Examining the use of Multiple Representations to teach vectors in Grade 10 Physical Sciences

by

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Declaration

I, Maxhoba Ngwane, declare that this thesis **Examining the use of multiple representations to teach vectors in Grade 10 Physical Sciences** is my own original work and has not been submitted to any other university for a degree. All sources have been fully acknowledged in the text and a list of references have been provided. Furthermore, it represents my own opinions and not necessarily those of the University of Western Cape.

Maxhoba Ngwane **Date**

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DEDICATION

This academic study is dedicated to:

My parents Mr and Mrs Ngwane for always believing in me and providing me with opportunities to achieve my goals.

My children Palesa Hlalumi and Kgalefa Smanye. May this inspire you to achieve what you desire and always aim to do your best.

ABSTRACT

The purpose of this paper was to examine the use of the multiple representation approach as a teaching strategy to improve learners understanding of vectors in Grade 10 Physical Sciences. The study also wanted to consider the MR approach through the lens of the learners. A sample consisting of 45 Grade 10 learners from a total of 160 Grade 10 Physical Sciences learners participated in the study. Both quantitative and qualitative data were collected and analysed. Learners were first given a pre-test to establish their initial understanding of vectors. This pre-test was followed by an intervention in the form of a lesson. The lesson was conducted in order to expose learners to learning through Multiple Representations. A post-test was then administered to determine the impact of the intervention. To gather and quantify the learners' perceptions on the use of Multiple Representations in teaching and learning of vectors in Grade 10 Physical Sciences learners were given questionnaires to complete. The last step was interviewing of learners to triangulate the results from the three instruments. The study found that learners were struggling with understanding of vectors in their traditional chalk-and-talk lessons and their perceptions towards vectors were negative. The study also found that Multiple Representations can improve understanding and develop positive perception of learners towards the teaching and learning of vectors. This improvement occurs only if Multiple Representations is used correctly. The study further found out that when Multiple Representations is used improperly it limits deeper understanding by learners. A number of recommendations were made out of the findings of the study. Some of them were that multiple representations should be used when teaching vectors and that subject advisers and teachers should be developed on the proper use of multiple representations. The Physical Sciences textbooks must be designed to accommodate Multiple Representations.

Key words: Physics education, multiple representations, constructivism, vectors, and learner perceptions.

ABBREVIATIONS AND ACRONYMS

2D —	2 dimensions
3D	3 dimensions
ACE	Advanced Certificate in Education Advancement
CAPS	Curriculum and Assessment Policy Statement
DBE	Department of Basic Education
DoE	Department of Education
FET	Further Education and Training
ICT	Information and Communication Technology
LAIS	Learner Attainment Improvement Strategy
NCS	National Curriculum Statement
NMMU	Nelson Mandela Metropolitan University
NSC	National Senior Certificate
PCK	Pedagogical Content Knowledge
PhET	Physics education technology
RNCS	Revised National Curriculum Statement
SAASTA	South African Agency for Science and Technology
SMK	Subject matter knowledge
SMV-CHEM	Synchronised Multiple Visualisation of Chemistry
UWC	University of the Western Cape
VEs	virtual environments
VMW	Virtual Manipulatives and a Multimedia Whiteboard

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1.1 Introduction

This chapter presents the rationale of the study. It provides the background and context to the study illuminating the research problem. The research question to investigate the research problem is presented as well as the significance and limitations of the study.

1.2 Background

The researcher has taught Physical Sciences in the Libode Education District of the Eastern Cape for 12 years. He has been teaching in the Further Education and Training (FET) band grades 10 to 12. The school where the research was conducted is situated at Libode, one of the rural districts in the Eastern Cape. The district has a total of 211 schools with 21 of those being high schools. The area is a deep rural one with high illiteracy and high unemployment rates. The school is well fenced with a computer lab, a science lab and a library all in poor working condition. The school has an acceptable rate of learner absenteeism. The school runs from Grade 10 to Grade 12 [Further Education and Training (FET) Phase] and it has 1050 learners and its tuition time is from 8:00 to 15:00. There are 480 learners who are doing Physical Sciences and 190 of those learners are in Grade 10. The school has a principal, two deputy principals, three heads of departments and 20 post level 1 teachers. The total teacher population for the school is 26 and four of the teachers are teaching Physical Sciences. The school is in quintile 1 which is the lowest school in terms of poverty rating as given by national treasury. This means learners are not paying school fees. Learners in the school benefit from the school nutrition programme and scholar transport. Considering Physical Sciences, the Eastern Cape Province is the worst performing provinces in South Africa. This performance is based on the Grade 12 results. Libode district is one of the poorest performing districts in the province generally and in particular in Physical Sciences.

The graph below (Figure 1) shows the question by question analysis of the Physical Sciences Paper 1 provincial results that were published on page 368 of the National Senior Certificate (NSC) chief marker's report of 2014. As depicted by the graph, the questions that were poorly answered are those that require problem solving skills, scientific inquiry and application. The learners struggled to provide appropriate answers on higher order questions which reduced the provincial pass rate percentage.

