	Two examples of specific difficulties that learners experience in this area	1	2	3	4	5	6
A: Problems associated with conceptual understanding of kinematic quantities.	1.The learner has a weak understanding of different kinematic concepts and thus experiences difficulty differentiating between kinematic quantities.	•	•	•	•	•	•
	2. The learner has difficulty accepting that an object at rest (e.g. a bouncing ball at the top of its path) can still be accelerating, and that the acceleration remains constant throughout the motion.			•	•	•	
B: Problems associated with reference points, sign convention and negative kinematic quantities.	1. The learner does not recognise that reference points and positive and negative signs to represent direction of the motion are arbitrarily allocated.	•	•	•	•	•	•
	2. The learner associates the sign of velocity and/or acceleration with the magnitude of these quantities rather than with the direction of movement (in the case of velocity) and the direction of the resultant force (in the case of acceleration).			•	•	•	
C: Graph translation and transformation difficulties.	1. The learner draws/chooses a graph which closely resembles the shape of the path that the object takes.	•	•	•	•	•	•
	2. The learner cannot distinguish between different kinematic graphs representing the same motion. Draws/chooses graphs that resemble each other.	•	•	•	•	•	•
D: Graph interpretation difficulties.	1. The learner focuses on an incorrect aspect of the graph when describing features of the motion.	•	•	•	•	•	•
	2. The learner interprets negative slopes in a s/t graph are interpreted to mean that the object is slowing down rather than moving in a negative direction.	•	•	•	•	•	•

• indicates activities where learners will have opportunities to experience and possibly resolve particular difficulties.

Appendix 10
Learner workbook

Kinematics and Kinematic Graphs

A microcomputer-based learning programme

for Grade 11 and 12 learners

TRAC South Africa

Contents

Introduction

Welcome to this Learning Programme. We are happy to be working with you.

This programme has been designed to develop and enhance your understanding of kinematics and kinematic graphs. We have put together a series of practical, hands-on investigative activities which will allow you to explore various kinematic concepts using the TRAC PAC. This booklet will guide you through 6 practical learning activites which we will work through together.

You will note that the activities use a variety of teaching and learning approaches, including teacher explanation, group work, individual exercises, etc. We have done this intentionally, to create variety in the programme. Group work deserves special mention. We believe that learning is enhanced when learners have a chance to discuss their ideas with each other and thus we request that you try to participate fully in all the group activities that have been planned.

We hope that you enjoy working through the activities in this programme.

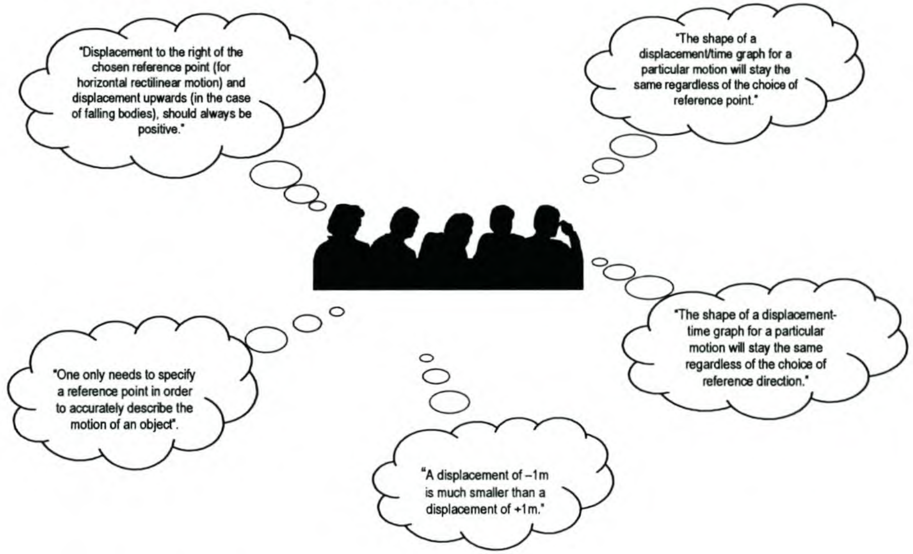
Activity 1
Reference points, reference directions and sign convention

Experiment files: ref1.exp, ref2.exp and ref3.exp

When you have completed these experiments you should be able to:
- Understand and explain the terms "reference point", "reference direction" and "sign convention".
- Choose reference points, reference directions and use a suitable sign convention to represent and describe a particular motion.
- Appreciate how choice of reference points and reference direction influences how we describe and represent the motion of the object.
- Answer/solve examination-type questions/problems that require understanding of these concepts.

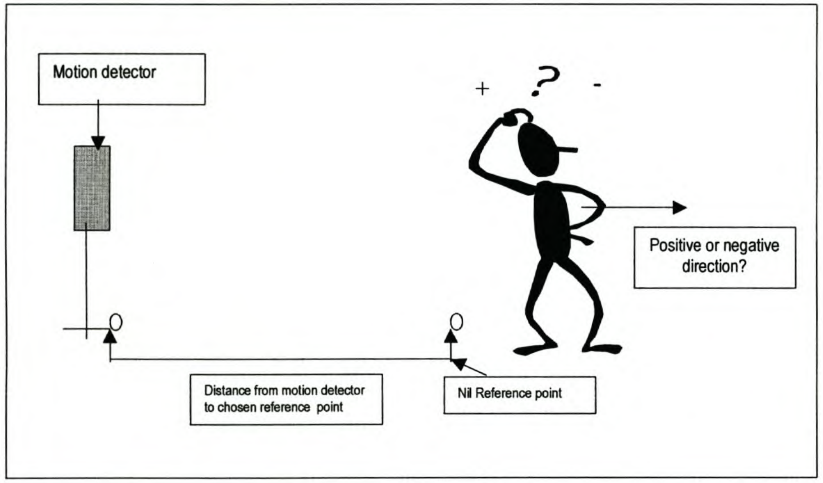
Introduction:

Learners in a class were answering the teacher's questions about reference points and reference directions. Here are the responses of some of them.



Discuss each of these statements in your group. Say whether you agree or disagree with them and suggest some arguments you could make to support your answer.

Experimental set-up:



Part I
Choosing a reference point

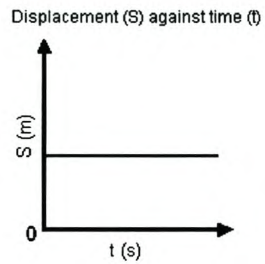
1. Place the motion detector on a chair or in a stand with enough room in front of it.
2. Measure a distance of 1,5m from the sensor and mark the point on the floor with a piece of chalk.
3. Do not move the sensor now.
4. The point will serve as the reference point for the experiment.
5. Open the file ref1.exp.
   (Note that in this experiment file, the point 1,5m away from the sensor has been entered as the reference point and displacement **away** from the sensor is measured as **positive**.)

The following are examples of displacement vs. time graphs generated using this set-up

1. Discuss the motion displayed by each graph.
2. Try to imitate the movement displayed in each graph by letting one person move in front of the sensor.
3. Click on ***Start*** to record the movement. 

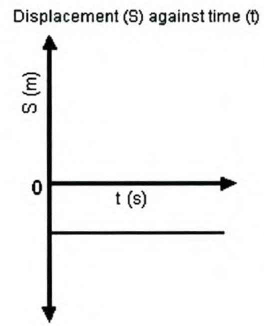
4. Give a short explanation of the movement next to each graph.

A



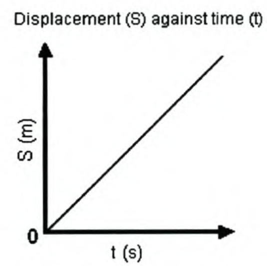
Description of movement

B.



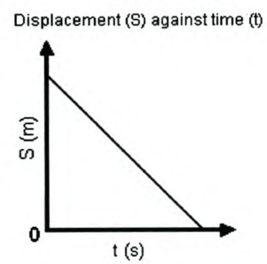
Description of movement

C.



Description of movement

D.



Desription of movement

Part II

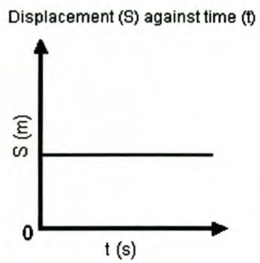
How does changing the position of the reference point affect the representation of motion using graphs?

1. Place the motion detector on a chair or in a stand with enough room in front of it.
2. Measure a distance of 2.5m from the sensor and mark the point on the floor with a piece of chalk.
3. Do not move the sensor now.
4. The point will serve as the reference point for the experiment.
5. Open the file ref2.exp.
   (Note that in this experiment file, the point 2,5m away from the sensor has been entered as the reference point and displacement **away** from the sensor is measured as **positive**.)

The following are examples of displacement vs. time graphs generated using this set-up

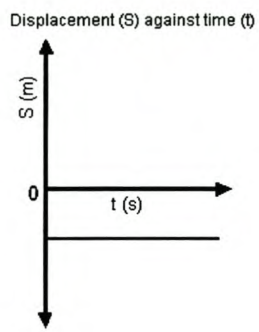
1. Discuss the motion displayed by each graph.
2. Try to imitate the movement displayed in each graph by letting one person move in front of the sensor.
3. Click on ***Start*** to record the movement. START
4. Explain the motion carried out to obtain each graph. In particular, say how it was different from the motion producing the identical graphs in part I.

A.



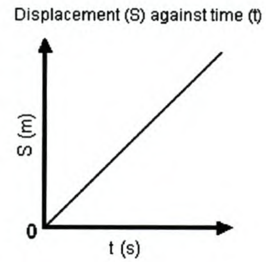
Description of movement

B.



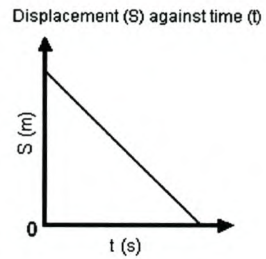
Description of movement

C



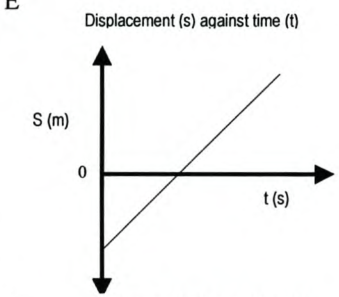
Description of movement

D



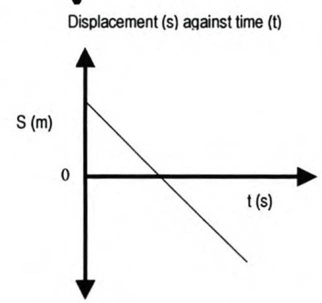
Desription of movement

E



Description of movement

F



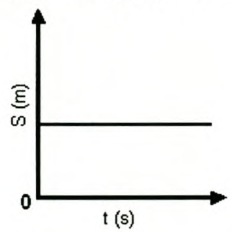
Desription of movement

Part III

How does changing the reference direction affect representation of motion using graphs?

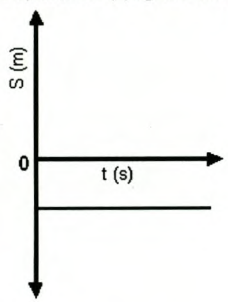
1. Open the file **ref3.exp**.
2. The mark on the floor is still the reference point (at a distance of 2,5m away from the sensor), but movement **towards** the sensor has been entered as being positive.
3. Imitate the graphs below again by simulating the motion that produced them.
4. Explain the motion carried out to obtain each graph. In particular, say how it was different from the motion producing the identical graphs in part II.

A. Displacement (S) against time (t)



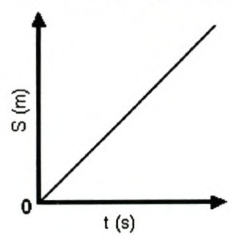
Description of movement

B. Displacement (S) against time (t)



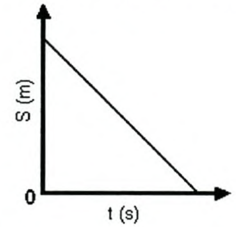
Description of movement

C. Displacement (S) against time (t)



Description of movement

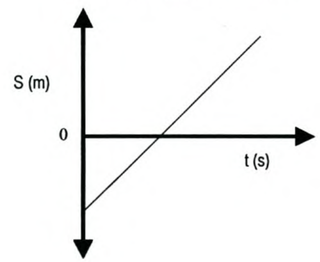
D. Displacement (S) against time (t)



Description of movement

E

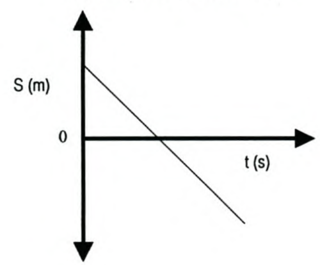
Displacement (s) against time (t)



Description of movement

F

Displacement (s) against time (t)

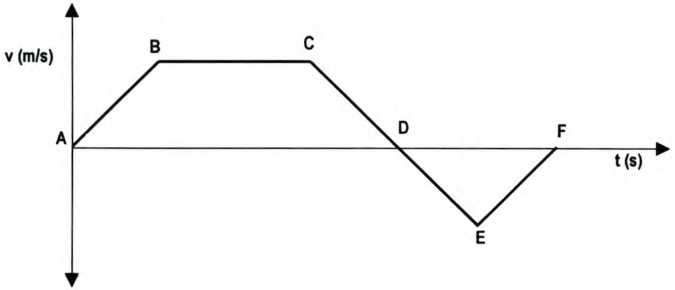


Desription of movement

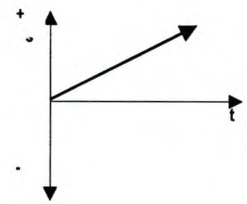
Part IV
Check your understanding.

Use what you have learnt to solve these exam-type problems. Work on your own for this part of the activity.

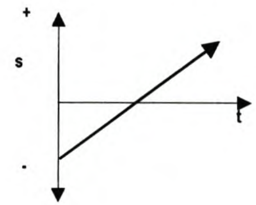
1. The accompanying velocity-time sketch graph represents the rectilinear motion of an object initially moving in a northerly direction. Use the letters A-F to describe part(s) of the graph where the object moves in a southerly direction. Write an explanation for your choice.



2. Two displacement–time graphs for a ball rolling on a smooth horizontal surface with a uniform velocity between two points A and B are shown below:



Graph 1



Graph 2

Use the graphs to work out where the reference point for the motion is, and which direction has been chosen as positive. Give reasons for your answer.

Graph A...

Graph B...

Activity 2
Investigating the relationship between the motion graphs of uniform accelerated motion

Experimental file: accel.exp

When you have completed this activity, you should be able to:

- Distinguish between displacement vs. time, velocity vs. time and acceleration vs. time graphs.
- Determine the gradient of a graph.
- Express the relationship between the displacement, velocity and acceleration graphs.
- Use the relationships to solve problems.

Experimental set-up

The apparatus for this experiment is set up as shown in the diagram below:

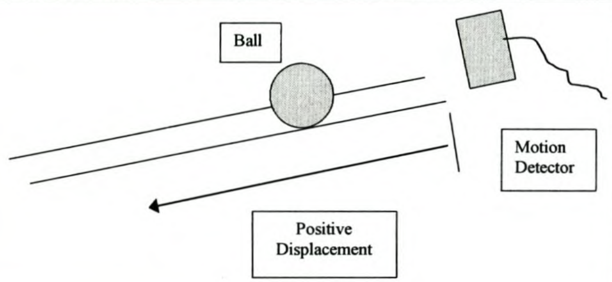


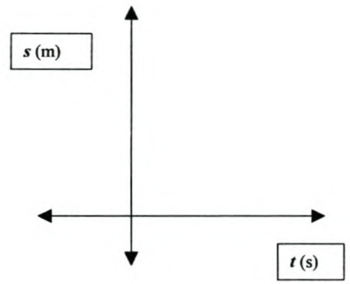
Figure 1: Apparatus for Experiment.

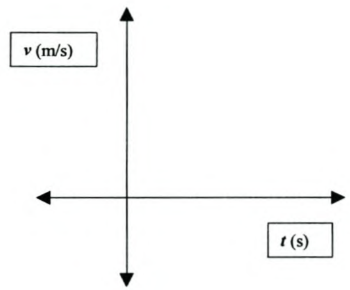
Introduction

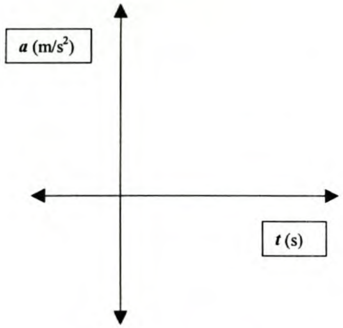
Work in small groups to conduct this part of the activity.

In this experiment we are investigating the relationship between the graphs of a constantly accelerated motion.

1. Hold the ball at the top of the incline and release it so that it starts moving from rest.
2. Study the movement of the ball closely. You may have to repeat the exercise a few times.
3. Use the following axes and draw sketch graphs of displacement vs. time, velocity vs. time and acceleration vs. time. Describe why the graphs have the specific shapes in the space next to the axes. You may discuss with your fellow learners before you make your drawing or write your description.







Answer the following questions:

1 The gradient of the s/ t graph gives the ____________________ of the motion.

2 The gradient of the v/ t graph gives the ____________________ of the motion.

3 The area under a velocity-time graph gives the ____________________ for the corresponding part of the motion.

Part I
Experimental Procedure

Work in small groups to carry out this part of the activity.

Simulate constant accelerated motion by rolling a ball down an incline.

1 The apparatus and TRAC sensors are already set up. See Figure 1.
2 Open the **accel.exp** file on the MPLI- Programme.
3 Let the ball run down the incline and click on the "Start" button immediately.
4 Wait for the graph to be plotted on the screen.
5 Repeat the experiment until a smooth graph is obtained. (This might require some practise!)

Use the results you obtained to answer the following questions.

Part II
Investigating the displacement vs. time graph

1. What shape does the d*isplacement vs. time* graph have?

   ....

2. How does this graph compare with the estimated graph that you've drawn in the introductory exercise? Is it different to the sketch you drew? If so, how is it different? Can you explain why it is different from your sketch graph? If not, call your teacher to help you.

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Part III
Investigating the velocity vs. time graph

Click on the title of the y-axis of the graph. Click in the little square next to "velocity" to activate that graph and then click "OK".

1. What shape does the *velocity vs. time* graph have?

   ....

2. How does this graph compare with the estimated graph that you've drawn in Part A? Is it different to the sketch you drew? If so, how is it different? Can you explain why it is different from your sketch graph? If not, call your teacher to help you.

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Part IV
Investigating the acceleration vs. time graph

Activate the acceleration-time graph in the same way that you activated the velocity-time graph above.

1. What shape does the *acceleration vs. time* graph have?

....

2. How does this graph compare with the estimated graph that you've drawn in Part A? Is it different to the sketch you drew? If so, how is it different? Can you explain why it is different from your sketch graph? If not, call your teacher to help you.

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Part V
Relationships between the graphs

Note:

Clicking on the Tangent Line-button will allow you to read the value of the slope of the graph at any point.

Clicking on the Examine-button will allow you to read the value of the graph at any point.

Clicking on the Integrate-button will allow you to select an area under any graph and find its magnitude.

Set up the screen display so that all three graphs are displayed at the same time. (Ask for the teacher's help to do this.)

1. Compare the value of the tangent/slope of the displacement-time graph to the value of the corresponding velocity for a few points on the graphs. Is there any relationship between the values?

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....

2. Formulate briefly (in words) the relationship that you had identified in question1.

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....

3. Compare the value of the tangent/slope of the velocity-vs. time graph to the value of the acceleration for a few points on the graphs. Is there any relationship between the values?

....
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....

4. Formulate briefly (in words) the relationship which you had identified in question3.

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....
....

5. Use the Integrate function to select an area under the velocity-time graph and determine the magnitude of this area. Write down the magnitude here.

....

6. Use the displacement-time graph to determine the displacement over an interval that corresponds to the one you used in question 5. Is there any relationship between the value you obtain here and the one you obtained in question 5?

....

....

....

....

7. Formulate briefly (in words) the relationship which you had identified in <u>question 6.</u>

....

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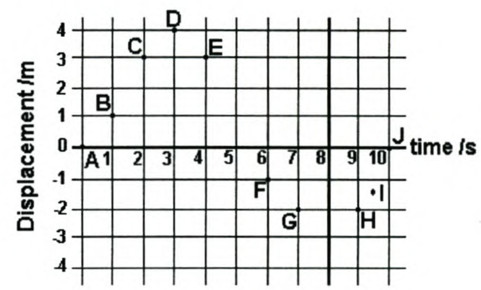
Part VI
Check your understanding!

Use what you have learnt to solve these exam-type problems. Work on your own for this part of the activity. Note that the two questions here are based on objects moving, both with a uniform velocity and a uniform acceleration at different times. Thus your understanding of the concepts covered in previous activities as well as this one need to be applied to solve the problems.

1. The graph shows the displacement of an object to the right of its initial position as a function of time



Make use of the letters on the graph to indicate between which times the object is:

1.1. Stationary for a length of time

....

1.2. Moving with the greatest speed

....

Use the graph to determine the following:

1.3. The total distance travelled by the object from t=0 to t= 10s.

....

....

....

....

....

....

1.4. The displacement from t=3 to 10s.

....

....

1.5. The instantaneous velocity of the object at position D.

....

1.6. Whether the acceleration of the object at the position D is zero or non- zero. Give a reason for the answer.

....

....

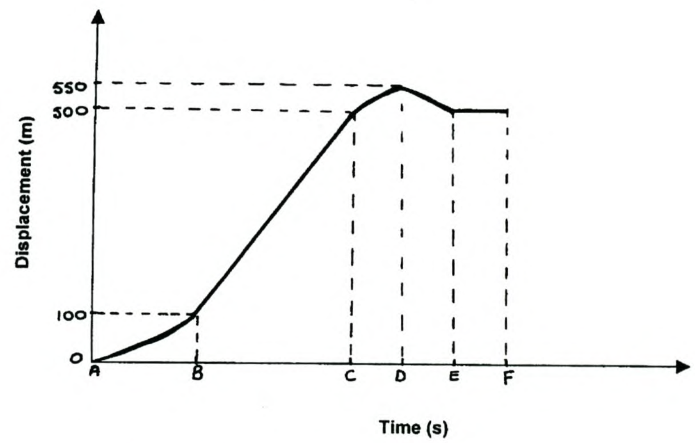
....

1.7. The velocity of the object between E and F.

....

....

2. The accompanying sketch represents the displacement-time graph of a motor cyclist from a time A when he starts moving until a time F.



2.1 For each of the intervals AB, BC, CD, DE and EF, briefly describe the motion of the motorcyclist.

AB: ....

....

BC: ....

....

CD: ....

....

DE: ....

....

EF: ....

....

2.2 Make a rough sketch-graph of the velocity-time graph of the motion. Do not indicate values for velocity, but indicate the points of time (letters) on the time axis.

2.3 What happened at time E? Explain your answer.

....

....

....

2.4 What is the distance travelled by the motorcyclist from A to F? Explain your answer.

....

....

....

Activity 3
Investigating the motion of a ball on different slopes

Experiment file: slopes.exp

When you have completed this activity, you should be able to:

- Describe the motion of an object moving on level and sloped surfaces.
- Draw sketch graphs to represent the motion.
- Generate displacement/time, velocity/time and acceleration/time graphs for the motion using the TRAC PAC.
- Describe features of the motion represented on the generated graphs.
- Use what you have learnt to solve exam-type problems.

Experimental set-up

Set up the apparatus as shown in the diagram below:

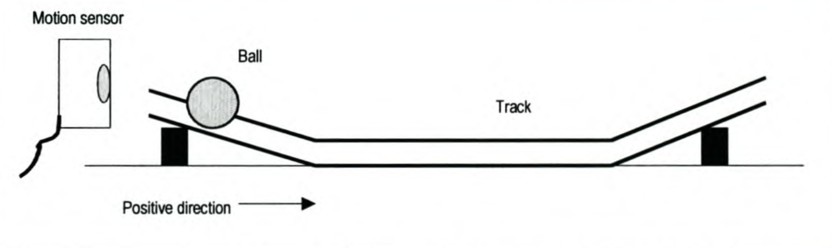


Figure 1: Apparatus for investigating the motion of a ball moving on different slopes

Introduction

Do this prediction exercise before you carry out the investigation:

1. Release the ball, allowing it to roll backwards and forwards on the track. Observe the motion of the ball and describe it in words using terms like positive displacement, uniform velocity, at rest, acceleration, etc. Consider one complete cycle of the ball moving forward and backward. Write down your description here.

2. Draw sketch graphs of displacement versus time, velocity versus time and acceleration versus time for the motion of the ball on the track in the space below. Consider one complete cycle of the ball moving forward and backward.

Now use the motion sensor to capture data about the motion of the ball and the TRAC PAC to generate graphs of motion using this data.

Part I
Experimental Procedure

1 Open the experiment file slopes.exp. In this experiment, the sensor is calibrated to measure displacement away from the sensor as positive.

2 Release the ball on the incline and click on the "**Start**" button immediately.

3 Wait for the graph to be plotted on the screen.

4 Repeat the experiment until a smooth graph is obtained.
(This might require some practise!)

Part II
Analysis

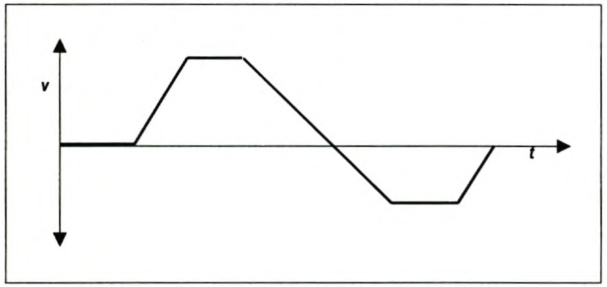
1. Compare the graphs that were generated to your description and sketch graphs in the introductory activity. Were your descriptions and sketches correct? What are the differences, if any, between your sketch graphs and those generated using the TRAC PAC?

2. Go back to your sketch graphs and use a different colour to correct any errors you made.

Part III
Check your understanding!

Use what you have learnt to solve this exam-type problem. Work on your own for this part of the activity.

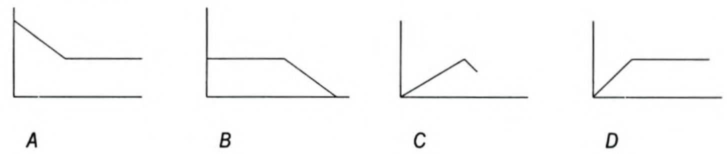
1 A boy takes a "roller-coaster" ride at an amusement park. A velocity-time graph for the motion of the boy in the car on the "roller-coaster" can be drawn as follows:



Use this graph to draw the shape of the track on which the "roller-coaster" is moving and on which the boy rode. Assume that the motion of the "roller coaster" is only determined by gravity once it is moving.

2 A frictionless trolley runs down a sloping runway then over a frictionless horizontal plane.

2.1 Which one of the following graphs of velocity versus time best represents the motion of the trolley? Circle the correct answer.



2.2 Explain your choice.

....

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....

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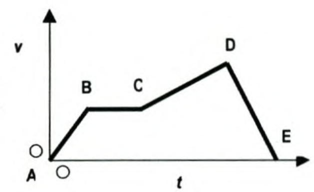
....

3 The accompanying sketch represents the velocity-time graph of a skier skiing across an uneven landscape. Assume that friction is negligible and sketch a profile of the landscape across which the skier was probably skiing. Assume that he in no way interferes with his motion.



Activity 4
Investigation of free fall, as a special case of projectile motion

Experiment files: prjktl+.exp, prjktl-.exp

When you have completed this activity, you should be able to:

- represent the motion of a projectile using sketch graphs.
- use these graphs to explain if/how the **displacement, velocity** and **acceleration** of the projectile changes during its motion, particularly as it is going up, at the turning point, and as it comes down.
- use what you have learnt to solve exam-type problems.

Experimental set-up

Set up the apparatus as shown in the diagram below:

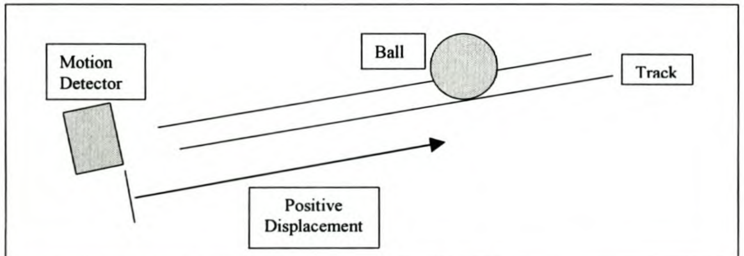


Figure 1: Apparatus for Free Fall Experiment.

Introduction

The questions/tasks below should be tackled by your group:

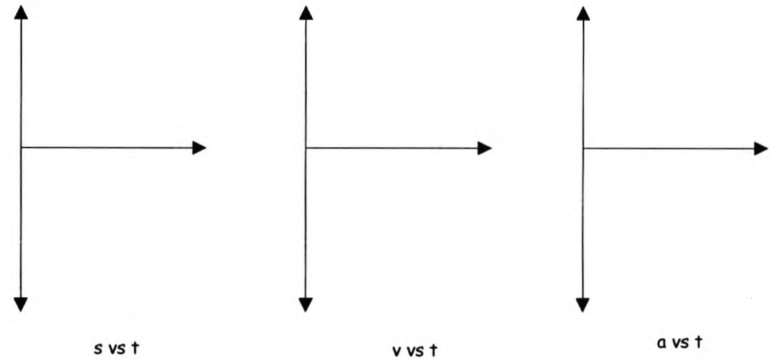
1. Consider the apparatus (track and ball) as it is set up. Why can this be regarded as a simulation of free-fall? What is different about "true" free-fall and the scenario, as we have set it up? Ask for your teachers input if you are having difficulty here.

………………………………………………………………………………………………………

………………………………………………………………………………………………………

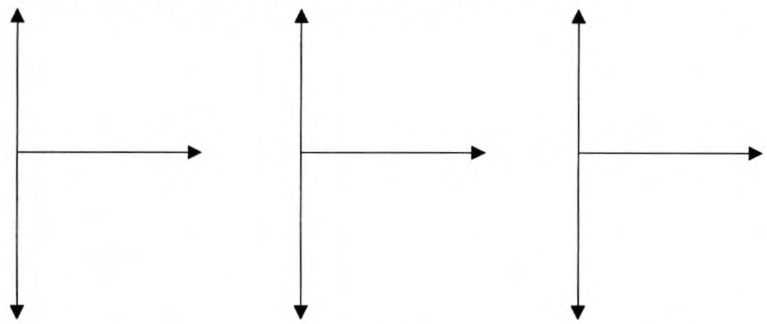
………………………………………………………………………………………………………

2. Without using the motion detector and computer facility, roll the ball up the slope, allowing it to reach a highest point and to roll down again. Observe its motion and discuss it in your group. Choose the upward direction to be positive and use a table to describe the motion of the ball. Then, draw s/t, v/t and a/t sketch graphs for the motion of the ball. Record your description and graphs in the space provided below.



	What happens to...		
	displacement	velocity	acceleration
As the ball goes up			
At the turning point			
As the ball comes down			

3. Repeat this exercise, but this time **choose the upward direction to be negative**. Record the results of your groups' discussion in the space below.



s vs t   v vs t   a vs t

	What happens to...		
	displacement	velocity	acceleration
As the ball goes up			
At the turning point			
As the ball comes down			

Now do the following investigation:

Part I
Graphical representation of free-fall when the upward direction is chosen to be positive

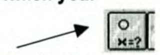
Simulate free fall motion by rolling a ball up and down an incline to measure displacement, velocity and acceleration.

1. Open the experiment file prjktl+.exp.
2. The apparatus and TRAC sensors are already calibrated to measure displacement away from the sensor as positive. See Figure 1.
3. Roll the ball up the incline and click on the "**Start**" button immediately. 

4. Wait for the graph to be plotted on the screen.
5. Repeat the experiment until a smooth graph is obtained. (This might require some practise!)

Part II
Analysis

Use the experimental graphs on the screen, as well as the printed graph which your teacher will hand to you, to answer the following questions :



6. Draw a vertical line, on the printed graph, at time t_1 = 1.5 s. Use the examine function to determine and record the displacement and velocity at this time from your experimental graphs. Use appropriate signs where necessary to indicate the direction of the quantity at that point.

t_1	1,5s
s_1	
v_1	
a_1	

7. Indicate the turning point on the printed graphs and draw a vertical line through it. Use the examine function to determine and record the time, displacement, velocity and acceleration at the turning point from your experimental graphs. Use appropriate signs where necessary to indicate the direction of the quantity at that point.

t_2	
s_2	
v_2	
a_2	

8. Indicate by means of a vertical line on the graph, a time later than time t_1 at which the displacement is the same (the ball is at the same point) as at time t_1. Use the examine function to determine and record the time, displacement, velocity and acceleration at this time (t_3) from your experimental graphs.

t_3	
s_3	
v_3	
a_2	

9. Now use your results above to describe, in words, if/how the displacement, velocity and acceleration changes when the ball rolls up and down the slope.

Displacement:

....

....

....

Velocity:

....

....

....

....

Acceleration:

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....

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....

Part III

Graphical representation of free-fall when the upward direction is chosen to be negative

Simulate free fall motion by rolling a ball up and down an incline to measure displacement, velocity and acceleration.

1. Open the experiment file prjktl-.exp.
2. The apparatus and TRAC sensors are already calibrated to measure displacement away from the sensor as negative.
3. Roll the ball up the incline and click on the "**Start**" button immediately. 

4. Wait for the graph to be plotted on the screen.
5. Repeat the experiment until a smooth graph is obtained. (This might require some practise!)