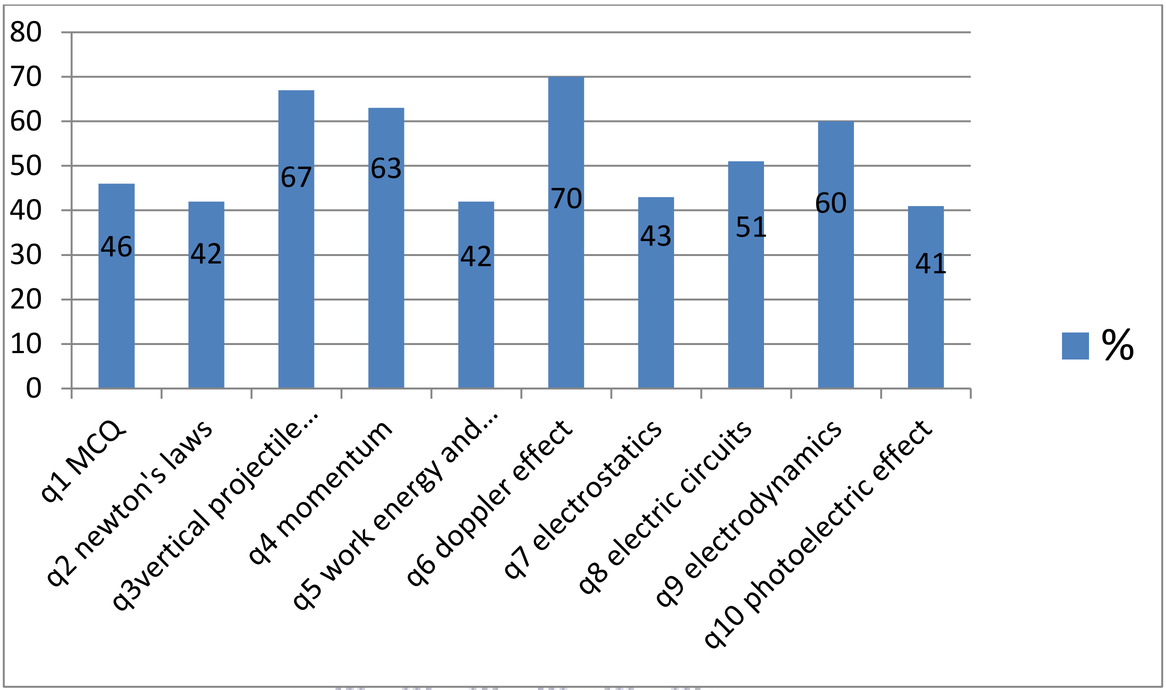

Figure 1: Question by question analysis for 2014 Physical Sciences paper 1

Table 1 below shows that the results of Physical Sciences are generally improving year after year. The national results for each year are higher than those of the province. The district performs below the province. The provincial average and the district average for the four years are all below 60%. This study is conducted as an attempt to remedy the above situation by an approach that can be used in one of the problem areas in Physical Sciences, namely vectors in mechanics. The approach can be used in other topics as well.

Table 1: The analysis of NSC results from 2011 to 2014

Year	National	Eastern Cape	Libode
2011	53.4%	46%	49.1%
2012	61.3%	50.4%	48.7%
2013	67.4%	64.9%	54.6%
2014	65.4%	51.5%	50.3%

1.3 State of science education in the Eastern Cape

The Eastern Cape Province is predominantly a rural province. The province has the poorest Physical Sciences results as depicted in Table 1 above. There are various reasons for the underperformance shown in Table 1. According to Duit (2007) research in science education plays an essential role in analysing the actual state of scientific literacy and the practice in schools, in addition to the improvement of instructional practice and teacher education. In line with Duit (2007) Hobden (2005) and Mugler (2010) argue that learners who are unable to understand physics concepts often label the subject as difficult and that may not only adversely affect their progress in Physical Sciences, but also discourage them from choosing Physical Sciences as a subject and consequently limit their future possibilities in careers in sciences. For so many years the province has had a high shortage of Physical Sciences teachers, more especially in the rural schools. Magadla (2014) cited that South Africa has used teachers from outside South Africa to minimise the shortage of teachers. Temporary educators were introduced where most of them were foreign nationals. Most of these temporary teachers were under qualified or even unqualified for teaching. Some of them did Physics and/or Chemistry but they were not qualified as teachers. Students taught by such unqualified teachers perform poorly in the Grade 12 examinations. Makgato & Mji (2006) as cited in the TIMSS 2011 report and Howie (2003) concluded that the qualifications of teachers teaching learners and the performance of learners could be one of the reasons why South African learners were placed last against 38 and 58 countries which participated in 2001 and 2003 respectively. Kriek & Grayson (2009) further argued that the learners' underperformance has led to a decrease in the number of learners who entered into science-based programmes at universities due to the decrease in the number of learners who passed Science on higher grade between the years 2005 and 2007. Statistically most of the well qualified Physical Sciences teachers are concentrated in towns. Most of the rural schools are under resourced. There are no science laboratories, no libraries or ICT laboratories. Some have old non-functional laboratories.

1.4 Interventions in the Eastern Cape to address the challenge

Due to the major challenge faced by the South African schools due to their Grade 12s not producing good results, the National Department of Education introduced intervention programmes with the aim of giving support to teachers to contribute effectively in teaching and learning. Though the programmes demonstrated some improvement in the results, the intervention programmes did not have much impact because of limitations due to funding, lack of proper planning and difficulty to provide for Eastern Cape as it is having the largest number of schools. Table 2 shows intervention programmes with their limitations.

Part of the interventions introduced by the National Department of Education is the Fundza Lushaka bursary scheme to encourage and fund learners who are interested in doing education for teaching Physical Sciences and Mathematics. There was also a programme of Dinaledi that aimed at improving the quantity and the quality in the performance of Physical Sciences in South Africa. The programme had a specific focus on the rural schools though the town schools were also part of it. Scientific calculators, programmed laptops with digital projectors and mobile science laboratories were supplied to schools through the programme. There was also the introduction of a learner attainment improvement strategy (LAIS). This strategy is derived from the National Department of Basic Education's National Strategy for learner attainment meant to assist provinces to implement changes which will lead to improved learner outcomes throughout the basic education system. It focuses on the underperforming schools, more especially Grade 12. This programme involves all the stakeholders in the school. These stakeholders are referred to as the Quality Learning and Teaching Campaign. This is composed of teachers, school management teams, counsellors, religious leaders and chiefs. It consists of a plan where learners will be taught or study beyond the normal teaching periods like Saturdays and Sundays, afternoons and in the evenings. It also includes holiday schools like autumn, winter and spring schools. The programmes are summarised in Table 2 below.

Table 2: Intervention programmes to improve poor performance

Intervention programme	Limitation
1. Dinaledi Project	To be part of the project, schools must have registered a minimum of 50 learners in Mathematics and Physical Sciences or the school must have obtained a minimum of 50% in both Mathematics and Physical Sciences. The project also caters for 60 schools per. These requirements forbid other schools from getting this opportunity of being part of this project.

2. Incubation classes	These classes were accommodating a maximum of ten learners per school and learners were selected according to their performance. It was only for learners who are performing well in both Mathematics and Physical Sciences.
3. Winter and spring schools	Highly dominated by overcrowded classes with little or no individual attention. Educators are rushing to cover all the challenging topics over a short period leaving behind most learners.
4. Science festivals usually attended in Grahamstown	Not all learners are able to attend those science festivals. Parents have to arrange payments for their children to attend festivals. Eastern Cape as one of the provinces with a high rate of poverty, it is difficult for some parents to cater for their children to attend these festivals.
5. Mini quiz and Astro quiz competitions	Most schools do not show any interest in motivating learners to attend these competitions. Schools can register a maximum of three learners.
6. Science Olympiads, SAASTA science debate, Eskom Expo, science weeks	Most educators do not show interest in motivating their learners to attend these programmes. In most cases, it is the schools that are already performing that are showing interest in such programmes.
7. NMMU Skills Development Programme for FET Mathematics and Physical Sciences educators	Catered for a limited number of educators. There are about 6500 in Eastern Cape Province mostly in rural areas and this makes it difficult for the Department to reach out to every educator.
8. Short course for Grade 9 Natural Science educators offered by UWC	Only a limited number of educators were accommodated in the programme due to funding. Not all learning areas were covered because of short period and lack of funds.
9. UWC programme for Physical Sciences educators	A maximum of 50 educators were taken in the programme from ACE now are currently doing Masters in Science Education. It is not easy for these educators to conduct workshops for other educators in their districts because there is no money in the Eastern Cape Department of Education to support these educators to facilitate workshops in their respective districts.