Use the experimental graphs on the screen, as well as the printed graph which your teacher will hand to you, to answer the following questions:

6. Draw a vertical line, on the printed graph, at time $t_1 = 0.5$ s. Use the <u>examine</u> function to determine and record the displacement and velocity at this time from your experimental graphs. Use appropriate signs where necessary to indicate the direction of the quantity at that point.

t_1	0,5s
s_1	
v_1	
a_1	

7. Indicate the turning point on the printed graphs and draw a vertical line through it. Use the examine function to determine and record the time, displacement, velocity and acceleration at the turning point from your experimental graphs. Use appropriate signs where necessary to indicate the direction of the quantity at that point.

t_2	
s_2	
v_2	
a_2	

8. Indicate by means of a vertical line on the graph, a time later than time t_1 at which the displacement is the same (the ball is at the same point) as at time t_1. Use the examine function to determine and record the time, displacement, velocity and acceleration at this time (t_3) from your experimental graphs.

t_3	
s_3	
v_3	
a_2	

Now use your results above to answer the following questions:

9. What are some of the differences and similarities between this set of graphs and the previous set? Suggest some reasons for the differences.

Differences/Similarities	Reasons

10. Why does the velocity start off as a large negative value, decrease to zero and end up as a large positive value?

....

....

....

11. One could describe the gradient of this velocity-time graph as being a positive gradient (it's moving upwards from left to right) and yet it means different things above and below the x-axis.

What does the gradient tell you about the velocity of the ball after it reaches its turning point?

....

....

....

What does the gradient tell you about the velocity of the ball before it reaches its turning point?

....

....

....

Thus, a positive gradient for a v/t graph above the x-axis means that the velocity of the object is...................................... and a positive gradient below the x-axis means that the velocity of the object is ....

12. Why is the acceleration now a constant positive value regardless of whether the ball is moving up or down the slope?

....

....

....

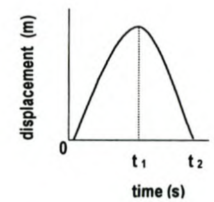
Part IV
Summary: What have you learnt?

1. Go back to the graphs and tables you drew at the beginning of this activity. Were any of the observations/results not what you expected? What was different about them? Use a different colour marker/pen to correct any errors you made on these diagrams/tables. Can you think of explanations for the differences between what was expected and what you actually observed? Ask for your teacher's help here if you cannot explain the discrepancies.

Part V
Check your understanding!

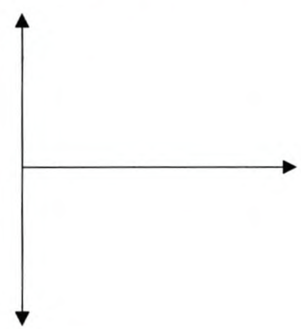
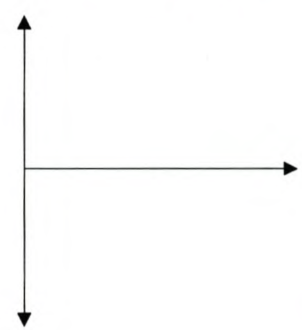
Use what you have learnt to solve this exam-type problem. Work on your own for this part of the activity.

1 The displacement-time graph alongside represents the motion of an object which has been thrown vertically upwards.



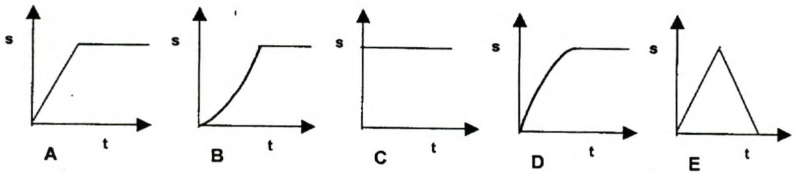
1.1 Describe the motion of the object in terms of its velocity and acceleration?

1.2 Draw neat sketch-graphs of velocity-time and of acceleration-time of the object's motion corresponding to the above displacement-time graph.

Velocity– time graph for object thrown vertically upwards	**Acceleration– time graph for object thrown vertically upwards**
	

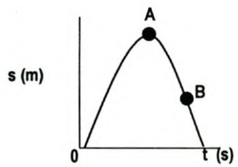
2. A ball of putty is dropped from a height of 45m. It does not bounce.

   Which one of the following graphs best represents the displacement *(s)* measured from the starting point against time *(t)*? Ignore friction and take down as positive (+). Circle or tick your choice.



   Give a reason/explanation for your choice.

3 The graph alongside is a displacement-time graph representing the motion of a ball as it is thrown upwards and then caught. Displacement upwards is positive.



3.1 What information can you deduce about the velocity and the acceleration of the ball at points A and B?

velocity at point A

acceleration at point A

velocity at point B

acceleration at point B

Activity 5
Investigating the motion of a bouncing ball

Experiment file: Bounce.exp

When you have completed this activity, you should be able to:

- Use a verbal description and graphical representations to describe the changes (if any) in the displacement, velocity and acceleration of a ball as it bounces up and down.
- Be able to translate between observation of a physical situation, verbal/written descriptions, and graphical representation of the situation.
- Use what you have learnt to solve exam-type problems.

Experimental set-up

Set up the apparatus as shown in the diagram below.

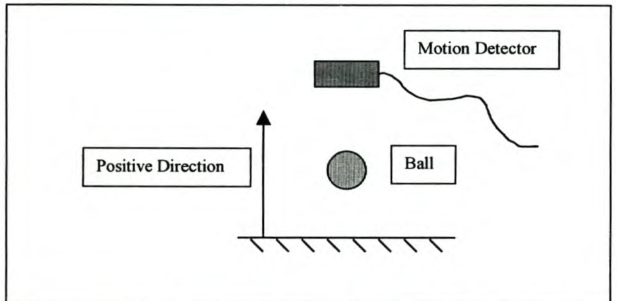


Figure1: Experimental Set-up

Introduction

In this activity we want to capture the motion of a bouncing ball using the TRAC equipment, and use the graphs we obtain to explain what is happening during the ball's motion. Before we do the actual investigation, carry out the following task in your groups.

1. Allow the ball to bounce a few times and observe its motion. Choose the upward direction to be positive and take the floor to be the reference level. Describe the motion of the ball for one complete bounce, i.e from when it hits the floor for the first time, to when it hits the floor for the second time. How do the displacement, velocity and acceleration of the ball change during this time? Write down the description of the motion here.

   ....

   ....

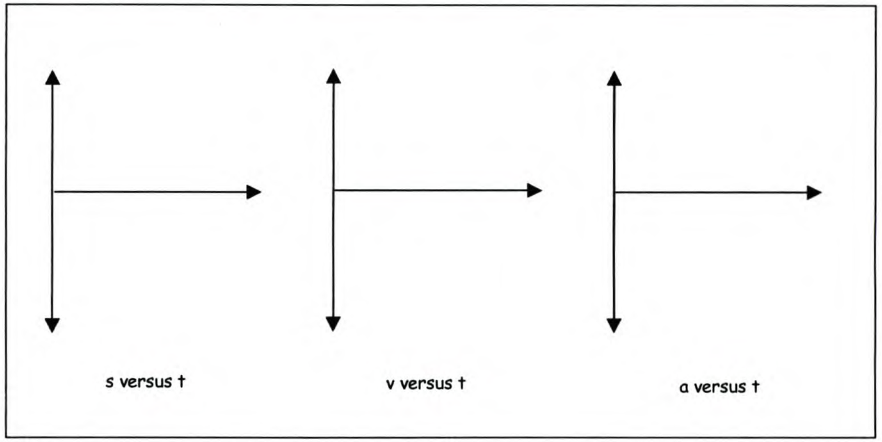
   ....

   ....

   ....

   ....

2. Now convert this verbal description into a graphical representation. Draw s/t, v/t and a/t sketch graphs that depict the motion of the ball for the one complete bounce.



Let's use the apparatus to see how similar your representations are to those created by the TRAC equipment.

Part I
Experimental Procedure

1 Fix the Motion Detector at a height of about 1,8m above the floor, facing downwards.

2 Hold the ball about 0.5m directly below the motion detector. Stand as far away as possible so that the motion detector does not detect your presence.

3 Release the ball and simultaneously START collecting data. Make sure that the ball bounces directly below the sensor.

4 Carry out the procedure a few times until you are satisfied with the graphs you obtain.

Part II
Analysis

Work in your groups to answer the following questions. Use your graphs on the screen and the graphs your teacher hands to you to answer the questions.

1 Consider the points marked A, B, C and D on the graphs that your teacher gave to your group. For each point, describe:

- Where the ball was at that moment in time.
- Its displacement at that point.
- Its velocity at that point.
- Its acceleration at that point.

Use terms like maximum, minimum, zero, constant, negative positive, where applicable, to enhance your description.

A:..

....

....

....

B:..

....

....

....

C:..

....

....

....

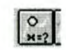
D:..

....

....

....

2 Now use the EXAMINE function to determine the displacement, velocity and acceleration at these points. Were your descriptions correct? Explain.



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3 Note that the upward direction is taken as positive. Look at the graphs given to you and describe how the motion of the ball changes over the region AB.

....

....

....

4 What happens to the ball during the very short interval BC?

....

....

....

5 Describe how the motion of the ball changes over the region CD.

....

....

....

6 By examining all the graphs, we can see that the bounce of the ball is getting smaller and smaller every time. Why is this so?

....

....

....

Part III
What have you learnt?

1 Revisit the descriptions you wrote and the graphs you drew in the introductory activity. Were they correct? Do you need to change anything? If so, what needs changing and why should it be changed? If your graphs or descriptions need changing in any way, use a different colour pen/marker to make the changes on the original descriptions and diagrams.

2 Imagine that we reset the computer to read the upward direction as being negative. How would this change the representation of the s/t, v/t and a/t graphs? Draw the graphs you expect to see in the places provided below, and give a short explanation of why you have drawn it in that particular way.

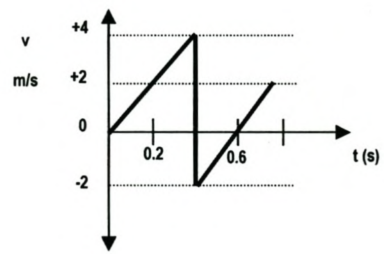
v/t graph for bouncing ball when upwards is taken as negative	**Explanation**
s/t graph for bouncing ball when upwards is taken as negative	**Explanation**
a/t graph for bouncing ball when upwards is taken as negative	**Explanation**

Part IV
Check your understanding!

Use what you have learnt to solve this exam-type problem. Work on your own for this part of the activity.

1 The velocity-time graph represents the motion of a ball which falls freely from rest from a height of 0,8m. The ball collides with a horizontal surface and bounces back up.

1.1 Fully describe the motion of the ball as represented by the graph.



1.2 Determine, with the aid of the graph, how high the ball will bounce. Show your working clearly.

1.3 Draw the corresponding displacement-time graph and acceleration-time graph for the ball's motion.

Corresponding s/t graph

Corresponding a/t graph

Activity 6
Interpreting, matching and transforming displacement-time graphs

Experiment files: match1d.exp
Match2d.exp
Match3d.exp
Match4d.exp

When you have completed this activity, you should be able to:

- Interpret and describe the motion of an object represented in a displacement-time graph.
- Manipulate apparatus to replicate the motion and the graphs representing the motion.
- Draw sketch graphs of velocity versus time and acceleration versus time for the motion.
- Use what you have learnt to solve exam-type problems.

Experimental set-up

Set up the apparatus as shown in the diagram below:

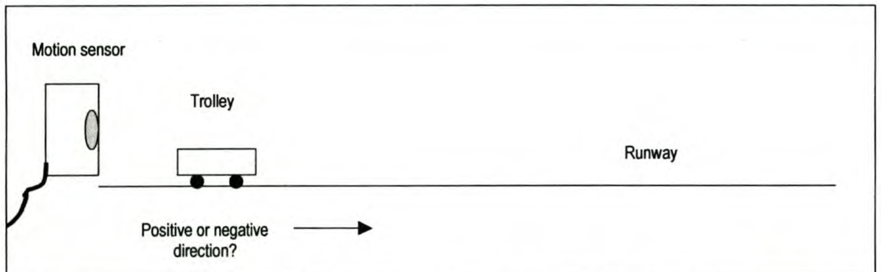


Figure 1: Apparatus for replicating s/t graphs representing the motion of an object.

Take note:

- Attach a large, hard, flat piece of cardboard to the back of the trolley so that the sensor can easily detect it.
- You are going to move the trolley with your hand each time to replicate the motion represented in the graphs. Try to keep your body out of the range of the motion sensor so that it does not affect the graphs you obtain.

Part 1
Experimental Procedure

Exercise 1

1. Open experiment file match1d.exp.
2. The following graph should appear on the computer screen.

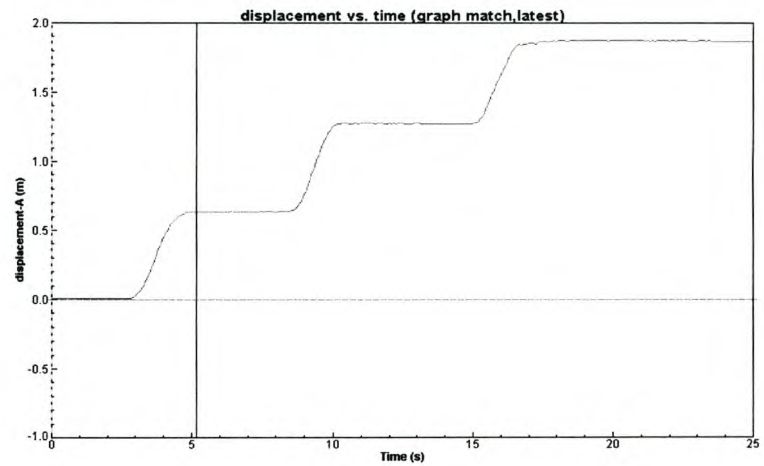


Figure 2: Displacement-time graph for matching exercise 1.

3. In your small group, discuss the motion represented by this graph. Consider things like:
   - The reference point is 0.5m away from the sensor.
   - Which direction is positive?
   - Where is the object at different times during its motion?
   - What types of motion are represented by the various parts of the graph?
4. Make chalk markings on the track to represent important points during the trolley's motion.
5. Press the start button to begin collecting data.
   - Simultaneously begin moving the trolley with your hand to replicate the motion represented by the graph in Figure 2. 
   - Your graph will appear over the graph already on the screen.
   - How does your graph compare to the original one? Do you need to change any part of your movement?
   - Repeat the exercise until you get the closest possible match.

6. Draw a sketch graph of velocity versus time for the motion represented in the s/t graph in Figure 2, in the space below:

Exercise 2

1. Open experiment file match2d.exp.
2. The following graph should appear on the computer screen.

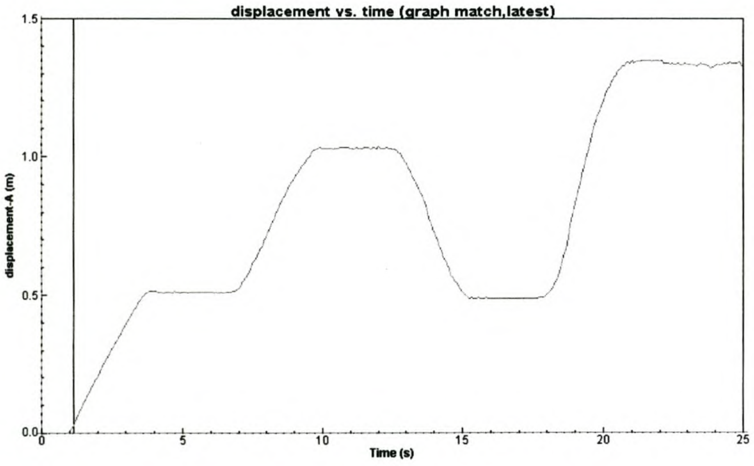


Figure 3: Displacement-time graph for matching exercise 2.

3. In your small groups, discuss the motion represented by this graph. Consider things like:
   - The reference point is 0.5m away from the sensor.
   - Which direction is positive?
   - Where is the object at different times during its motion?
   - What types of motion are represented by the various parts of the graph?

4. Make chalk markings on the track to represent important points during the trolley's motion.

5. Press the start button to begin collecting data.
   - Simultaneously begin moving the trolley with your hand to replicate the motion represented by the graph in Figure 3.
   - Your graph will appear over the graph already on the screen.
   - How does your graph compare to the original one? Do you need to change any part of your movement?
   - Repeat the exercise until you get the closest possible match.

6. Draw a sketch graph of velocity versus time for the motion represented in the s/t graph in Figure 3 in the space provided below.

Exercise 3

1. Open experiment file match3d.exp.
2. The following graph should appear on the computer screen.

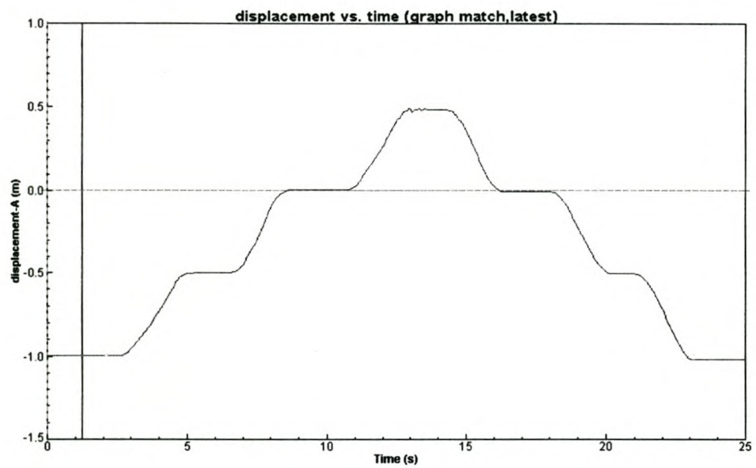


Figure 4:	Displacement-time graph for matching exercise 3.

3. In your small groups, discuss the motion represented by this graph. Consider things like:
   - The reference point is 1.5m away from the sensor.
   - Which direction is positive?
   - Where is the object at different times during its motion?
   - What types of motion are represented by the various parts of the graph?

4. Make chalk markings on the track to represent important points during the trolley's motion.

5. Press the start button to begin collecting data.
   - Simultaneously begin moving the trolley with your hand to replicate the motion represented by the graph in figure 4.
   - Your graph will appear over the graph already on the screen.
   - How does your graph compare to the original one? Do you need to change any part of your movement?
   - Repeat the exercise until you get the closest possible match.

6. Draw a sketch graph of velocity versus time for the motion represented in the s/t graph in Figure 4, in the space provided below.

Exercise 4

1. Open experiment file match4d.exp.
2. The following graph should appear on the computer screen.

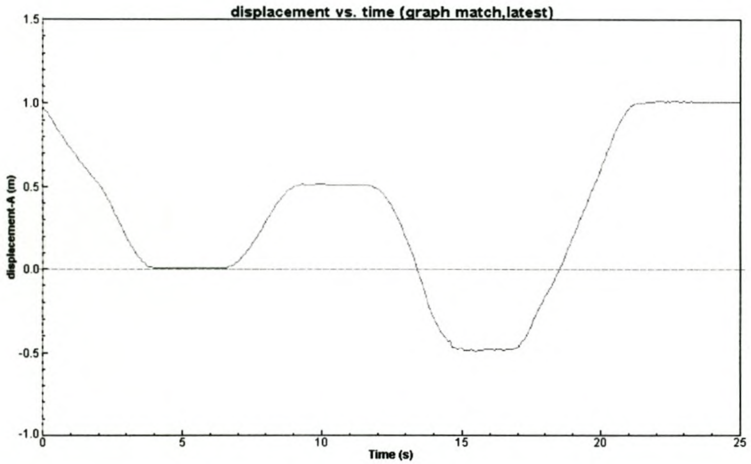


Figure 5:	Displacement-time graph for matching exercise 4.

3. In your small groups, discuss the motion represented by this graph. Consider things like:
   - The reference point is 1.5m away from the sensor.
   - Which direction is positive?
   - Where is the object at different times during its motion?
   - What types of motion are represented by the various parts of the graph?

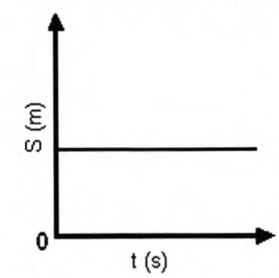
4. Make chalk markings on the track to represent important points during the trolley's motion.

5. Press the start button to begin collecting data.
   - Simultaneously begin moving the trolley with your hand to replicate the motion represented by the graph in Figure 5.
   - Your graph will appear over the graph already on the screen.
   - How does your graph compare to the original one? Do you need to change any part of your movement?
   - Repeat the exercise until you get the closest possible match.

6. Draw a sketch graph of velocity versus time for the motion represented in the s/t graph in Figure 5 in the space provided below.

Appendix 11
Coding for analysis of argumentation segments.

Argumentation Episode 1
(Part of Activity 1)



Task:
The group needs to describe the motion an object would have it was represented by the displacement-time graph alongside, given that a point 1.5m away from the sensor is the reference point, and the direction away from the sensor is positive.

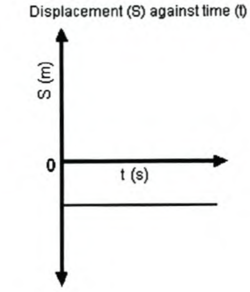
Claim:
The object is stationary at the reference point.
Alternative claim:
The object is stationary at a point beyond the reference point in the positive sector.

Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
81. Thandeka: Ok the first one is standing still.						
	82. Mondli: Yah, because it's....at the...					
83. Thandeka: One point five…						
	84. Mondli: …at the reference point.					
			85. Craig: That will be further away from the reference point…	because it's above the axis.		
	86. Mondli: No … stand still at the reference point…for a certain time… a certain amount of time.					
			87. Craig: No the first… the first one is			
			88. Nelisiwe: …move positively and then stand still at that point			
			89. Craig: Yah …. Stand ahead of the reference point … beyond the reference point			
90. Mondli: Oh yah.						
91. Kevin: If there's no gradient in a displacement – time graph that						

Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
means there is no velocity.						
			92. Craig: Yah You'd have to stand still but you'd have to stand ahead of the graph.			
				93. Thandeka: Because at the reference point the displacement will be zero.		
94. Craig: Yah.						
95. Nelisiwe: Stands still…						
	96. Mondli: Stand still…stand still at the reference point which is					
			97. Craig: Beyond the reference point…	because if you're at the reference point it will be zero.		
98. Nelisiwe: Stand still at…						
	99. Mondli: No, but that… that's the reference point.					
			100. Craig: The reference point is the x-axis.			
101. Mondli: No.						
102. Craig: Yes.						
103. Mondli: No.						
				104. Thandeka: If you're standing at the reference point…		
105. Mondli: Oh yah.						
				106. Thandeka: …your displacement will be zero so…		
				107. Kevin: Your reference point is where they describing everything. That's where you take all your information from.		
				108. Thandeka: Yah, so in relation to the reference point you haven't moved so your displacement is zero - get what I'm saying?		
			109. Mondli: Oh? Ok. Stand still Ok … I get it… beyond the reference point…			
110. Nelisiwe: He said when you move forward it's						

Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
...positive?						
111. Craig: Yah.						
112. Kevin: But there's no direction on the ...						
113. Nelisiwe: No, there's no direction.						
			114.Mondli: The displacement is zero in relation to the reference point...			
					115. Craig: If you're standing on the reference point...	

Argumentation Episode 2
(Part of Activity 1)



<u>Task:</u>
The group needs to describe the motion an object would have it was represented by the displacement-time graph alongside, given that a point 1.5m away from the sensor is the reference point, and the direction away from the sensor is positive.

<u>Claim:</u>
The object is in front of the reference point (between the reference point and the sensor).
<u>Alternative claim:</u>
The object is behind the reference point.

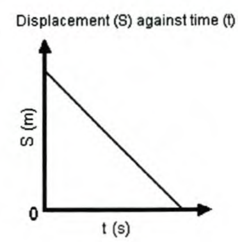
Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
	116. Thandeka: So for B...you'd have to stand still ... in front of the reference point					
117. Kevin: There's movement.						
118. Thandeka: No, there's no movement						
119. Kevin: Oh, there's been no movement						
	120. Nelisiwe: So you stand a few metres away...					
121. Thandeka: Its only 1.5 metres						
			122. Mondli: So you stand...			

Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
	123. Nelisiwe: ...in front.					
			124. Mondli: No, you stand behind			
	125. Thandeka: No you stand in front...					
	126. Kevin: You stand in front			because it's negative as you move forward.		

Argumentation Episode 3
(Part of Activity 1)

[Note that argumentation episodes 3 and 4 deal with the same section of transcript. Two alternative ideas are presented in this segment, and each is dealt with separately.]

Task: The group needs to describe the motion an object would have it was represented by the displacement-time graph alongside, given that a point 1.5m away from the sensor is the reference point, and the direction away from the sensor is positive.



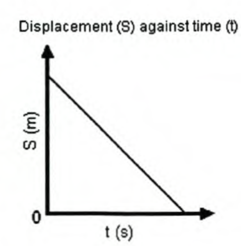
<u>Claim 1:</u>
Object is moving away (backwards) from the reference point in positive direction.
<u>Alternative claim 1:</u>
Object is moving towards the reference point in negative direction.

Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
135. Kevin: D?						
	136. Nelisiwe: D... move backwards.					
137. Thandeka: No... no...						
	138. Nelisiwe: **Wouldn't you still be moving away** but slowing down?					
	139. Kevin: Still positive...					
	140. Thandeka: ...still positive					
			141. Mondli: No **move towards** the reference point.			
			142. Craig: Yah, I agree			
						143. Thandeka: Why?
				144. Craig: 'Cos your displacement		

Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
				...you're quite far away.		
	145. Kevin: It's not negative.					
				146. Craig: It is and you're moving towards the displacement of zero.		
	147. Kevin: But it's not negative…it's positive.					
			148. Thandeka: Oh yeah, but… So you're moving… towards the reference point...			
	149. Kevin: No, you still have to move away from...					
150. Thandeka: ...at a constant decelerating rate…I'm sure that's it.						
151. Mondli: Yeah.						
152. Thandeka: Am I right?						
153. Craig: You decelerate... yeah…						
	154. Kevin: You decelerate, moving away from... the thing.					
			155. Thandeka: towards…Towards…			
	156. Kevin: Away,	because its positive. Away...				
157. Mondli: No it's not necessarily... like… decelerating...						
			158. Thandeka: No. No towards. Because … it's not away.			
		159. Kevin: This is positive and negative …				
160. Craig: There's no acceleration or deceleration.						
161. Mondli: Yah, cos it can just stop…like at a constant pace and then just stop.						
				162. Thandeka: No look here. This is your reference point. You got to start here, and move there at a decelerating rate.		
163. Mondli: No. You don't have to decelerate for the whole …like...interval. Cos you can just walk …						

Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
like constant velocity… and then just stop. I think so – we've got no proof.						
164. Kevin: They don't say where you start…						
165. Craig: Yah, you have to start…						
166. Thandeka: No. But you have to start away.						
			167. Craig: You start in the positive sector and move towards the reference point.	Say then, here's your sensor … here's your reference point.		
168. Mondli: … and this is the negative sector.						
				169. Craig: That's your positive… that's the positive sector …that's negative		
			170. Mondli: Yah			
171. Kevin: Yeah?						
				172. Craig: So you'd have to start here then move that way towards the reference.		
			173. Mondli: Yeah, I agree.			
			174.Kevin: Move towards the sensor slowing down.			

Argumentation Episode 4
(Part of Activity 1)



Task: The group needs to describe the motion an object would have it was represented by the displacement-time graph alongside, given that a point 1.5m away from the sensor is the reference point, and the direction away from the sensor is positive.

<u>Claim:</u>
Object is decelerating.
<u>Alternative claim:</u>
Object is moving at a uniform velocity.

Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
135. Kevin: D?						
136. Nelisiwe: D… move backwards.						
137. Thandeka: No… no…						
	138. Nelisiwe: Wouldn't you still be moving					

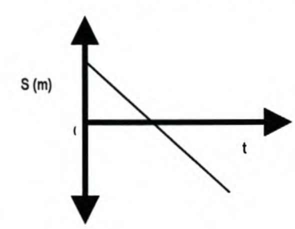
Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
	away **but slowing down?**					
139. Kevin: Still positive...						
140. Thandeka: ...still positive						
141. Mondli: No move towards the reference point.						
142. Craig: Yah, I agree.						
143. Thandeka: Why?						
144. Craig: 'Cos your displacement ...you're quite far away.						
145. Kevin: It's not negative.						
146. Craig: It is and you're moving towards the displacement of zero.						
147. Kevin: But it's not negative...it's positive.						
148. Thandeka: Oh yeah, but... So you're moving... towards the reference point...						
149. Kevin: No, you still have to move away from...						
	150. Thandeka: ...at a constant decelerating rate...I'm sure that's it.					
151. Mondli: Yeah.						
152. Thandeka: Am I right?						
	153. Craig: You decelerate... yeah...					
	154. Kevin: You decelerate, moving away from... the thing.					
155. Thandeka: towards...Towards...						
156. Kevin: Away, because it's positive. Away...						
			157. Mondli: No **it's not necessarily...like... decelerating...**			
158. Thandeka: No. No towards. Because ... it's not away.						
159. Kevin: This is positive and negative ...						
			160. Craig: There's no acceleration or deceleration.			
			161. Mondli: Yah,	cos it can just		

Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
				stop…like at a **constant pace** and then just stop.		
	162. Thandeka: No look here. This is your reference point. You got to start here, and move there at a decelerating rate.					
			163. Mondli: No. You don't have to decelerate for the whole …like...interval. Cos you can just walk … like constant velocity… and then just stop. I think so – we've got no proof.			
164. Kevin: They don't say where you start…						
165. Craig: Yah, you have to start…						
166. Thandeka: No. But you have to start away.						
167. Craig: You start in the positive sector and move towards the reference point. Say then, here's your centre … here's your reference point.						
168. Mondli: … and this is the negative sector.						
169. Craig: That's your positive… that's the positive sector …that's negative						
170. Mondli: Yah.						
171. Kevin: Yeah?						
172. Craig: So you'd have to start here then move that way towards the reference.						
173.Mondli: Yeah, I agree.						
	174. Kevin: Move towards the sensor slowing down.					
			175. Craig: No, it's at a constant speed.			
			176. Thandeka: Constant …OK.			
177. Mondli: Yeah						
				178. Craig: Yeah. This is a displacement-time graph so it's constant velocity. If it was accelerating it would be curved.		
179. Nelisiwe: Is it ok if I just write, "starting from the						

Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
positive sector"?						
180.Mondli: Yah.						
181. Craig: Yah.						
			182. Thandeka: So you move in a negative direction towards the reference point at a constant velocity. Yeah, that seems like it.			
183. Nelisiwe: You just move towards the reference point starting at the positive sector.						
184. Thandeka: Yah.						

Argumentation Episode 5
(Part of Activity 1)

Displacement (s) against time (t)



Task: The group is describing the motion an object would have from the displacement-time graph alongside, given that a point 2.5m away from the sensor is the reference point, and direction away from the sensor is positive.

<u>Claim:</u>
The object has a **negative** velocity throughout its motion.
<u>Alternative claim:</u>
The **direction of the object changes** at the point where the graph crosses the x-axis.

Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
						305. Craig: Now tell me...it ends with the velocity being negative?
306. Mondli: Velocity... no it's constant.						
						307. Craig It's constant but would it be negative constant or positive constant?
	308. Thandeka: Would change...					
			309. Mondli: No. It's the same velocity because the thing is...			
						310. Craig The velocity... the magnitude would be the

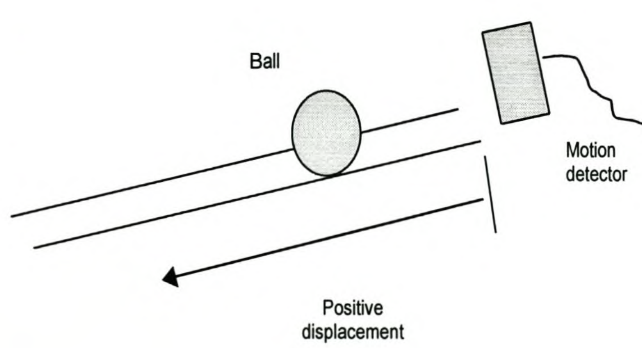
Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
						same but...
311. Mondli: So it's the same velocity?						
						312. Craig: Yah, but is it positive or negative?
313. Kevin: No, positive and negative just describes the direction.						
314. Craig: Exactly.						
	315. Thandeka: So it would change.					
	316. Kevin: So it would change. So it would be a negative velocity.					
			317. Mondli: No. It's the same direction.			
318. General: No, no.						
	319. Nelisiwe: It can't be the same.					
320. Kevin: Velocity is a vector so it has magnitude and direction.						
321. Thandeka: ...and direction so...						
				322. Craig: In E you would be moving away from the sensor.		
323. Mondli: Oh...the opposite direction.						
			324. Craig: So it will be negative... negative velocity. I think so.			
	325. Thandeka: ...would change Craig.					
	326. Mondli: The velocity can't be negative.					
	327. Kevin: No, it mustn't be.					
328. Thandeka: Listen to me, dammit.						
		329. Kevin:				

Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
		Velocity is a vector so it got magnitude and direction, the magnitude will be the same but the direction will change.				
						330. Craig: So the direction will be negative?
331. Kevin: Yes.						
332. Nelisiwe: We're going to the negative direction.						
		333. Thandeka: OK guys. When you going to the reference point your velocity is positive. Once you have passed the reference point you have a negative velocity... cos you changed... direction				
	334. Craig: Ok I see what you saying.					
		335. Thandeka: It's there in the graph see...				
336. Nelisiwe: It says from positive to negative ... and there's a line there that says 0(nought).						
337. Kevin: Reference point.						
338. Nelisiwe: Yah.						
	339. Craig: It actually makes more sense. Ok.					
340. Thandeka: Ok. Let's go do the experiment.						
						341. Mondli: So, you mean if you... No, if you mean that... If you... You moving in the opposite direction then no it won't be like that.
		342. Thandeka:				

Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
		(exasperated) No, see... While you walking towards the thing it's a positive velocity, and once you've gotten past you walking away from it so it's changed direction so its a negative velocity.				
			343. Mondli: But then you still going in the same direction			
		344. Thandeka: No it's not the same direction. No. Listen to this..this way-you, when you're looking at the movement, with reference to you it's the same direction, but reference to the reference point there's a change of direction cos its no longer moving towards, it's moving away, so it's changed direction... it's positive.				
	345. Mondli: Oh, Ok Thank you.					
346. Craig: Ok now let's check out our movements.						