1.5 Rationale

The study investigates the effectiveness of multiple representations in the teaching of vectors. The study was conducted in the Libode Mega district where the researcher works. It is motivated by continued underperformance of learners in the National Senior Certificate Examination. The National Diagnostic Report (2014) highlighted that learners' achievement in Physical Sciences has been poor, especially in the Eastern Cape Province. It is further indicated in the report that one of the topics contributing to the poor performance is work energy and power which is based on vectors (question 4 and question 5). In addition, the examiner's report indicated that Physical Sciences is composed of Paper 1 and Paper 2. Paper 1 is mostly composed of mechanics and from the examiners' reports it is where learners perform the worst. Most part of mechanics is based on vectors. The reason learners have done particularly badly in physics during the era of NCS is that vectors were not part of the curriculum, among other things. This led to the inclusion of vectors in the CAPS curriculum. The structure of the curriculum is a problem but also other factors including the strategies that teachers use in teaching some topics. Representation of data is one important point that determines whether or not learners will understand the content and whether they will enjoy learning it.

1.6 Problem statement

The results of Physical Sciences is a big problem in South Africa as stated above and it becomes imperative that teaching approaches become more significant and successful. Vectors are a challenging topic in Physical Sciences as is evident in the performance of learners in Physical Sciences Paper 1. This paper is mostly mechanics which is based mainly on vectors. Because the learner performance was identified as a problem, the researcher saw it fit to look at ways that could help solve the problem. The study seeks to examine the perceptions of learners towards the use of multiple presentations in teaching vectors. This is based on the belief that if a concept is represented in a manner that is perceived positively by learners it will help improve the interest and understanding of the learners. Representations can be categorised into two classes, namely internal and external representations. Internal representations are individual cognitive configurations inferred from human behaviour describing some aspects for the process of physics and problem solving. This is from the head of the learner. External representations are situated in the students' environments (Meltzer, 2005). Examples of external representations in physics include words, diagrams, equations, graphs, electrical circuit diagrams, ray diagrams and sketches.

1.7 Research question

The study seeks to answer the following main research question:

How can a Multiple Representation approach be used to teach vectors in Grade 10 Physical Sciences?

In order to address the main research, question the following sub-questions were posed:

(i) What was learners' understanding of vectors prior to the Multiple Representation lessons?

(ii) How was the Multiple Representation lesson implemented?

(iii) What was learners' understanding of vectors after the Multiple Representation lessons?

(iv) What was the perception of learners on the use of Multiple Representations to learn vectors in Grade 10 Physical Sciences?

1.8 Significance

This study is worth undertaking as its results can be used to help teachers develop different ways of representing vectors in Physical Sciences. These ways of representing vectors will help improve the learners' level of knowledge and interest in the topic. The improvement in understanding, methodology and interest in turn will help develop their confidence in presenting the topic. All these improvements will benefit the learners by improving their interest and level of understanding. The end result will be the improvement in the general performance of Physical Sciences in the province and the country.

1.9 Limitations of the study

The case study sample was a school situated in a disadvantaged community on the periphery of Ngqeleni in the Eastern Cape. The study was consciously undertaken within difficult socio-economic conditions; therefore, its findings cannot be generalised to other socio-economic contexts. It is not the intention of the study to make generalisations from this sample to any context. The findings are specific to a disadvantaged community in the Eastern Cape. Research was conducted as a singular case study of a school in a disadvantaged community. The research concern could be investigated over a time period to measure change in the perception of learners; however, this is not a longitudinal study considering the time frame of the study.

1.10 Structure of the thesis

Chapter 1: Introduction to the study

Under the introduction, the researcher looked at the background of the study, the state of science education in the Eastern Cape, intervention strategies, rationale, problem statement, research questions, significance and the limitations of the study.

Chapter 2: Literature review

Chapter two focuses on the theoretical framework and the literature on the research that has been done already on the study.

Chapter 3: Research methodology.

Methodology deals with the procedure to be followed in conducting the study. This includes pilot, case study, research approach, sample, data collection plan, data collection instruments, data analysis, validity and reliability, and ethics.

Chapter 4: Research findings and discussion

Chapter four deals with the findings of the study. The findings are analysed and discussed.

Chapter 5: Conclusion

Chapter five contains the conclusion and recommendations of the study.

1.11 Conclusion

This chapter presented the background and rationale to the study and identified the research problem and research question. It painted a picture of the background and the rationale of the study. The next chapter is the literature review which focuses on the theories that underpin the study.

CHAPTER 2

Literature review

2.1 Introduction

The previous chapter focused on the introduction to the study. This chapter outlines the theoretical framework that underpins this study and the relevant literature that supports and elucidates it.

Key words: Physics education, multiple representations, constructivism, pedagogical content knowledge, vectors, and learner perceptions.

2.2 Literature review

According to Geertz (1980) a literature review refers to the selection of the available documents (both published and unpublished) on the topic which contains information, ideas, data and evidence written from a particular standpoint to fulfil certain aims or express certain views on the nature of the topic and how it is to be investigated and the effectiveness of the evaluation of these documents in relation to the research being researched. This literature review starts by looking at the theoretical framework that underpins the study.

2.3 Theoretical framework

This study is underpinned by the theory of constructivism and pedagogical content knowledge (PCK).