Argumentation Episode 6
(Part of Activity 2)

Task: The group is predicting the shape of the acceleration-time graph for an object rolling down a slope (or being dropped), given that the starting point of the ball is the reference point, and the downward direction is positive.



Claim:
For free-fall, a special case of projectile motion, the acceleration of the object is constant.

Alternative claim:
The acceleration of the object increases when it's coming down and decreases when it's going up.

Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
46. Kevin: But now we're saying acceleration-time graph...						
	47. Mondli: Acceleration's constant so it's like a straight line.					
			48. Kevin: But the acceleration is increasing.			
	49. Craig: No.					
	50. Craig & Mondli (together): No, the acceleration is constant.					
	51. Mondli: It says there.					
		52. Craig: Constant acceleration. Gravity is always constant at ten metres per second, to the negative two that is.				
	53. Mondli: It's constant, yah. Even if it's a ... Even if the velocity is zero, the acceleration stays constant					
		54. Craig: We've only dealt with constant acceleration, so we won't get a confusing acceleration. Cos then all the other graphs would just be impossible.				
55. Mondli: Yeah.						
56. Nelisiwe: How, how low can you go ...(singing the						

Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
words of a currently popular song).						
57. Craig: So displacement is ...						
58. Mondli: Explanations?						
59. Chistopher: Yeah. That's the question.						
60. Thandeka: Okay.						
61. Mondli: We just said it. Let's put it into writing.						
62. Nelisiwe: Let's put it into writing – so how do we explain this?						
63. Craig: As the ball starts off it's moving slowly and then it gets to the bottom, it...						
64. Mondli: Yah.						
65. Craig: So therefore as time increases, for each unit of time...						
66. Mondli: It covers more distance.						
67. *Craig*: it is covering more distance.						
68. Mondli: Yah.						
69. Thandeka: As time increases it's ... okay, now start again. As...						
70. Nelisiwe: As time...						
71. Craig: As the ball starts rolling...						
72. Nelisiwe: You said as time increases...						
73. Craig: Yah.						
74. Mondli; As the ball starts rolling...						
75. Nelisiwe: as the ball (talking while writing.)						
76. Mondli:						

Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
...starts to roll...						
77. Nelisiwe: starts to roll...						
78. Craig: It only covers a small distance.						
Mondli: That's a certainty.						
79. Craig: ...due to the acceleration...						
80. Craig: i.e. as the ball covers more distance for every unit of time.						
81. Nelisiwe: Due to?						
	82. Craig: To acceleration, constant acceleration.					
	83. Mondli: Due to uniform acceleration.					
	84. Craig: Uniform... constant acceleration – the same thing.					
85. Mondli: increasing...						
86. Thandeka: i.e. ... (talking while writing.)						
87. Mondli: ...per unit time...						
88. Craig: Per unit time the ball covers... for each...						
89. Thandeka: Why are you saying i.e, Noms?						
90. Craig: Just saying it in a different way basically.						
91. Nelisiwe: As velocity... as velocity increases the time stays constant. Is that the next one? Or velocity stays constant?						
92. Thandeka: No.						
93. Mondli: It covers...						

Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
94. *Craig:* The velocity is uniformly increasing.						
95. *Nelisiwe:* The velocity is ...						
	96. *Craig:* is increasing uniformly.					
	97. *Thandeka:* There is a change in velocity at a constant rate. So there's definitely acceleration.					
98. *Craig:* Yes.						
						99. *Kevin:* (still unclear – so raises a question) Doesn't the acceleration increase?
100. *Craig:* Uh, uh.						
	101. *Mondli:* No, it's constant. It says there – constantly accelerated. It's the velocity that's like, that's like increasing.					
		102. *Craig:* Yah, the velocity will be increasing due to the accelerating.				
103. *Kevin:* (inaudible but still appears to be unsure.) Have we decided what we gonna write?						
		104. *Craig:* Acceleration due to gravity is constant, 'cos gravity is constant. That's what I would say.				

Later in the same activity the group is examining the computer generated graphs of the motion.

Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut
168. Craig: Okay, now the question is… what's what?					
169. Thandeka: The green line… remember… he said it's acceleration-time graph.					
170. Craig: The green line?					
171. Thandeka: The red line is the first one we did… you know… on these things (referring to previous activity) … displacement-time graph, that's the red one. The blue one is velocity-time. The last one is acceleration time.					
172. Craig: So that's acceleration-time?					
			173. Kevin: Green? Green? Told you'll… I'm telling you'll the graph is wrong.		
174. Craig: It is confusing.					
175. Thandeka: It is confusing.					
			176. Kevin: The thing should be going like that.		
		177. Thandeka: Think of it this way Kevin. Once the ball is out of your hands there's only one force acting on it and that's gravity. And gravity is constant no matter where you are.			
				178. Kevin: Is that acceleration or… velocity and time. If you increase velocity and the time stays the same… there will definitely be an increase in acceleration.	
		179. Thandeka: No. It's constant acceleration. See… it's straight.			

And then later, after the group makes another attempt to generate better graphs.

Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
			228. Kevin: The acceleration goes like that... Okay, it's still staying the same. The acceleration keeps changing.			
	229. Craig: Acceleration should be constant at all points. Con...					
				230. Kevin: But look here, right. Acceleration is equal to velocity over time. How can you tell me it stays the same when you increasing velocity? Then acceleration can't be... can't be staying constant. Acceleration is going to increase if the velocity increases.		
231. Nelisiwe: Okay, let's do another thing. Wow!						
232. Nelisiwe: Let's go again. And... go.						
233. Craig: Yah.						
234. Kevin: That's better.						
235. Nelisiwe: Well done Thand's.						
236. Thandeka: What can I say?						

Later in the activity they are answering the question, "What shape does the acceleration-time graph have?", but this time basing their answer on the graph they generated.

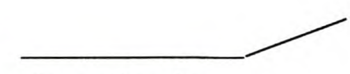
Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
272. Craig: Acceleration versus time graph.						
	273. Thandeka: It's – it's a straight line parallel to the x-axis.					

Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
274. *Craig:* Go for it, girl.						
275. *Nelisiwe:* There we go.						
276. *Mondli:* Above the x-axis? No, it isn't.						
277. *Craig:* Yah.						
278. *Mondli:* Not necessarily.						
279. *Craig:* In this case it is.						
280. *Mondli:* It could be negative.						
281. *Thandeka:* I can't spell parallel.						
282. *Mondli:* Because we've got no proof.						
283. *Craig:* There it is. Above the x-axis. On the PC here.						
	284. *Kevin* A straight line parallel to the...					
285. *Mondli:* Oh, yah.						
286. *Thandeka:* We got it right.						

Argumentation Episode 7
(Part of Activity 3)

(An example of an 'agreeing to disagree' argument episode where the group does not reach some form of resolution of the debate.)

Task:
The group is predicting the shape of the acceleration time graph for a ball that is rolled to and fro on the track shown alongside, given that the start is the reference point and forward along the track is the positive direction.



Claim: The position of the acceleration-time graph should alternate above and below the x-axis depending on the direction that the object is going (the direction of the acceleration is dependant on the direction of the movement).

Alternative claim: For periods when the object is accelerating, the acceleration-time graph is a straight line below the x-axis.

Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
206. Mondli: Okay, now we have the acceleration-time…						
207. Craig: Okay.						
208. Thandeka: It's above the x-axis.						
209. Craig: Okay, so your first little point there will be a constant acceleration, then there will be no acceleration…						
	210. Kevin: But acceleration is a vector, so it should reach below the x-axis when there is a change in direction. Constant... down					
211. Thandeka: But look at... at our velocity-time graph...						
			212. Mondli: Yeah, it should be below.			
213. Thandeka: First, it's constant, meaning there's no acceleration and then it accelerates so it drops, and then it goes up again, and then it goes down.						
			214. Mondli: No. It will be below the x...			
215. Thandeka: I'm sure it does that...						
	216. Kevin: First it has to be above the x-axis because it is moving in that direction...					
			217. Mondli: No, it will be below.			
	218. Kevin: ...and then it's going to be below....	because it changes direction.				

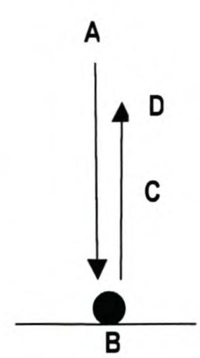
Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
			219. Mondli: No. It's always below. 'Cos, look...			
			220. Craig: Yah. It will always be either...			
				221. Mondli: 'Cos it will be slowing down as it goes up and then it will be like, going faster in the opposite direction, so it's...it's still below. So it's just a straight line below.		
222. Thandeka: No. Won't it...						
223. Nelisiwe: You brought that book?						
224. Craig: Yah, I did. I'm confused.						
			225. Mondli: It's a straight line below the x-axis.			
			226. Craig: Yah.			
227. Nelisiwe: (exasperated) Graphs of motion!						
	228. Thandeka: No, guys, won't it look something like this? I'm not sure.					
	229. Kevin: Yah. That's what I'm trying to say it'll be....	because it changes direction.				
230. Thandeka; Um...						
				231. Mondli: No, but then... it's accelerating in the opposite direction...		
			232. Chistopher: Yah.			
				233. Mondli: ...so it can't be on top.		
		234. Kevin: acceleration is a vector.				
235. Craig: Yah.						
		236. Kevin: So you got negative and positive. So you changed direction.				
					237. Mondli:	

Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
					No. If it was decelerating, but in the opposite…	
		238. Kevin: But can you see over here, with the velocity – velocity is a vector. That's when you reached the x-axis...then below. So acceleration is a vector so...				
239. Thandeka: Yah, so it's ... No, it goes...						
		240. Kevin: It changes direction.				
241. Thandeka: There's no acceleration here. Then it accelerates, and then there's no acceleration again.						
242. Mondli: Okay, for this... let's draw the graph for this. For this it will be below, yah?						
243. Kevin and Craig: Yah.						
244. Mondli: 'Cos it's decelerating.						
	245. Kevin: And then it's gonna come above...					
	246. Thandeka: And then come above...					
247. Mondli: If it was decelerating in the ... For this it would be...						
				248. Craig: But, now, it's going in the opposite direction so you gotta take that into account as well.		
			249. Mondli: Yah, so it's still below.			
				250. Craig: You're not increasing. You not accelerating in the same direction as you were originally. You're accelerating in the		

Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
				opposite direction, so it will stay below the graph.		
			251. Mondli: Yah.			
			252. Craig: It's a negative acceleration in a negative...			
				253. Mondli: 'Cos there's... 'cos there's gravity.		
				254. Craig: It's going faster and faster in a negative direction, not in a positive direction.		
				255. Mondli: If it was going slower and slower in the opposite direction, then it would be above. But it's going faster and faster.		
256. Kevin: Is that your final answer?						
257. Craig: That's my final answer.						
				258. Mondli: So, if you're confused, just think of gravity. It's like, accelerating downwards.		
259. Kevin: But see here right...						
260. Craig: Yah.						
		261. Kevin: When you over here... over here there's no acceleration.				
262. Craig: Yah.						
		263. Kevin: And then once you reach the slope you going up, gravity is going down.				
264. Craig: Yah.						
		265. Kevin: So, won't your acceleration... If this is positive, your acceleration will be ...	...Okay, okay, okay.			

Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
266. Mondli: Let's just check.						
				267. Craig: It's the same thing as if you throwing a ball up. Anyway...		
268. Kevin: Well, we'll see if we right.						
269. Craig: We'll see, we'll see.						
270. Mondli: We'll see.						
271. Craig: I reckon I am.						
272. Mondli: Yah, me too.						
273. Thandeka: Ah... guys.						
274. Craig: Sorry.						
274. Mondli: Sorry, dudes.						
275. Nelisiwe: I need some Panados.						
276. Craig: And you need to give the computer a chance to be experimentally incorrect. Shall we go and do it?						

Argumentation Episode 8
(Part of Activity 5)



Task:
The group is describing the motion characteristics of a bouncing ball at various points in its motion. Here the group is considering a point B which is the point where the ball strikes the floor. The floor is the reference point and upwards is the positive direction. In this extract the group is working to determine the displacement of the ball at point B.

Claim:
The displacement of the ball on the ground (at the reference point) is a minimum (zero).

Alternative claim:
The displacement of the ball on the ground is a maximum because it's furthest away from its starting point.

Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
	457. Kevin: Okay, then what's it at B? Zero at that point?					
458. Craig: Okay.						
459. Thandeka: Where's B? B is … when it hits the ground, isn't it?						
460. Kevin: Velocity…						
461. Thandeka: At B there is… that is the… when it hits the ground.						
462. Nelisiwe: Yebo.						
			463. Thandeka: By the floor. And at B there is maximum displacement.			
464. Mondli: ……. (unclear)….						
			465. Nelisiwe: And it's 0.3 guys.			
466. Craig: Okay.						
			467. Nelisiwe: It hits the … ground at 0.3… 0.3, that's what the displacement is.			
468. Craig: That's A. B is when it hits the ground…						
469. Kevin: Wait, the displacement at B is…						
470. Thandeka: On the floor.						
471. Craig: C is halfway up the middle.						
	472. Kevin: There's it… maximum displacement… no, no, no, no…	displacement-time graph… this is your reference point… so there's no displacement.				
473. Nelisiwe: Does he want us to judge one another's?						
474. Craig: Yah.						

Uncoded	Claim	JustClaim	AltClaim	JustAltClaim	QualRebut	QuesClaim
			475. Nelisiwe: Then Ghandi, this is not zero displacement, this is maximum displacement… maximum displacement,			
			476. Thandeka: Ghandi, maximum displacement.			
		477. Kevin: Hey now. It's on the ground.				
478. Nelisiwe: Oh wena… men and women…						
479. Thandeka: The fairer sex versus the most empowered sex. And what's the velocity here? Zero? Why aren't you writing?						
	480. Kevin: Velocity zero, displacement zero. Okay…					
			481. Nelisiwe: No, no, no, no. This is maximum displacement.			
482. Craig: Sorry, but…						
	483. Thandeka: No, no…	the floor is the reference.				
	484. Craig: Okay, minimum displacement…					
485. Kevin: Zero velocity…						
486. Kevin and Craig: Constant acceleration.						
	487. Mondli: Displacement is zero.					
488. Craig: Sorry. Let's wait for people to catch up with each other.						

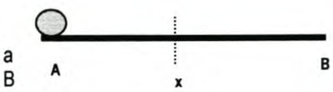
Appendix 12
Coding for analysis of discussion/explanation segments.

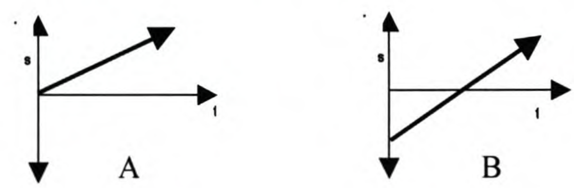
Discussion/Explanation Episode 1
(Part of Activity 1)

Context of discussion:

The group is working on the problem described alongside. The discussion here refers to graph B.

Task under discussion:
Two displacement-time graphs for a ball rolling on a smooth horizontal surface with a uniform velocity between two points A and B are shown below:





Use your graphs to work out where the reference point for the motion is, and which direction has been chosen as positive. Give reasons for your answer.

Learner difficulty or 'alternative idea' evident here:
Two learner difficulties seem to be evident:
1. Inability to recognize that the intersection with the x-axis represents the reference point in a displacement-time graph.

Uncoded	PHC	AQ	CMR	EXP
583. Mondli: Two displacement-time graphs...(reading aloud from exercise).				
584. Thandeka: Two displacement-time graphs of a ball...(reading aloud from exercise).				
	585. Thandeka: Graph A ... constant . It's moving at a constant velocity.			
586. Kevin: No. Use the graphs to work out where the reference (drawing group's attention to requirements of exercise).				
	587. Mondli: (cuts in) So there's no acceleration ... there's no frictional force.			
588. Kevin: No. Over here, all they asking us to do is work out where the reference point is and which direction is chosen as positive.				
589. Thandeka: Okay...(reads) " Use the graphs to work out where the reference point....	In graph A the reference point is the starting point and your reference direction is...Towards B is positive.			
590. Mondli: So.. so...uh...				
	591. Kevin: Between A and X is positive.			

Uncoded	PHC	AQ	CMR	EXP
592. Mondli: Oh, so for graph A ..for graph 1..				
593. Craig: For graph 1...				
	594 Mondli: Reference point is A...			
	595. Craig: Yah. The reference and the starting point is A.			
	596. Mondli: (continuing) Yah, and then the other one it's B.			
597. Craig: I haven't ..				
598. Nelisiwe: And the reference direction is...				
599. Mondli: (continuing) Yah it is.				
	600. Kevin: Uh, uh, it's x.			
	601. Thandeka: (agreeing with Kevin) It's not. It's x.			
	602. Craig: Yah.			
	603. Kevin: It's x.			
	604. Craig: The starting point is still A but the reference point is x.			
		605. Mondli: No. But then how come it's x?		
606. Thandeka: Because th...				
				607. Kevin: Because there' negative to...
				608. Thandeka: Because there's a change of direction now.
				609. Kevin: (cont.) Yah.
610. Thandeka: And our movement is ...				
		611. Mondli: So?		
			612. Kevin: For these graphs here... (referring to the MBL graphs that they had to replicate) In order to get these graphs, you had to walk from behind the reference point towards the positive. So it has to be x because you moving from A to B, positive to negative.	
613. Craig: (to Mondli) You're confused?				
614. Mondli: Mmm...				
615. Craig: Give me a second to ...				
			616. Kevin: See. This part over here...	