2.3.1 Constructivism

2.3.1.1 The constructivist view of human learning

Constructivism is an epistemological view of knowledge acquisition emphasising knowledge construction rather than knowledge transmission and the recording of information conveyed by others. The role of the learner is conceived as one of building and transforming knowledge. According to Robottom (2004) knowledge consists of concepts that are constructed in the mind of the learner. Ausubel (1968) suggested that according to the constructivist learning theory the learner constructs his/her own knowledge in such a way that new knowledge is connected with existing knowledge. For this reason, prior knowledge is of importance in the learning and teaching of

Physics. Unfortunately, learners' prior knowledge is not always acceptable from a scientific point of view. According to Van de Walle & Lovin (2006) learners do not absorb thoughts as teachers present them; instead they create their own knowledge. Mc Dermott & Rakgokong (1996) further argued that the learner learns by constructing what has been learnt into a mental network using a unique and personal technique. Le Grange (2014) cited that as early as in the first year of Grade R learners come to school with prior knowledge from their own social environment. This differs from learner to learner because of the wide range of social environments in South Africa, especially between the rural areas and the urban areas.

According to Piaget, (1977) learners acquire knowledge by constructing it through their interactions with the environment. Learners do not wait to be instructed to do this; they continually try to make sense out of everything they encounter. Piaget divides knowledge into three areas. The first knowledge according to Charlesworth & Lind (2007) is a physical knowledge. They explained this knowledge as the type of knowledge that includes learning about objects in the environment and their characteristics: colour, weight, size, texture, and other features that can be determined through observation and are physically within the object. In this study, Grade 11 learners use exploration to discover new knowledge in learning Ohm's law especially using computer simulations.

The second knowledge is known as logico-scientific knowledge. This knowledge is the type that includes relations each individual constructs: such as same and different, more and less, number, classification, and so on, to make sense of the world and organise information (Charlesworth & Lind, 2007). In this study, these concepts are integrated within the Grade 11 daily programme and formal teaching takes place to initiate learning these concepts. Social or conventional knowledge is the type that is created by people: such as rules for behaviour in various social situations. Logico-scientific categories are constructed to organise information. For example, in this study the three physical quantities (electric current, potential difference/voltage and resistance) has varying sizes (same and different, more and less, number (quantity/size) and classification).

The third type per Charlesworth & Lind (2007) is an intellectual autonomy. This is an atmosphere where learners feel safe in their relationships with grown-ups, where they have the chance to share their thoughts with other learners, and where they are stimulated to be vigilant and inquisitive, come up with interesting thoughts, problems and questions, use creativity in solving problems, have self-confidence in their aptitudes to figure out things for themselves, and speak their minds with confidence. Learners need to be presented with problems to be solved through games and other activities like Multiple Representations (MR) that challenge their minds. They must work with tangible materials and real problems. In this study the researcher provided learners with concrete objects and used classroom situations to solve problems to ensure that what they learn is sustainable and that it is not learned by rote. Most of the scientific concepts for Grade 10 Physics can be established through this active participation and this is rational and effective for scientific learning of all learners.

Smith (2001) cited that the general conception of learning by Piaget is still appropriate for today's classroom. The strength of his approach is centred on the child's thinking, or the progression (not just the answer) self-initiated, active involvement in a rich environment, and viewing the role of the teacher as a guide or resource person.

Learners come to class with their own personal ideas about physical phenomena and attach their own meanings to concepts. Driver (1989) pointed out that the intuitive (or alternative) conceptions of learners have been identified as an important source of their difficulties in understanding Physics. The construction of knowledge by a learner depends on mostly the methods that a teacher uses. Learners construct knowledge in different ways.

Within constructivism there are different notions of the nature of knowledge and the knowledge construction process. Moshman (1982) has identified three types of constructivism: exogenous constructivism, endogenous constructivism and dialectical constructivism. According to Cobb (1994) and Moshman (1982) endogenous constructivism or cognitive constructivism focuses on internal, individual constructions of knowledge. This perspective, which is derived from Piagetian theory (Piaget 1977, 1970), emphasised individual knowledge construction stimulated by internal cognitive conflict as learners strive to resolve mental disequilibrium. Students may be said to author their own knowledge, advancing their cognitive structures by revising and creating new understandings out of existing ones. This is accomplished through individual or socially mediated discovery-oriented learning activities.

Brown, Collins, & Duguid (1989) and Rogoff (1990) pointed out that dialectical constructivism or social constructivism views the origin of knowledge construction as being the social intersection of people, interactions that involve sharing, comparing and debating among learners and mentors. Through a highly interactive process, the social milieu of learning is accorded centre stage and learners both refine their own meanings and help others find meaning. In this way knowledge is mutually built. This view is a direct reflection of Vygotsky's (1978) sociocultural theory of learning, which accentuates the supportive guidance of mentors as they enable the apprentice learner to achieve successively more complex skills, understanding, and ultimately independent competence.

The fundamental nature of social constructivism is collaborative social interaction in contrast to the individual investigation of cognitive constructivism. Through the cognitive give and take of social interactions one constructs personal knowledge. In addition, the context in which learning occurs is inseparable from emergent thought. This latter view known as 'contextualism' in psychology becomes a central tenet of constructivism when expressed as situated cognition.

Constructivism is one of the major influences in present-day science and mathematics. Constructivism inspires science education reform programmes, is the subject in major international conferences, and is the foundation of many science-teacher training programmes where constructivist teaching methods are widely advocated. Driver and Oldham (1986) proposed that many have recommended the creation of science curricula on constructivist lines. In New Zealand, for instance, one such curriculum has been developed (Bell, 1991).

Matthews (2003), O'Loughlin (1992), Osborne (1996) and Kanuka and Anderson (1998) suggested that the history of constructivism can be traced back to Socrates. Socrates described teaching practice as revolving around the idea of reducing knowledge to order, using questioning (Fenshaw et al., 1994). The reduction involves students creating their own meaning from the information supplied to them (ibid). This is termed a reductionist approach. Von Glaserveld (1984) associates himself with the reductionist approach, claiming that humans only believe knowledge that is made true. Osborne (1996), Piaget (1951), Staver (1997) and Vygotsky (1978) cited that the modern interpretations of constructivism pedagogy have been developed through two interpretations of constructivism developed by Piaget and Vygotsky. Those interpretations are radical and social constructivism. Matthews (2003), Osborne (1996), Piaget (1952) and Staver 1997) pointed out that Piaget developed the reductionist approach into the constructivist approach, that learning is a dynamic process within the construction of knowledge. Radical constructivism then concludes that knowledge can only be developed if the knowledge about world is true, the person believes the knowledge and there is a reasonable belief that the knowledge is true (ibid).