Uncoded	PHC	AQ	CMR	EXP
617. Craig: Yah, let me just finish the A...				
			618. Kevin: (continuing)... you had to move from the positive through the reference point to the negative...(referring to previous example).	
619. Craig: Yah.				
620. Kevin: That's what I'm saying so...				
	621. Craig: So this is your indicator of reference point... Yah, which is x.			
	622. Mondli: X is the reference point.			
		623. Thandeka: We have to give reasons. What are our reasons guys?		
		624. Mondli: No, it depends. What are we taking as the reference point?		
	625. Craig: Which one? For A? A, I said that... If you looking at this diagram on top here...I said was A was the ... reference point and the starting point...			
626. Nelisiwe: Yah.				
	627. Craig: (continuing) ...and the positive direction is from A to B.			
	628. Thandeka: Yah, away from A towards B.			
	629. Craig: Yah, it's positive from A to B.			

Discussion/Explanation Episode 2
(Part of Activity 4)

Context of discussion:

The group is describing the acceleration of a ball that rolls up and down an incline, given that the starting point is the reference point and the upward direction is positive. They need to describe the acceleration as the ball moves up the slope, at the turning point, and as it moves down the slope.

Learner difficulty or 'alternative idea' evident here:
Acceleration decreases as the ball moves up the slope because it is slowing down, and acceleration increases as the ball moves down the slope because it is speeding up.

Uncoded	PHC	AQ	CMR	EXP
		35. Kevin: Why is acceleration negative again... below the x-axis?		
				36. Thandeka: Because the force acting on it is...
		37. Nelisiwe: (interrupts)... is influencing it?		
				38. Thandeka: (continuing) ...doesn't change direction.
				39. Craig: Cos it's slowing down.
	40. Thandeka: Velocity as the ball goes up is decreasing.			
		41. Kevin: Acceleration. Increasing?		
	42. Thandeka: Increasing. At the turning point zero. Acceleration – turning point non-zero, isn't it? As the ball comes down acceleration is increasing.			
		43. Kevin: Acceleration decreasing? Okay, so why is the acceleration decreasing when it is going up?		
				44. Thandeka: Cos it's slowing down.
			45. Kevin: But there... You showed the acceleration to be constant... (comparing to a previous discussion)	
		(Kevin, cont) ...so why should it be decreasing, non-zero, increasing?		
46. Thandeka: Okay. Put me on the spot.				
47. Craig: Alright...				
	48. Thandeka: Constant, constant, constant.			
		49. Kevin: Because?		
50. Mondli: When you throw the ball upward...				
				51. Thandeka: Because it's free fall, it can only be 10m.s^{-2}. Yah.
	52. Mondli: Yah, it's constant.			
	53. Craig: Yah, acceleration should always be constant.			
		54. Kevin: But at the turning point?		
55. Thandeka: It's still... It's still...				
	56. Kevin. No movement at the turning point.			
				57. Thandeka: No. No it's... No matter where it is, it will still be under the influence of gravity.
58. Mondli: Yah.				
	59. Nelisiwe: Constant, constant, constant.			
60. Kevin: Okay.				
61. Mondli: As the ball goes up...				
	62. Thandeka: Constant, constant, constant.			
	63. Craig: Yah, constant			

Discussion/Explanation Episode 3
(Part of Activity 4)

Context of discussion:

The group is describing and comparing the velocity of a ball at the same point on a slope when it moves up and down the slope.

Learner difficulty or 'alternative idea' evident here:
The magnitude of the velocity of a ball at a point going up an incline is not the same as the magnitude of the velocity at that point on its way down the incline.

Uncoded	PHC	AQ	CMR	EXP
		208. Craig: Okay, and the velocity? The velocity at the same point on either side of... Okay.		
	209. Kevin: Velocity decreases as it goes up....			
210. Craig: Yah.				
	211. Kevin: (continuing) ...and increases...			
	212. Craig: And increases as it rolls down... but if you say now you had to... as it's going up you... say now you select a point...as you go up that velocity will be X.			
		213. Kevin: There's the point, right?		
214. Craig: Yah.				
			215. Kevin: The velocity was zero point one (0.1) and as it goes to the turning point it is zero point zero two (0.02), so that's a decrease.	
	216. Craig: Yah, it should. At the turning point it should have been zero.			
	217. Kevin: It is zero...point zero...			
218. Thandeka: (laughs) If you round...				
219. Craig: Yah, but...				
	220. Kevin: It's point zero. You can't round point zero, so it still ends up zero.			
221. Craig: Okay, let's just go back to the other thing first...				
222. Mondli: The velocity...				
223. Craig: Okay, if you're going up the slope...				
224. Thandeka: Yah.				
			225. Craig: There's this point...You're going up the slope. Your ball will be over here...that's your velocity...your velocity is X.	
			226. Thandeka: And if you take the same point on the other side, it will be the same.	
			227. Craig: (continuing) ... it goes up...it comes back down...it will also be X.	
	228. Mondli: No, it's decreasing.			
229. Thandeka: Say,,,say like this... If you going up like this...				

Uncoded	PHC	AQ	CMR	EXP
	230. Craig: You're looking at a **particular** point on the slope. (sounds frustrated).			
231. Kevin: Okay, wait...No...				
232. Thandeka: It is...				
				233. Kevin: When it's going up it's decreasing...so it's got less velocity.
234. Mondli: No, looking at the first...				
				235. Kevin: (continuing) ...when you're going down it's increasing
236. Craig; Yes, but in...				
				237. Kevin: (continuing) ...so you might have a different reading.
			238. Thandeka: No, but if you have this point here...and this point here...and you take the readings, these points will be equal. Like here and here...zero point one eight (0.18) ....and zero point one eight one (0.181). Except that it will be negative.	
239. Kevin: Okay...direction...okay.				
240. Craig: That's cool. Now how can I say that in words?				
	241. Kevin: Must say up and down are equal.			
242. Thandeka: Okay.				
243. Craig: The velocity of the ball...				
	244. Kevin: Goes up with the same speed as it comes down... comes down with the same speed as it went up...			
245. Nelisiwe: No...something like that...				
246. Kevin: What?				
	247. Nelisiwe: It increases...it slows down...			
			248. Kevin: That's what ... that's what the data says. Look here, zero comma one eight (0,18),,,, zero comma one eight (0,18).	
			249. Thandeka: But the difference is here. That reading we took near the end of the guy's journey and this reading you took at the beginning of the guy's journey from there to there.	
250. Kevin: No, it s still on the same... exhibit.				
251. Thandeka: (laughs) exhibit...				
252. Thandeka: Nunt's, what are you thinking of?				
253. Nelisiwe: The velocity of the ball at ...				
	254. Mondli: No, we've got to say it starts slower.			
255. Craig: Sorry?				
	256. Mondli: (continuing) ...It starts...it starts... goes faster and faster and then slows down, then stops, then goes faster and faster...stops...			
	257. Craig: No. As it goes up the slope it goes slower and slower, stops, then it goes faster and faster as it moves down the slope.			

Uncoded	PHC	AQ	CMR	EXP
258. Thandeka: Yah, I think I'll write that.				
			259. Kevin: See here, right. Going up is zero point one (0.1). (Showing his book to Craig.)	
260. Craig: Yah.				
			261. Kevin: (continuing) ...coming down is zero point one (0.1).	
	262. Thandeka: At a certain point! (Emphasises with voice).			
	263. Nelisiwe: Where it slows down at a certain point...			
264. Kevin: So at a certain point...				
			265. Craig: No, it doesn't slow down at that point. If you're going up the... Say now here's your incline...say now over there you decide is where you're going to take your point...	
266. Kevin: They said a point on the graph. So we have to look at the graph.				
267. Craig: Not the graph. At the... the incline, okay?				
268. Thandeka: The ball.				
269. Kevin: Okay.				
270. Thandeka: Uh huh.				
			271. Craig: (Continuing from previous) Okay, you're watching? If you go up here...say we decide on that point. The ball is rolling up...Okay, I admit it's slowing down but at that point your velocity will say now be X. It's gonna go up there, turn around, come back down. When it reaches that point again it will be negative X. ...	...but its still X, just going in the opposite direction. (Explaining, making gestures with his hands.)
	272. Kevin: So velocity up the slope is equal to the velocity down the slope...			
273. Craig: Which is what we said...				
274. Nelisiwe: Okay, that's why we should have put...				
275. Facilitator: At a specific point.				
	276. Craig: At a specific point.			
277. Thandeka: At a...				
		278. Kevin; And acceleration is... Acceleration is just constant. Nothing more to say about the acceleration? And what do we say about the acceleration? It's constant?		
279. Thandeka: You're a fast writer.				
280. Kevin: You're writing an essay there, Craig?				
281. Nelisiwe: Eh, Craig is writing an essay here and I'm even lost.				
282. Kevin: Share with us what you're writing.				
283. Craig; I'll tell you now, let me just get my words right.				

Uncoded	PHC	AQ	CMR	EXP
	284. Craig: Okay, I'll just read what I wrote: "The velocity of the ball at a particular point on the incline as it rolls up the incline is the same as that when it reaches the same point when it rolls back down the incline, just in the opposite direction.			
285. Thandeka: Direction.				
286. Kevin: Okay, not bad.				
287. Craig: Does it make sense?				
288. Kevin: Yah.				
289. Craig: That's cool.				

Discussion/Explanation Episode 4
(Part of Activity 4)

<u>Context of discussion:</u>

The group is comparing the motion of a ball rolling up and down a slope for two cases, firstly where the upward direction is positive, and then when the upward direction is negative, and are constructing a table of similarities and differences. In both cases the starting point at the bottom of the slope is the reference point. In this discussion, learners are comparing the velocity of the ball at the turning point in both cases.

<u>Learner difficulty or 'alternative idea' evident here:</u>
Assigning directional signs (+ or -) to a zero velocity.

Uncoded	PHC	AQ	CMR	EXP
	408.Thandeka: They're both zero. So similarities is...um... at the turning point...			
409. Nelisiwe: What are you talking about now?				
410. Thandeka: We have to use differences and similarities...				
	411. Kevin: At the turning point they're the same.			
	412. Thandeka: At the turning point they're both zero...			
	413. Kevin: Or positive.			
	414. Thandeka: You cannot get a negative zero so can only be positive...			
415. Kevin: This is the turning point...				
	416. Thandeka: Yah, and they're zero...			
			417. Kevin: You have negative displacement...	
418. Nelisiwe: No...				
			419Kevin: (continuing) Just as at this turning point, you have a positive displacement...	
420. Thandeka: We're talking about velocity.				
421. Kevin: Okay, okay... my mistake.				

Uncoded	PHC	AQ	CMR	EXP
				422. Nelisiwe: Turning point should both be zero... because of a change in direction.
				423. Thandeka: Because it stops.
	424. Kevin: it... you can get a negative zero... you can get a negative zero...			...but it doesn't mean negative... it just shows direction.
	425. Thandeka: Just zero's.			
				426. Kevin: (continuing) ...so you got nought in that direction, and you got nought in that direction.
				427. Thandeka: But there's no direction, because it just stops.
428. Kevin: Exactly... (group laughter)				
	429. Thandeka: (as she writes) ...turning points are both zero,			and the reason for that... it stops for an instant... stops for an instant.

Discussion/Explanation Episode 5
(Part of Activity 4)

Context of discussion:

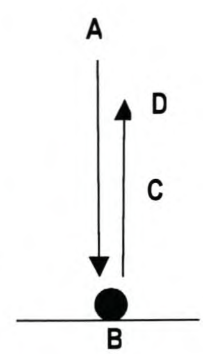
The group is discussing the motion of a ball rolling up and down a slope, where the upward direction is negative, and the starting point at the bottom of the slope is the reference point. In this discussion, learners are discussing why the velocity of the ball is decreasing.

Learner difficulty or 'alternative idea' evident here:
A negative velocity means that the object is slowing down, and a positive velocity means that the object is speeding up.

Uncoded	PHC	AQ	CMR	EXP
		560. Mondli: The velocity is decreasing... velocity... but then, why is it decreasing... Because the... because the upward movement...		
				561. Kevin: Because it's going up the slope.
		562. Mondli: (continuing) ...is a negative direction?		
	563. Craig: Don't forget that you must say the velocity in a negative direction.			
	564. Kevin: Negative doesn't mean...negative...yah...			...negative just means the direction, negative doesn't influence the values.
				565. Mondli: Yah, that's why it's decreasing velocity. If it was positive it would be increasing.
				566. Kevin: No. That's what I'm trying to explain to you. Negative and positive doesn't ... like negative two and positive two, in physics it's the same thing, Like you know, in maths, negative two is smaller than two, but in physics,

Uncoded	PHC	AQ	CMR	EXP
				negative two and two is positive... just that it's in the opposite direction.
		567. Mondli: So the reference direction, if it's up then it's negative, that's why it's decreasing...		
568. Kevin: Yeah... then				
		569. Mondli: (continuing) ...if it was positive?		
		570. Kevin: Then it would be increasing?		
571. Mondli: You have to write that down.				
	572. Kevin: No, they just asking you below the turning point, that's below over here, so it would be decreasing. Look at your graph. (Reaches over to Mondli's book and pages back to his graph.)			
573. Mondli: Yah, I know.				
574. Kevin: Below... Before you get to the turning point.				
		575. Mondli: Yah, but then why... is it decreasing? Because it's negative?		
				576. Kevin: Because it's going down. Gravity is acting down the slope. The ball is going up the slope, so it will decrease.

Discussion/Explanation Episode 6
(Part of Activity 5)



<u>Context of discussion:</u>

The group is discussing the motion of a bouncing ball, where the ball is dropped, strikes the ground and moves up again. In the discussion, A is the starting point of the ball, B is when it strikes the ground, C is midpoint on its way up again, and D is the high point it reaches on its upward movement.

<u>Learner difficulty or 'alternative idea' evident here:</u>
The collision of the ball with the ground imparts a force which causes the ball to speed up over the first part of its upward motion, before it begins to slow down, as the effects of the force are no longer felt.

Uncoded	PHC	AQ	CMR	EXP
		612. Kevin: Where's CD?		
	613. Thandeka: CD is here. C to the turning point.			
		614. Kevin: What happens at CD?		
	615. Thandeka: Goes slower and slower towards D, and at D it stops... for an instant.			
		616. Kevin: Wait, but... when it bounces... doesn't it speed up and then start slowing down?		

Uncoded	PHC	AQ	CMR	EXP
617. Thandeka: Say what?				
618. Kevin: Okay, never mind.				
		619. Kevin: (repeating) Wait. See... uh... from... wait... from B to C... doesn't it speed up a little bit and then from C to D, slow down?		
	620. Thandeka: C to D. It slows down.			
621. Craig: Um... I see what you saying.....				
		622. Kevin: Okay, then... it... it doesn't start slowing down from here and ... it speeds up?		
	623. Thandeka: You have to accelerate after you stop... You know what I'm saying... you have to accel...			
	624. Craig: Yah, for a very short time. For a very short...			
		625. Kevin: Between B and C, doesn't the velocity increase?		
626. Craig: Yah. Yah.				
	627. Nelisiwe: So it goes faster and faster, then it slows down.			
628. Thandeka: Ay... Ghandi.				

Discussion/Explanation Episode 7
(Part of Activity 6)

Context of discussion:

The learners are interpreting the motion represented in a series of displacement-time graphs before attempting to replicate the graphs using the computer.

Learner difficulty or 'alternative idea' evident here:
Learner difficulty with the idea that displacement-time graphs can go underneath the x-axis (representation of negative displacements).

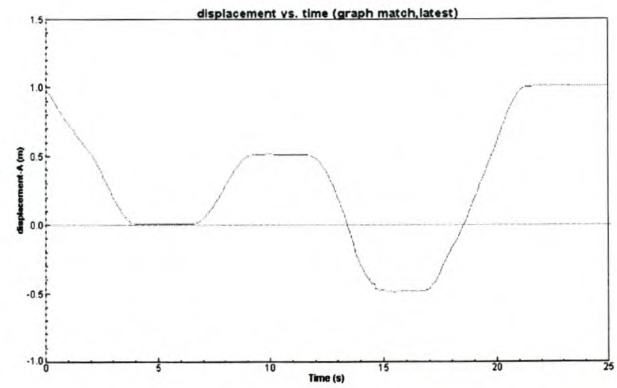
Uncoded	PHC	AQ	CMR	EXP
		47. Kevin: Craig, does the displacement-time graph ever go below the x-axis?		
	48. Craig: Yes, if you're going...			
49. Kevin: I mean like... like this...				
	50. Thandeka: Yes it does.			
		51. Kevin: (continuing) I mean, does it ever go... I mean... on one graph... top and bottom?		
				52. Craig: Yah. Say that now here is your sensor, there's your reference point...Say now positive is going away... If you now...
53. Kevin: Yah?				
				54. Craig: (continuing) (...few unclear words...) ... when you standing away from it...or you can go before it...so now you can go away and come back and go ...

Uncoded	PHC	AQ	CMR	EXP
	55. *Kevin*: So we going away from the sensor? We are not going...			
	56. *Craig*: Correct... away from it.			

Discussion/Explanation Episode 8
(Part of Activity 6)

<u>Context of discussion:</u>

The learners are interpreting the motion represented in a series of displacement-time graphs before attempting to replicate the graphs using the computer. The graph that the learners are discussing is shown alongside.



Graph for Exercise 4 under discussion.

<u>Learner difficulty or 'alternative idea' evident here:</u>

Two learner difficulties seem to be evident:

1. A negative gradient on an s/t graph means that the object is slowing down.
2. The intersection of an s/t graph with the x-axis indicates a change in direction for the object.

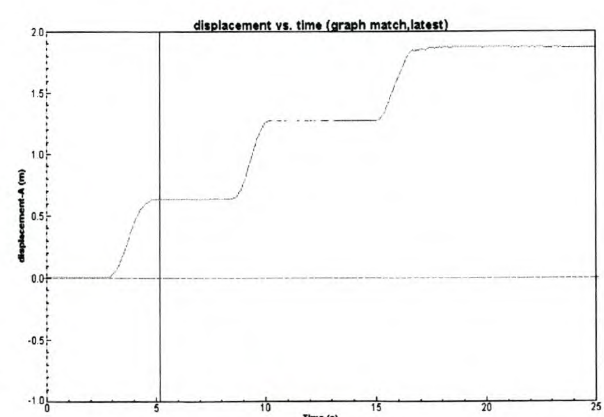
Uncoded	PHC	AQ	CMR	EXP
		65. *Thandeka*: Where does it change direction?		
66. *Nelisiwe*: Okay, wait...				
	67. *Thandeka*: It changes direction here.			
	68. *Mondli*: No, that just means that it is slowing down.			
			69. *Thandeka*: No, it actually changes direction... and also changes direction here.	
			70. *Mondli*: No... it changes direction at... It's these two points.	
				71. *Craig*: No, you just going beyond the reference point. That's your reference point... Say now... here's your sensor...here's your reference point. It's going that way.
72. *Mondli*: Yah, if it's the reference point, then...				
				73. *Craig*: You not changing direction. You still going straight. Just that the displacements are positive and negative.
	74. *Kevin*: This has to start behind... not at the reference point.			
		75. *Mondli*: Okay, please explain the situation here?		

Uncoded	PHC	AQ	CMR	EXP
				76. *Craig*: Okay... standing away from the graph. Starting... you put your sensor... Here's your reference point. You starting here. You moving towards it till you get to it...
				77. *Kevin*: Then you move away from it.
				78. *Craig*: (continuing) ... then you stopping for a while. Then you moving away again.
	79. *Mondli*: Yah, that's the change in direction.			
				80. *Craig*: (continuing) Yah, so you gonna accelerate away, stop.
				81. *Kevin*: (continuing) Move back...
				82. *Craig*: (continuing) Move back down that way... beyond it...back there...stands for two seconds... move way beyond it again to wait up here.
83. *Thandeka*: I agree with you.				
84. *Kevin*: Yah.				
85. *Craig*: Is that all?				

Discussion/Explanation Episode 9
(Part of Activity 6)

Context of discussion:

The learners are converting a series of displacement-time graphs into their corresponding velocity-time graphs and then checking their graphs using the computer equipment. In the discussion below, they have started working on converting the graph shown alongside.



Graph for exercise 1 under discussion.

Learner difficulty or 'alternative idea' evident here:
Two learner difficulties seem to be evident:

1. Acceleration and deceleration do not apply to motion on a flat surface, only to inclines and to projectile motion.
2. Difficulty representing mixed motion on a v/t graph (i.e. a combination of stationary, uniform velocity and uniform acceleration). There's a suggestion that changing velocity can be represented by curves on a velocity-time graph.

Uncoded	PHC	AQ	CMR	EXP
94. *Craig*: I need something to work with.				
	95. *Thandeka*: No, but a sketch graph is not detailed.			

Uncoded	PHC	AQ	CMR	EXP
96. Mondli: All sketch graphs are... displacement versus time and velocity versus time.				
97. Craig: One... two... three... four... . five...				
		98. Thandeka: Wait. How do you show that something's like really still for a really long time?		
				99. Kevin: You draw it on the x-axis. You have to... you have to draw a line on the x-axis....
100. Thandeka: Okay, let's do this.				
				101. Kevin: (continuing) ...to show that it's really still for some time... and then a dotted line to show that it's an increasing velocity.
102. Thandeka: Yah.				
103. Mondli: We got velocity-time.				
	104. Kevin: Here it's going really slow... it's going really slow... and increasing here.			
105. Craig: Huh?				
	106. Kevin: (continuing) Then it gets even more slower...			
	107. Thandeka: And every time... Oh, they're the same velocity... sort of... kind of...			
108. Kevin: It's the first time I ever said it properly, Craig.				
109. Craig: Yah.				
	110. Kevin: It goes down to zero.			
111. Craig: Yep.				
112. Mondli: Let's see... velocity...				
113. Craig: No... wait... one minute...				
114. Kevin: No, it's right.				
	115. Craig: Don't forget you got deceleration in there.			
		116. Thandeka: What deceleration?		
	117. Kevin: No. That's for uphills and downhills. No, this is flat movement.			
118. Craig: Okay.				
		119. Kevin: So increasing displacement will mean an increasing velocity?		
120. Craig: Yah, but as soon as you start moving...				
	121. Kevin: That's for projectile motion.			
	122. Craig: You've still got to... you still gotta slow down.			
	123. Thandeka: So it mustn't be straight...it must be curved.			
	124. Kevin: No. It moves fast...stops.			

Uncoded	PHC	AQ	CMR	EXP
	125. Craig: No. Let's just see. It's got a curve.			
126. Thandeka: Yah.				
	127. Kevin: Okay... so it will be a curve? And then dotted... curve... and then dotted.			
	128. Craig: Okay. I'm not... no... it wouldn't be a curve. It wouldn't be curved.			
		129. Kevin: Wouldn't it be?		
	130. Thandeka: Yes it... uh... actually velocity-time graphs don't have curves.			
131. Craig: Yes.				
	132. Thandeka: So I am right... oh no... I'm not right. It's not a curve.			
	133. Mondli: No, it's like this.			
	134. Thandeka: It doesn't slow down... yes it does... It doesn't just stop.			
	135. Kevin: But... wait, wait. Did you see when I done it. I never go fast then slow down. I went fast... and then I stopped.			
136. Craig: (Unclear sentence here.) ... completely accurate.				
137. Kevin: Let's go do it again.				
138. Craig: Do it again? I'm not gonna go up there again now.				
139. Kevin: No... I'm doing the graph... Come on Craig.				
140. Craig: Okay, I'll push the enter button.				
	141. Mondli: It's like this. This is the graph. It's not like a slope. It's not like a landscape. (pointing to Craig's graph.)			
142. Thandeka: While the boys go argue this out... (she carries on sketching)				
143. Craig: See. I was right, I was right... don't argue with me.				
	144. Thandeka: Velocity time graph don't have curves.			
145. Craig: Yeah, let's just work with what we know...				
146. Kevin: Look at that curve... look at that curve.				
		147. Thandeka: Are we having curves, Craig?		
				148. Craig: No... I'm having no curves. I haven't put curves in the velocity-time graph...That wouldn't imply constant...um...constant acceleration.
149. Nelisiwe: Now the second one... The second one, guys. All right... exercise... Where are you guys? Still drawing the...				
150. Craig: The first graph.				
151. Nelisiwe: The one everyone's got a... a point about.				
	152. Craig: ... each one is the same.			
	153. Thandeka: And the height of the things is the same.			

Uncoded	PHC	AQ	CMR	EXP
154. Craig: Yah.				
	155. Kevin: Craig... But Craig, it doesn't slow down.	Doesn't it just... the second line there... a dotted line.... This one coming down...Shouldn't it be a dotted line?		
			156. Craig: No, because you don't just go...	
	157. Kevin: You do...			
	158. Thandeka: No...			
			159. Craig: (continuing) Look at the curve in here. They've all got a curve. You can see this has got a curve. So you have to assume that it slowed down.	
	160. Thandeka: You did slow down. Your hand ... jerked at the end.			

Appendix 13
Testing the significance of changes in understanding in relation to each hypothesis

Hypothesis A1

Student	Pre-Test			Post-Test			Shift in understanding
	Question 2 (A1.1)	Question 15(A1.2)	Classif.	Question 14(A1.1)	Question 5(A1.2)	Classif.	
1	✓×	✓✓	SO	✓×	✓✓	SO	SO-SO
2	✓✓	✓✓	SU	✓×	✓×	LU	SU-LU
3	××	✓✓	SO	✓×	✓×	LU	SO-LU
4	××	××	LU	✓✓	××	SO	LU-SO
5	×✓	✓✓	SO	×✓	✓✓	SO	SO-SO
6	✓×	×✓	LU	✓×	✓✓	SO	LU-SO
7	✓✓	××	SO	✓✓	✓✓	SU	SO-SU
8	✓×	✓✓	SO	✓✓	✓✓	SU	SO-SU
9	✓✓	✓✓	SU	✓✓	✓✓	SU	SU-SU
10	×✓	××	LU	✓✓	××	SO	LU-SO
11	✓×	××	LU	✓✓	××	SO	LU-SO
12	✓×	✓✓	SO	✓×	✓✓	SO	SO-SO
13	✓✓	✓×	SO	××	✓✓	SO	SO-SO
14	✓✓	××	SO	✓✓	××	SO	SO-SO
15	✓×	✓✓	SO	✓✓	✓✓	SU	SO-SU
16	✓×	××	LU	✓✓	××	SO	LU-SO
17	✓×	××	LU	×✓	×✓	LU	LU-LU
18	✓✓	××	SO	✓×	✓×	LU	SO-LU
19	××	×✓	LU	×✓	✓✓	SO	LU-SO
20	✓✓	✓✓	SU	✓✓	××	SO	SU-SO

Applying the Stuart-Maxwell Test for Matched Pairs with more than two outcomes to the results in relation to hypothesis A1.

H_0: The shifts in levels of understanding demonstrated by learners over the pre- and post-tests, in relation to Hypothesis A1, occurred purely by chance, i.e. the scores calculated for different levels of understanding in relation to each hypothesis in the post-test and the scores calculated for different levels of understanding in relation to each hypothesis in the pre-test, come from identical population of learners.

INPUT TABLE	PRE-TEST			
POST-TEST	SU	SO	LU	TOTAL
SU	1	3	0	4
SO	1	5	6	12
LU	1	2	1	4
TOTAL	3	10	7	20

Chi-square 1.0909
Degrees of freedom 2
p-value 0.67958

Conclusion:

Since the p-value is greater than 0.05, the null hypothesis cannot be rejected at the 5% level of significance. Changes in understanding in relation to this hypothesis **are thus not statistically significant** at this level.

Hypothesis A2

Student	Pre-Test			Post-Test			Shift in understanding
	Question 12 (A2.1)	Question 1(A2.2)	Classif.	Question 4(A2.1)	Question 3(A2.2)	Classif.	
1	✓✓	xx	SO	✓x	✓✓	SO	SO-SO
2	xx	xx	LU	✓✓	x✓	SO	LU-SO
3	xx	xx	LU	✓✓	x✓	SO	LU-SO
4	xx	xx	LU	xx	xx	LU	LU-LU
5	✓x	xx	LU	xx	xx	LU	LU-LU
6	xx	xx	LU	xx	x✓	LU	LU-LU
7	xx	xx	LU	xx	xx	LU	LU-LU
8	xx	xx	LU	xx	x✓	LU	LU-LU
9	xx	xx	LU	xx	✓✓	SO	LU-SO
10	x✓	xx	LU	✓✓	x✓	SO	LU-SO
11	xx	x✓	LU	xx	xx	LU	LU-LU
12	xx	✓x	LU	xx	xx	LU	LU-LU
13	xx	xx	LU	✓✓	✓✓	SU	LU-SU
14	✓✓	xx	SO	✓✓	x✓	SO	SO-SO
15	✓✓	x✓	SO	✓✓	✓✓	SU	SO-SU
16	✓✓	xx	SO	✓✓	✓✓	SU	SO-SU
17	xx	xx	LU	xx	xx	LU	LU-LU
18	xx	xx	LU	✓✓	x✓	SO	LU-SO
19	xx	xx	LU	x✓	x✓	LU	LU-LU
20	xx	xx	LU	xx	✓x	LU	LU-LU

Applying the Stuart-Maxwell Test for Matched Pairs with more than two outcomes to the results in relation to hypothesis A2.

H_0: The shifts in levels of understanding demonstrated by learners over the pre- and post-tests, in relation to Hypothesis A2, occurred purely by chance, i.e. the scores calculated for different levels of understanding in relation to each hypothesis in the post-test and the scores calculated for different levels of understanding in relation to each hypothesis in the pre-test, come from identical population of learners.

INPUT TABLE	PRE-TEST			
POST-TEST	SU	SO	LU	TOTAL
SU	0	2	1	3
SO	0	2	5	7
LU	0	0	10	10
TOTAL	0	4	16	20

Chi-square 7.4118
Degrees of freedom 2
p-value 0.02458

Conclusion:

Since the p-value is less than 0.05, the null hypothesis can be rejected at the 5% level of significance. Changes in understanding in relation to this hypothesis **are thus statistically significant** at this level.

Applying McNemar's Test for matched pairs with two outcomes to the results in relation to hypothesis A2.

Question: What is the nature of the shift shown to be significant in the Stuart-Maxwell Test above?

Investigate significance of shift from LU/SO to SU

	Pre-Test		
Post-Test	SU	LU+SO	Total
SU	0	3	3
LU+SO	0	17	17
Total	0	20	20

% SU in pre-test	0.00%
% SU in post-test	15.00%
McNemar's Chi Square	1.333
p-value	0.248

Conclusion:
The p-value is greater than 0.05, thus, the shift from Little Understanding / Some Understanding to Substantial Understanding **is not statistically significant** at the 5% level of significance.

Investigate significance of shift from LU to SO/SU

	Pre-Test		
Post-Test	LU	SO+SU	Total
LU	10	0	10
SO + SU	6	4	10
Total	16	4	20

% LU in pre-test	80.00%
% LU in post-test	50.00%
McNemar's Chi Square	5.143
p-value	0.023

Conclusion:
The p-value is less than 0.05, thus the shift from Little Understanding to Some Understanding / Full Understanding **is statistically significant** at the 5% level of significance.

Hypothesis B1

Student	Pre-Test			Post-Test			Shifts in Understanding
	Question 6 (B1.1)	Question 10(B1.2)	Classif.	Question 12(B1.1)	Question 10(B1.2)	Classif.	
1	xx	xx	LU	xx	xx	LU	LU-LU
2	xx	x✓	LU	✓✓	✓✓	SU	LU-SU
3	x✓	✓✓	SO	xx	xx	LU	SO-LU
4	xx	xx	LU	x✓	✓✓	SO	LU-SO
5	xx	xx	LU	xx	x✓	LU	LU-LU
6	xx	x✓	LU	x✓	xx	LU	LU-LU
7	xx	x✓	LU	✓✓	✓✓	SU	LU-SU
8	xx	xx	LU	✓✓	✓✓	SU	LU-SU
9	xx	x✓	LU	✓✓	✓✓	SU	LU-SU
10	xx	x✓	LU	✓✓	x✓	SO	LU-SO
11	✓✓	xx	SO	✓x	xx	LU	SO-LU
12	xx	xx	LU	✓✓	✓✓	SU	LU-SU
13	xx	xx	LU	✓✓	✓✓	SU	LU-SU
14	xx	✓✓	SO	x✓	✓✓	SO	SO-SO
15	✓✓	✓✓	SU	✓✓	✓✓	SU	SU-SU
16	✓✓	x✓	SO	✓✓	✓x	SO	SO-SO
17	xx	xx	LU	x✓	✓x	LU	LU-LU
18	xx	✓✓	SO	✓✓	✓✓	SU	SO-SU
19	xx	✓✓	SO	✓✓	xx	SO	SO-SO
20	xx	xx	LU	✓✓	xx	SO	LU-SO

Applying the Stuart-Maxwell Test for Matched Pairs with more than two outcomes to the results in relation to hypothesis B1.

H_o: The shifts in levels of understanding demonstrated by learners over the pre- and post-tests, in relation to Hypothesis B1, occurred purely by chance, i.e. the scores calculated for different levels of understanding in relation to each hypothesis in the post-test and the scores calculated for different levels of understanding in relation to each hypothesis in the pre-test, come from identical population of learners.

INPUT TABLE	PRE-TEST			
POST-TEST	SU	SO	LU	TOTAL
SU	1	1	6	8
SO	0	3	3	6
LU	0	2	4	6
TOTAL	1	6	13	20

Chi-square	7.1707
Degrees of freedom	2
p-value	0.02773

Conclusion:

Since the p-value is less than 0.05, the null hypothesis can be rejected at the 5% level of significance. Changes in understanding in relation to this hypothesis **are thus statistically significant** at this level.

Applying McNemar's Test for matched pairs with two outcomes to the results in relation to hypothesis B1.

Question: What is the nature of the shift shown to be significant in the Stuart-Maxwell Test above?