There is much that is laudable, insightful, and progressive about constructivist theory and practice. It is far superior to the behaviourist theory of mind and learning against which Piaget and early cognitive psychologists, such as Bruner, struggled. Constructivism's stress on the pupil's engagement in learning, and the importance of understanding the student's current conceptual schemes in order to teach fruitfully, are progressive, as is its stress on dialogue, conversation, argument, and the justification of student and teacher opinion in social settings. Piaget identifies three stages that are important in the construction of knowledge. Those stages include: pre-operational stage, concrete operational stage and formal operational stage. For my context, the learners I will be working with are in the concrete and formal operational stages. Many science classrooms are characterised by rote learning and mantra-like repetition of formulae. Richard Feynman said, "The students had memorised everything but they did not know what anything meant" (Feynman, 1985:212). Constructivism stresses understanding as the goal of science instruction.

This clearly shows the importance of how the information should be presented to the learners. Learners can understand a phenomenon differently based on how it was presented. Methods and representations that will allow different learners a chance to interpret information in ways that make meaning to them are important. Either learners construct knowledge from within the learner her/himself or through the interaction with other learners, hence the concepts of radical constructivism and social constructivism.

2.3.1.2 Radical constructivism

The epistemology of radical constructivism finds its fundamental assumptions in a specific epistemology and philosophy of science. According to this epistemology, all human knowledge - from everyday observations to scientific knowledge-formation - as apprehension and representation of some kind of reality that lies outside of the knowing subject and existing as such by itself, is in principle impossible. Everything that can be known of this external reality is a creation of the observer. Everything that human beings can know of this external reality is a construction. We can understand our reality only in the form in which it has been constructed by ourselves. Constructions also take place as co-constructions in social contexts and, thus, must be tested there. According to von Glasersfeld (1996) the formation of scientific knowledge is not in principle, but only in graduated steps, different from everyday knowledge. In its ultimate metaphysical implication, this in principle always-constructed and always-provisional status of knowledge is considered to be a cogent call for tolerance between different systems of knowledge and convictions and their followers.

2.3.1.3 Social constructivism

Kanuka and Anderson (1998), Kroll and LaBoskey (1996), Matthews (2003), O'Loughlin (1992), Osborne (1996), Rodriguez (1998) and Staver (1997) proposed that, in a sense, as in 2.3.1.2., Piaget neglected to include a social aspect to his constructivist theory. Vygotsky emphasised how the culture and social contexts in which we develop influence our learning. He argued that intellectual growth happens twice for a child, at a social level and at a personal level, but emphasises the social aspect more (Matthew, 2003; Vygotsky, 1978). According to Driver et al. (1994) and Osborne (1996) social constructivism means that learners develop knowledge through social interactions and discourse. This social interaction means learners learn from their tutors and their peers. Social constructivism pedagogy has been linked to science education as it can be used for epistemology of science as well as the science content (ibid). This means learners should be much involved in their learning. Bruner (1961) expanded constructivism to include the role of the teacher as it is neglected in social constructivism. Raccord et al. (1997) pointed out that learning should be directed through some teaching methods like discussions, questioning, and investigations. These methods enable teachers to play a very active role in social constructivism. Teachers need to be confident and competent to implement the social constructivist approach and they must understand the epistemology of science. Teacher education needs to include the social constructivist approach. In my case of Multiple Representations social constructivism is key. This is so because some representations need social interpretations from peers to make them more effective whilst the individual also needs to give his/her own interpretation of the representation. The learners in the process need to be scaffolded by the teacher to achieve the desired outcomes.

The fundamental nature of social constructivism is collaborative social interaction in contrast to individual investigation of cognitive constructivism. Through the cognitive give and take of social interactions, one constructs personal knowledge. In addition, the context in which learning occurs is inseparable from emergent thought. According to Mwamwenda (2004) the context in which learning occurs is called 'contextualism'. Mwamwenda (2004) further argued that this contextualism is a central principle of constructivism when expressed as situated cognition.

2.3.1.4 Social constructivism and curriculum reforms

The notion that a student can actively construct knowledge for conceptual understanding by drawing on their everyday experiences is supported by research (Duit et al., 2008). Both personal and social forms of constructivism (e.g. Confrey, 1990; Brooks and Brooks 1999) are supported, but most curriculum reforms, as in the case of South Africa, place emphasis on social constructivism. Through the dawn of democracy in South Africa a breakthrough towards non-racial and democratic society brought about some social changes. One of the changes was curriculum reforms that resulted in three curriculum changes namely Curriculum 2005 in 1998, (Department of Education (DoE), 1997), the Revised National Statement (RNCS) in 2002 (DOE, 2002), and the Curriculum and Assessment Policy Statement (CAPS) in 2012 (Department of Basic Education (DBE), 2011). In the natural sciences, the RNCS places a strong emphasis on social constructivist-based theories of learning in science classrooms (DoE, 2002).

2.3.1.5 Theoretical background of the constructivist argument in didactics

According to Ewald Terhart (2003) constructivist didactics constructs the foundation on which it bases itself by drawing on different kinds of levels and areas of theory. He asserts that starting from those different kinds of levels and areas of theory it arrives at a structure of core statements which include, in addition to strategic practical recommendations for classroom teaching, certain general normative assumptions regarding the goal of the enterprise of 'teaching and education'. Essentially, there are four very different theoretical contexts which represent the background for constructivist didactics, or which are being used by the protagonists of this movement: radical constructivism, the neurobiology of cognition, systems theories, and current conceptions of learning developed in the field of cognitive psychology. These very different background positions are being used and combined by the various representatives of constructivist didactic thought in different ways and in different intensities. Ewald Terhart (2003) proposed that, from a systematic point of view, these supporting theories are not all on the same level. Also, these very different background positions are being used and combined by the various representatives of constructivist didactic thought in different ways and in different intensities.

In the end, it not only becomes unclear what constructivism in its various variants really is; it also remains unclear what constructivist didactics that is to be constructed on this difficult-to-determine basis can be. The explanation above shows very clearly that constructivism is more than just the build up of knowledge by the learner from inside the learner or from the environment.

2.3.1.6 The systematic core of constructivist didactics

Ewald Terhart (2003) suggested that human knowledge must always be regarded as only a currently adequate, currently useful result of socially-shared construction processes. Hence, it is meaningless to try to structure the learning of others by teaching on the basis of a model of transmitting and receiving information. On the other hand, it is possible and responsible to understand teaching, and the practice of teaching, as something that makes stimulating environments available, which make things easier. Through these environments, independent learning can be facilitated, both in the form of acts of constructing and reconstructing knowledge and acts of gaining insight and understanding. Learning, in the real sense of the word, is never controlled in its course and result but always involves an individual - but in social contexts - constructing and reconstructing inner-worlds. This means the responsibility for learning lies with the learner. For this learning to be possible the teacher must teach in a relaxed environment. Teaching must not be a transmission of a prepared package of knowledge divorced from concrete situations. Von Glasersfeld (1996) suggested that the extent to which constructivist didactics limits itself to the claim that all learning starts from already existing knowledge, and the teacher, therefore, has to start always with students' pre-existing knowledge in order to facilitate construction processes in the direction of the acknowledged instructional goal of transmitting book and scientific knowledge, is dismissed by more radical exponents of constructivism with some justification as 'trivial constructivism'. Nevertheless, constructivist didactics is clearly dominated by moderate positions whose influence grows in proportion to the extent to which they pursue concrete research and practical projects, not just programmatic arguments.

Wolff (1994:418) suggested that learning environments (instructional materials, classrooms, media, and other aids, and, ultimately, the school itself as an organization) have to be structured in such a way that they "are authentic and complex in the sense of real-world experience", that by starting with different initial individual abilities they make construction processes possible, that contents of learning can be embedded in them, and that what has been learned can, in such a learning environment, be made useful in a concrete way.

2.3.2 Pedagogical content knowledge

2.3.2.1 What is pedagogical content knowledge?

Shulman (1987) first introduced the notion of pedagogical content knowledge (PCK) as a fundamental component of the knowledge base for teaching. PCK, according to Shulman (1987), is what makes possible the transformation of disciplinary content into forms that are accessible and attainable by students. This includes knowledge of how particular subject matter topics, problems, and issues can be organized, represented, and adapted to the diverse interests and abilities of learners and presented for instruction. It distinguishes the teacher from the content specialist.

Shulman's model has been elaborated upon and extended by other scholars (e.g., Grossman, 1990; Magnusson, Krajcik, & Borko, 1999). It was pointed out that while there is no universally accepted conceptualization of PCK, there is agreement with two key elements of Shulman's model - knowledge of representations of subject matter and understanding of specific learning difficulties and student conceptions. Firstly, PCK refers to particular topics and therefore it is distinct from general knowledge of pedagogy, educational purposes, or learner characteristics; second, it differs from subject matter knowledge (SMK); and, third, PCK is developed through an integrative process rooted in teachers' classroom practice, implying that beginning or novice teachers will have relatively undeveloped PCK.

2.3.2.2 Conceptions of PCK

Since the 1980s in the United States (US), politicians and policy makers have attacked teacher education. Their concern was the quality of teachers produced (Bullough 2001). For example, A Nation at Risk (National Commission on Excellence in Education, 1983) pointed out that teacher preparation programmes need substantial improvement. For example, according to A Nation at Risk (National Commission on Excellence in Education, 1983) the teacher preparation curriculum is weighted heavily with courses in 'educational methods' at the expense of courses in subjects to be taught. Scepticism about the value of teacher education has also resulted in efforts to create contravening arguments that describe teaching as a profession involving special forms of knowledge and skill (Bullough, 2001). It is this understanding that leads to Shulman (1986) describing the concept of pedagogical content knowledge (PCK) as a distinct body of knowledge that distinguishes teachers from content specialists. The emphasis was on combining the content knowledge and how the content knowledge is presented to learners.

Since Shulman (1986) proposed the notion of PCK, many scholars have worked on the concept (e.g., Park and Oliver, 2008a; Cochran et al., 1993; Grossman, 1990; Hashweh, 2005; Loughran et al., 2006; Magnusson et al., 1999). Some of these scholars have tried to refine the concept of PCK by modifying Shulman's definition, but at the centre of those various definitions is the idea that the transformation of subject matter knowledge for the purposes of teaching is at the heart of PCK. This combines what teachers know about subject matter and how they transform that knowledge into classroom curricular events. Cochran et al. (1993) defined PCK as "the manner in which teachers relate their pedagogical knowledge to their subject matter knowledge in the school context, for the teaching of specific students" (p. 1).

Marks (1990) broadened Shulman's (1987) concept by including knowledge of subject matter per se and as well as knowledge of media for instruction. Grossman (1990) also expanded the concept by defining four central components of PCK: (a) knowledge and beliefs about the purposes for teaching a subject, (b) knowledge of students' understanding, conceptions, and misconceptions of particular topics in a subject matter, (c) knowledge of curriculum and curriculum materials, and (d) knowledge of instructional strategies and representations for teaching particular topics. Park and Oliver (2008a, 2008b) identified five constituent components by including knowledge of assessment of student understanding. As different as ideas from the scholars are, the central themes of PCK are (a) knowledge of instructional strategies incorporating representations of subject matter and understanding of specific learning difficulties and (b) student conceptions with respect to that subject matter.

According to Clermont et al. (1993), Loughran et al. (2006) and Van Driel et al. (1998) there are other lines of research on teaching. These lines have emphasised the critical role of PCK in teachers' planning and actions when dealing with subject matter in classrooms as this shapes teachers' learning of new instructional approaches and strategies (Borko and Putnam, 1996), and influences student learning (Carpenter et al., 1988). This means PCK should be central to science education and science teachers should possess PCK to facilitate student learning.

2.3.2.3 Pedagogical content knowledge and effective science teaching

According to Geddis (1993) and Magnusson, Borko & Krajcik (1998), the first key component of PCK is the knowledge of students' understanding, conception and misconceptions of a specific topic. This component helps teachers to interpret students' actions and ideas as well as to plan effective instruction. Studies conducted by Hope and Townsend (1983) and Jong (1992) demonstrated that experienced teachers who were very knowledgeable in their subjects but failed to consider the pupils' way of thinking about the subject matter often faced difficulty in teaching content. This shows very clearly that good understanding of the subject alone is insufficient for effective teaching. In a study with 20 Canadian physics high school teachers, Berg and Brouwer (1991) found that the physics teachers were relatively unaware of their students' misconceptions prior to instruction. Teachers believe that the difficulty faced by the students is due to the students' lack of interest and their poor mathematical competency rather than difficulties due to conceptual understanding of the topics (Caillods, Gottelmann-Duret, & Lewin, 1997). Content knowledge of representation of specific topics is a product of previous planning, teaching and reflecting.

It appears from above that teachers with a mastery of the subject matter as well as those who are lacking the understanding may be oblivious to students' conceptions and misconceptions of the topics. Similarly, acquiring teaching experience does not ensure that teachers will develop both types of knowledge: knowledge of pupils' learning difficulties and knowledge of representations of specific topics for development of conceptual understanding. Arguably, both types of knowledge need to be explicitly dealt with by both novice and experienced teachers. Since the PCK touches on both components it is very effective for science teaching.