Investigate significance of shift from LU/SO to SU

	Pre-Test		
Post-Test	SU	LU+SO	Total
SU	1	7	8
LU+SO	0	12	12
Total	1	19	20

% SU in pre-test	5.00%
% SU in post-test	40.00%
McNemar's Chi Square	5.143
p-value	0.023

Conclusion:
The p-value is less than 0.05, thus, the shift from Little Understanding / Some Understanding to Substantial Understanding **is statistically significant** at the 5% level of significance.

Investigate significance of shift from LU to SO/SU

	Pre-Test		
Post-Test	LU	SO+SU	Total
LU	4	2	6
SO + SU	9	5	14
Total	13	7	20

% LU in pre-test	65.00%
% LU in post-test	30.00%
McNemar's Chi Square	3.273
p-value	0.070

Conclusion:
The p-value is more than 0.05, thus the shift from Little Understanding to Some Understanding / Full Understanding is **not statistically significant** at the 5% level of significance.

Hypothesis B2

Student	Pre-Test			Post-Test			Shifts in Understanding
	Question 8 (B2.1)	Question 9(B2.2)	Classif.	Question 1(B2.1)	Question 2(B2.2)	Classif.	
1	xx	xx	LU	✓✓	xx	SO	LU-SO
2	x✓	xx	LU	x✓	xx	LU	LU-LU
3	✓✓	xx	SO	x✓	✓✓	SO	SO-SO
4	x✓	xx	LU	✓✓	✓✓	SU	LU-SU
5	x✓	xx	LU	xx	xx	LU	LU-LU
6	✓✓	xx	SO	✓✓	xx	SO	SO-SO
7	✓✓	xx	SO	✓✓	xx	SO	S0-SO
8	xx	x✓	LU	✓✓	xx	SO	LU-SO
9	✓✓	xx	SO	✓✓	✓✓	SU	SO-SU
10	✓✓	xx	SO	✓✓	✓✓	SU	SO-SU
11	✓✓	xx	SO	✓✓	✓✓	SU	SO-SU
12	✓✓	xx	SO	✓✓	xx	SO	SO-SO
13	✓✓	✓✓	SU	✓✓	✓✓	SU	SU-SU
14	x✓	xx	LU	✓✓	✓✓	SU	LU-SU
15	✓✓	✓x	SO	✓✓	✓✓	SU	SO-SU
16	✓✓	xx	SO	✓✓	✓✓	SU	SO-SU
17	x✓	✓✓	SO	✓✓	xx	SO	SO-SO
18	x✓	xx	LU	x✓	xx	LU	LU-LU
19	✓✓	✓✓	SU	✓✓	✓✓	SU	SU-SU
20	✓✓	xx	SO	✓✓	✓✓	SU	SO-SU

Applying the Stuart-Maxwell Test for Matched Pairs with more than two outcomes to the results in relation to hypothesis B2.

H$_o$: The shifts in levels of understanding demonstrated by learners over the pre- and post-tests, in relation to Hypothesis B2, occurred purely by chance, i.e. the scores calculated for different levels of understanding in relation to each hypothesis in the post-test and the scores calculated for different levels of understanding in relation to each hypothesis in the pre-test, come from identical population of learners.

INPUT TABLE	PRE-TEST			
POST-TEST	SU	SO	LU	TOTAL
SU	2	6	2	10
SO	0	5	2	7
LU	0	0	3	3
TOTAL	2	11	7	20

Chi-square 9.1429
Degrees of freedom 2
p-value 0.01034

Conclusion:

Since the p-value is less than 0.05, the null hypothesis can be rejected at the 5% level of significance. Changes in understanding in relation to this hypothesis **are thus statistically significant** at this level.

Applying McNemar's Test for matched pairs with two outcomes to the results in relation to hypothesis B2.

Question: What is the nature of the shift shown to be significant in the Stuart-Maxwell Test above?

Investigate significance of shift from LU/SO to SU

	Pre-Test		
Post-Test	SU	LU+SO	Total
SU	2	8	10
LU+SO	0	10	10
Total	2	18	20

% SU in pre-test	10.00%
% SU in post-test	50.00%
McNemar's Chi Square	6.125
p-value	0.013

Conclusion:
The p-value is less than 0.05, thus, the shift from Little Understanding / Some Understanding to Substantial Understanding **is statistically significant** at the 5% level of significance.

Investigate significance of shift from LU to SO/SU

	Pre-Test		
Post-Test	LU	SO+SU	Total
LU	3	0	3
SO + SU	4	13	17
Total	7	13	20

% LU in pre-test	35.00%
% LU in post-test	15.00%
McNemar's Chi Square	2.250
p-value	0.134

Conclusion:
The p-value is more than 0.05, thus the shift from Little Understanding to Some Understanding / Full Understanding **is not statistically significant** at the 5% level of significance.

Hypothesis C1

Student	Pre-Test			Post-Test			Shifts in Understanding
	Question 14 (C1.1)	Question 5(C1.2)	Classif.	Question 9(C1.1)	Question 13(C1.2)	Classif.	
1	✓✓	✓✓	SU	✓✓	✓✓	SU	SU-SU
2	xx	xx	LU	✓✓	✓✓	SU	LU-SU
3	✓✓	xx	SO	✓x	xx	LU	SO-LU
4	✓✓	✓✓	SU	✓✓	✓✓	SU	SU-SU
5	✓✓	xx	SO	✓✓	xx	SO	SO-SO
6	✓✓	x✓	SO	✓✓	✓✓	SU	SO-SU
7	✓✓	xx	SO	✓✓	✓x	SO	SO-SO
8	✓x	x✓	LU	✓✓	✓x	SO	LU-SO
9	✓✓	x✓	SO	✓✓	✓x	SO	SO-SO
10	✓x	x✓	LU	✓x	✓✓	SO	LU-SO
11	✓x	xx	LU	✓x	✓✓	SO	LU-SO
12	xx	✓✓	SO	✓✓	✓x	SO	SO-SO
13	✓✓	✓✓	SU	✓✓	✓✓	SU	SU-SU
14	✓✓	✓✓	SU	✓✓	✓✓	SU	SU-SU
15	✓✓	✓✓	SU	✓✓	✓✓	SU	SU-SU
16	✓✓	x✓	SO	✓✓	✓✓	SU	SO-SU
17	✓x	xx	LU	✓✓	xx	SO	LU-SO
18	✓✓	✓✓	SU	✓✓	✓✓	SU	SU-SU
19	x✓	xx	LU	✓✓	x✓	SO	LU-SO
20	✓✓	x✓	SO	✓✓	✓✓	SU	SO-SU

Applying the Stuart-Maxwell Test for Matched Pairs with more than two outcomes to the results in relation to hypothesis C1.

H_o: The shifts in levels of understanding demonstrated by learners over the pre- and post-tests, in relation to Hypothesis C1, occurred purely by chance, i.e. the scores calculated for different levels of understanding in relation to each hypothesis in the post-test and the scores calculated for different levels of understanding in relation to each hypothesis in the pre-test, come from identical population of learners.

INPUT TABLE	PRE-TEST			
POST-TEST	SU	SO	LU	TOTAL
SU	6	3	1	10
SO	0	4	5	9
LU	0	1	0	1
TOTAL	6	8	6	20

Chi-square	6.3704
Degrees of freedom	2
p-value	0.04137

Conclusion:

Since the p-value is less than 0.05, the null hypothesis can be rejected at the 5% level of significance. Changes in understanding in relation to this hypothesis **are thus statistically significant** at this level.

Applying McNemar's Test for matched pairs with two outcomes to the results in relation to hypothesis C1.

Question: What is the nature of the shift shown to be significant in the Stuart-Maxwell Test above?

Investigate significance of shift from LU/SO to SU

	Pre-Test		
Post-Test	SU	LU+SO	Total
SU	6	4	10
LU+SO	0	10	10
Total	6	14	20

% SU in pre-test	30.00%
% SU in post-test	50.00%
McNemar's Chi Square	2.250
p-value	0.134

Conclusion:
The p-value is greater than 0.05, thus, the shift from Little Understanding / Some Understanding to Substantial Understanding **is not statistically significant** at the 5% level of significance.

Investigate significance of shift from LU to SO/SU

	Pre-Test		
Post-Test	LU	SO+SU	Total
LU	0	1	1
SO + SU	6	13	19
Total	6	14	20

% LU in pre-test	30.00%
% LU in post-test	5.00%
McNemar's Chi Square	2.286
p-value	0.131

Conclusion:
The p-value is greater than 0.05, thus the shift from Little Understanding to Some Understanding / Full Understanding **is not statistically significant** at the 5% level of significance.

Hypothesis C2

Student	Pre-Test			Post-Test			Shifts in Understanding
	Question 11 (C2.1)	Question 4(C2.2)	Classif.	Question 7(C2.1)	Question 16(C2.2)	Classif.	
1	✓x	x✓	LU	✓✓	x✓	SO	LU-SO
2	✓x	✓x	LU	✓✓	✓✓	SU	LU-SU
3	xx	xx	LU	✓x	x✓	LU	LU-LU
4	xx	xx	LU	✓✓	✓✓	SU	LU-SU
5	xx	xx	LU	xx	✓✓	SO	LU-SO
6	xx	xx	LU	x✓	✓✓	SO	LU-SO
7	xx	xx	LU	✓x	✓✓	SO	LU-SO
8	✓x	✓✓	SO	✓x	✓✓	SO	SO-SO
9	✓✓	x✓	SO	✓✓	x✓	SO	SO-SO
10	x✓	xx	LU	✓✓	x✓	SO	LU-SO
11	✓x	✓x	LU	xx	xx	LU	LU-LU
12	✓x	✓✓	SO	✓✓	✓x	SO	SO-SO
13	✓✓	✓✓	SU	✓✓	✓✓	SU	SU-SU
14	✓✓	xx	SO	✓✓	✓✓	SU	SO-SU
15	✓✓	x✓	SO	✓✓	✓✓	SU	SO-SU
16	✓✓	x✓	SO	✓✓	✓✓	SU	SO-SU
17	x✓	✓✓	SO	✓✓	✓✓	SU	SO-SU
18	✓✓	✓✓	SU	✓✓	✓✓	SU	SU-SU
19	✓✓	✓x	SO	x✓	✓✓	SO	SO-SO
20	xx	xx	LU	✓✓	✓✓	SU	LU-SU

Applying the Stuart-Maxwell Test for Matched Pairs with more than two outcomes to the results in relation to hypothesis C2.

H_0: The shifts in levels of understanding demonstrated by learners over the pre- and post-tests, in relation to Hypothesis C2, occurred purely by chance, i.e. the scores calculated for different levels of understanding in relation to each hypothesis in the post-test and the scores calculated for different levels of understanding in relation to each hypothesis in the pre-test, come from identical population of learners.

INPUT TABLE	PRE-TEST			
POST-TEST	SU	SO	LU	TOTAL
SU	2	4	3	9
SO	0	4	5	9
LU	0	0	2	2
TOTAL	2	8	10	20

Chi-square 10.7234
Degrees of freedom 2
p-value 0.00469

Conclusion:

Since the p-value is less than 0.05, the null hypothesis can be rejected at the 5% level of significance. Changes in understanding in relation to this hypothesis **are thus statistically significant** at this level.

Applying McNemar's Test for matched pairs with two outcomes to the results in relation to hypothesis C2.

Question: What is the nature of the shift shown to be significant in the Stuart-Maxwell Test above?

Investigate significance of shift from LU/SO to SU

	Pre-Test		
Post-Test	SU	LU+SO	Total
SU	2	7	9
LU+SO	0	11	11
Total	2	18	20

% SU in pre-test	10.00%
% SU in post-test	45.00%
McNemar's Chi Square	5.143
p-value	0.023

Conclusion:
The p-value is less than 0.05, thus, the shift from Little Understanding / Some Understanding to Substantial Understanding **is statistically significant** at the 5% level of significance.

Investigate significance of shift from LU to SO/SU

	Pre-Test		
Post-Test	LU	SO+SU	Total
LU	2	0	2
SO + SU	8	10	18
Total	10	10	20

% LU in pre-test	50.00%
% LU in post-test	10.00%
McNemar's Chi Square	6.125
p-value	0.013

Conclusion:
The p-value is less than 0.05, thus the shift from Little Understanding to Some Understanding / Full Understanding **is statistically significant** at the 5% level of significance.

Hypothesis D1

Student	Pre-Test			Post-Test			Shifts in Understanding
	Question 3 (D1.1)	Question 16(D1.2)	Classif.	Question 8(D1.1)	Question 15(D1.2)	Classif.	
1	xx	xx	LU	xx	xx	LU	LU-LU
2	xx	✓✓	SO	✓✓	✓✓	SU	SO-SU
3	xx	xx	LU	xx	xx	LU	LU-LU
4	xx	xx	LU	xx	xx	LU	LU-LU
5	xx	xx	LU	xx	xx	LU	LU-LU
6	xx	✓x	LU	xx	xx	LU	LU-LU
7	xx	xx	LU	xx	✓x	LU	LU-LU
8	✓✓	✓x	SO	xx	xx	LU	SO-LU
9	xx	xx	LU	xx	xx	LU	LU-LU
10	xx	xx	LU	xx	xx	LU	LU-LU
11	x✓	xx	LU	xx	✓x	LU	LU-LU
12	xx	xx	LU	xx	xx	LU	LU-LU
13	xx	✓x	LU	xx	✓✓	SO	LU-SO
14	✓✓	✓✓	SU	✓✓	✓x	SO	SU-SO
15	xx	✓✓	SO	✓✓	✓✓	SU	SO-SU
16	✓✓	xx	SO	✓✓	✓✓	SU	SO-SU
17	xx	xx	LU	xx	✓x	LU	LU-LU
18	✓✓	xx	SO	✓✓	x✓	SO	SO-SO
19	xx	xx	LU	✓✓	xx	SO	LU-SO
20	✓✓	✓✓	SU	✓✓	xx	SO	SU-SO

Applying the Stuart-Maxwell Test for Matched Pairs with more than two outcomes to the results in relation to hypothesis D1.

H_o: The shifts in levels of understanding demonstrated by learners over the pre- and post-tests, in relation to Hypothesis D1, occurred purely by chance, i.e. the scores calculated for different levels of understanding in relation to each hypothesis in the post-test and the scores calculated for different levels of understanding in relation to each hypothesis in the pre-test, come from identical population of learners.

INPUT TABLE	PRE-TEST			
POST-TEST	SU	SO	LU	TOTAL
SU	0	3	0	3
SO	2	1	2	5
LU	0	1	11	12
TOTAL	2	5	13	20

Chi-square	0.5333
Degrees of freedom	2
p-value	0.76593

Conclusion:

Since the p-value is more than 0.05, the null hypothesis cannot be rejected at the 5% level of significance. Changes in understanding in relation to this hypothesis **are thus not statistically significant** at this level.

Hypothesis D2

Student	Pre-Test			Post-Test			Shifts in Understanding
	Question 7 (D2.1)	Question 13(D2.2)	Classif.	Question 6(D2.1)	Question 11(D2.2)	Classif.	
1	xx	xx	LU	✓x	xx	LU	LU-LU
2	xx	xx	LU	✓x	✓x	LU	LU-LU
3	xx	xx	LU	✓✓	xx	SO	LU-SO
4	xx	✓✓	SO	✓✓	xx	SO	SO-SO
5	✓✓	✓✓	SU	xx	xx	LU	SU-LU
6	xx	xx	LU	xx	xx	LU	LU-LU
7	x✓	xx	LU	xx	xx	LU	LU-LU
8	x✓	xx	LU	✓✓	xx	SO	LU-SO
9	xx	✓✓	SO	✓✓	✓✓	SU	SO-SU
10	xx	✓✓	SO	✓✓	✓✓	SU	SO-SU
11	xx	xx	LU	x✓	xx	LU	LU-LU
12	x✓	xx	LU	✓x	xx	LU	LU-LU
13	✓x	xx	LU	✓✓	x✓	SO	LU-SO
14	x✓	✓✓	SO	✓✓	xx	SO	SO-SO
15	✓✓	✓✓	SU	✓✓	✓✓	SU	SU-SU
16	x✓	✓x	LU	✓✓	✓✓	SU	LU-SU
17	xx	xx	LU	✓x	xx	LU	LU-LU
18	xx	xx	LU	✓✓	✓x	SO	LU-SO
19	✓✓	✓x	SO	✓x	xx	LU	SO-LU
20	✓✓	xx	SO	✓✓	✓✓	SU	SO-SU

Applying the Stuart-Maxwell Test for Matched Pairs with more than two outcomes to the results in relation to hypothesis D2.

H_0: The shifts in levels of understanding demonstrated by learners over the pre- and post-tests, in relation to Hypothesis D2, occurred purely by chance, i.e. the scores calculated for different levels of understanding in relation to each hypothesis in the post-test and the scores calculated for different levels of understanding in relation to each hypothesis in the pre-test, come from identical population of learners.

INPUT TABLE	PRE-TEST			
POST-TEST	SU	SO	LU	TOTAL
SU	1	3	1	5
SO	0	2	4	6
LU	1	1	7	9
TOTAL	2	6	12	20

Chi-square 2.3226
Degrees of freedom 2
p-value 0.31308

Conclusion:

Since the p-value is more than 0.05, the null hypothesis cannot be rejected at the 5% level of significance. Changes in understanding in relation to this hypothesis are **thus not statistically significant** at this level.