2.3.2.4 Developing teachers' PCK

A growing dissatisfaction with the results of process-product research has shifted attention in research on teaching from observable behaviours or teaching skills to teachers' knowledge and beliefs. Doyle (1990) argues that the focus in process-product research on indicators of effectiveness has led to a fragmented and mechanistic view of teaching in which the complexity of the teaching enterprise is not acknowledged. Teachers' craft knowledge is key in the teaching of sciences. According to Grimmett and MacKinnon (1992) the essence of craft knowledge pertains to a teaching sensibility rather than to a knowledge of propositions. Van Driel (1997) defines craft knowledge as integrated knowledge which represents teachers' accumulated wisdom with respect to their teaching practice.

Shulman introduced PCK as a specific category of knowledge "which goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge for teaching" (Shulman, 1986, p. 9). The key elements in Shulman's conception of PCK are knowledge of representations of subject matter on the one hand and understanding of specific learning difficulties and student conceptions on the other. These two elements are intertwined; therefore, the more representations teachers have at their disposal and the better they recognize learning difficulties, the more effectively they can deploy their PCK.

Later on Shulman included PCK in what he called the knowledge base for teaching (Shulman, 1986). This knowledge base consists of seven categories, three of which are content related (i.e. content knowledge, PCK, and curriculum knowledge). The other four categories refer to general pedagogy, learners and their characteristics, educational contexts, and educational purposes (Shulman, 1987). Whereas Shulman's knowledge base encompasses every category of knowledge which may be relevant for teaching, van Driel's (2007) definition of craft knowledge is restricted to types of knowledge which guide the teachers' behaviour during classroom practice. Within the definition of craft knowledge, he considers PCK to be a specific form of this craft knowledge. He asserts that PCK implies a transformation of subject matter knowledge, so that it can be used effectively and flexibly in the communication process between teachers and learners during classroom practice. Thus, teachers may derive PCK from their own teaching practice (e.g., analysing specific learning difficulties) as well as from schooling activities (e.g., an in-service course on student conceptions). More important, when dealing with subject matter, teachers' actions will be determined to a large extent by their PCK, making PCK an essential component of craft knowledge.

Marks (1990) also broadened Shulman's model by including in PCK knowledge of subject matter per se as well as knowledge of media for instruction. In a discussion of sources of PCK, however, Marks perceived the development of PCK as an integrative process revolving around the interpretation of subject-matter knowledge and the specification of general pedagogical knowledge, thereby focusing on Shulman's two key elements.

Teachers should promote conceptual change by discussing the anomalous results of certain phenomenon with students. They should challenge students' conceptions about a concept by urging students to explain a phenomenon and give reasons why a phenomenon does not behave as expected in (for example) an experiment. This helps teachers to understand conceptions and mis-conceptions that learners have about a concept.

Because pedagogical content knowledge (PCK) includes teachers' understanding of how students learn, or fail to learn, specific subject matter, the development of PCK is an important goal to focus on in professional development programmes. The research literature clearly indicates the complex nature of PCK as a form of teachers' professional knowledge that is highly topic, person, and situation specific. This implies that professional development programmes aimed at the development of teachers' PCK cannot be limited to supplying teachers with input, such as examples of expert teaching of subject matter. Instead, such programmes should be closely aligned to teachers' professional practice and, in addition to providing teachers with specific input, should include opportunities to enact certain instructional strategies and to reflect, individually and collectively, on their experiences.

2.3.2.5 Multiple Representations and pedagogical content knowledge

To learn science language, and thus to solve science problems successfully, students must become competent in Multiple Representations. This means that when solving a problem students must be able to interpret and construct different representations, identify their similarities and distinctions, and move between these representations. According to Shulman (1987) teaching science is a demanding task, requiring teachers to understand not only the science content but also how to translate the content and methods of science into analogous instructional practices. Such ability is what Shulman called pedagogical content knowledge or PCK. PCK is the knowledge of effective instructional practices pertinent to specific content areas. According to Lederman (1992) and Eick (2000), for science teaching this knowledge emphatically includes understanding of inquiry as an approach to the subject. Multiple Representation is also an approach that stops educators from treating learners as object banks to deposit knowledge into their brain, which strongly resembled what was termed the 'top-down' approach that was imposition by the apartheid curricula.

2.4 Research on Multiple Representation

From the constructivist viewpoint, using computer 3D virtual reality and its manipulation to support mathematical geometry learning activity is beneficial. According to Conceicao-Runlee and Daley (1998) constructivists claim that individuals learn through a direct experience of the world, through a process of knowledge construction that takes place when learners are intellectually engaged in personally meaningful tasks. Chittaro and Serra (2004) claimed that constructivism is the fundamental theory that motivates educational uses of virtual environments. The type of experience is a first person one, that is, a direct, non-reflective and, possibly, even unconscious type of experience. In several cases, interaction in virtual environments (VEs) can be a valuable substitute for a real experience. It provides a first-person experience and allows for a spontaneous knowledge acquisition that requires less cognitive effort than traditional educational practices. Winn (1993) cited that virtual environments can provide three kinds of knowledge-building experience that are not available in the real world; they are concepts of size, transduction and reification, which have invaluable potential for education.

Teachers use different approaches when teaching. They always think that those methods or approaches are best for learners but the reality is that learners are different and they perceive information differently. When teachers use Multiple Representations, they expose their learners to different representations. Some learners are more comfortable with visual representations than words and equations. 3D graphs, simulations, equations, words and pictures form part of Multiple Representations. This enables learners to associate well with Multiple Representations. From simple geometry and vector representations to deeper understanding Multiple Representations are able to cover all. This is because Multiple Representations cover different cognitive levels of learners.

There is a very clear connection between Multiple Representations and the theory of constructivism. This is so because, according to constructivist theorists, individuals learn through a direct experience of the world, through a process of knowledge construction that takes place when learners are intellectually engaged in personally meaningful tasks.

2.4.1 What is meant by Multiple Representations?

By ‘representations’, we refer to the many ways in which one can communicate physical concepts and situations. For instance, in kinematics one often uses the example of a car accelerating constantly from rest. One can express this motion with graphs of position, velocity, or acceleration versus time, with a written description of the motion, with equations appropriate to such motion, or with a series of snapshots depicting the motion. Socio-cultural views of learning consider that learning takes place in a cultural context via social processes wherein language plays a central role (Nieminen, 2013). In addition to talk and text, the language of physics includes a diverse set of other representations, such as graphs, vectors, and equations.

Representations can be categorised into two classes, namely internal and external representations. Internal representations are defined as individual cognitive configurations inferred from human behaviour describing some aspects for the process of physics and problem solving. On the other hand, external representations can be described as a structured physical situation that is embodying physical ideas (Van Heuvelen & Zou, 2000). According to a constructivist view, internal representations are inside the students’ heads, and external representations are situated in the students’ environments (Meltzer, 2005). Examples of external representations in physics include words, diagrams, equations, graphs, electrical circuit diagrams, ray diagrams and sketches. Hence, the positive role of Multiple Representations in student learning has been suggested by many educators.

2.4.2 Ways of learning scientific concepts with Multiple Representations

2.4.2.1. How to use Multiple Representations in learning

Multiple Representations of scientific concepts are provided for good educational reasons. The functions of Multiple Representations fall into three broad classes. Firstly, Multiple Representations can support learning by allowing for complementary information or complementary processes. The simplest illustration of complementary information in our force and motion example would be displaying values for mass, force, friction and velocity. Each representation, be it a graph, an equation, or a numerical display, is representing different aspects of a simulated body. The choice of which representations to use is therefore likely to depend on the properties of the represented information. For example, mass might be represented as a simple numerical display as it does not change as the simulation runs, whereas velocity might be represented in a dynamic graph or a table because these representations are time-persistent (Ainsworth & Van Labeke, 2004) and so show how velocity has changed over time. If all this information had to be included in a single representation, then this would either mean that it was represented in ways that were inappropriate to its form (e.g. mass on a time-series graph), at the wrong scale or in the simplest possible way (for example, numerical displays or tables of all the values). So, Multiple Representations in this case allow different information to be represented in ways that are most appropriate to the learners' needs.

Cognitive flexibility theory highlights the ability to construct and switch between multiple perspectives of a domain as fundamental to successful learning (Spiro & Jehng, 1990). Dienes (1973) argues that perceptual variability (the same concepts represented in varying ways) provides learners with the opportunity to build abstractions about mathematical concepts. It also can be the case that insight achieved in this way increases the likelihood that it will be transferred to new situations (Branford & Schwartz, 1998).

2.4.2.2. Learning complex scientific concepts

The learning of complex scientific topics is commonly, even invariably, supported by the use of Multiple Representations. It has been argued that there are many roles that different combinations of representations can play in supporting learning. However, it has been suggested that the benefits of Multiple Representations do not come for free – learners are faced with a number of complex tasks and as the number of representations increases so do these costs.

Mayer (2001) proposed that a number of possible frameworks exist and some researchers suggest design principles. However, for many of the complex representational systems to be used to support science learning we may not yet be at the point of producing definitive principles – instead there are a number of heuristics that could be used to guide a design. The first heuristic, according to Ainsworth and van Labeke (2004), is to use only the minimum number of representations that you can use. This minimises complexity in using the representations to learn scientific concepts. Secondly, carefully assess the skills and experience of the intended learners. For example, do they need support of constraining representations to stop misinterpretation of unfamiliar representations or would this extra representation not provide any new insight without a great deal of work by the learner.

Thirdly, consider how to sequence representations in such a way to maximise their benefits. Allow learners to gain knowledge and confidence with fewer representations before introducing more.

A fourth heuristics is to consider what extra support you need to help learners overcome all the cognitive tasks associated with learning with Multiple Representations. That is to identify if learners need additional help in relating the representation to the domain and whether the system has been designed to help learner see the relation between representations. For example, are consistent labels, colours and symbols used and representations that are related placed close to one another?

Finally, consider what pedagogical functions the multi-representational system is designed to support. If the primary goal is to support complementary functions, then it may be sufficient that learners understand each representation without understanding the relation between them.

The task for the teacher is to identify when to select particular representations for particular tasks. Learning may be hindered if learners spend considerable time and effort in relating representations unnecessarily and so designers may consider ways to discourage learners from doing this. If the goal is to constrain interpretation, it is imperative that the learner understands the constraining representation. Consequently, designers must find ways of signalling the mapping between representations without over-burdening learners by making this task too complex. If the goal is for learners to construct a deeper understanding of a domain, if they fail to relate representations, then processes like abstraction cannot occur (Ainsworth, 2006).

Moreover, although learners find it difficult to relate different forms of representations, if the representations are too similar, then abstraction is also unlikely to occur.

Consequently, it is difficult to recommend a solution to this dilemma. But if you need learners to abstract over Multiple Representations then you should provide considerable support for them to do so, by providing focussed help and support on how to relate representations and giving learners sufficient time to master this process.

Multiple Representations are powerful tools to help learners develop complex scientific knowledge. But, like all powerful tools, they require carefully handling and often considerable experience before people can use them to their maximum effectiveness. Beginners using powerful tools do not achieve the same results as experts and so we should consider how these tools can be designed to allow learners to develop their expertise. Moreover, beginners do not learn without support from others, either peers or teachers. Only a carefully planned, properly structured, research-based teaching intervention specifically designed to address these shortcomings and attitudes has proved capable of effecting significant change in such unpromising conditions.

Equipping students with multi-representational skills appears to allow them to step back from the required mathematics long enough to see the bigger picture', that is, the true nature of the problem, the underlying principles and concepts, and possible ways of solving it. As students gradually learn to use the new pre-mathematical strategies, they gain confidence in their ability to understand and solve physics problems. As they develop more conceptual insight through the use of alternative tools, such as physics diagrams, they learn to choose more appropriate mathematical representations and they make fewer mistakes in the numerical stages of problem solving.

2.4.2.3. Using Multiple Representations to support the construction of deeper understanding

Multiple Representations can support the construction of deeper understanding when learners relate those representations to identify the shared invariant features of a domain and the properties of individual representations. Kaput (1989) proposed that the cognitive linking of representations creates a whole that is more effective than the sum of its parts. Spiro and Jehng (1990) suggested that there are many different theoretical accounts of learning that emphasise the use of Multiple Representations. Cognitive flexibility theory highlights the ability to construct and switch between multiple perspectives of a domain as fundamental to successful learning. Dienes (1973) argued that perceptual variability (the same concepts represented in varying ways) provides learners with the opportunity to build abstractions about mathematical concepts. Branford and Schwartz (1999) further argued that insight achieved in this way increases the likelihood that it will be transferred to new situations.

To learn science language, and thus to solve science problems successfully, students must become competent in Multiple Representations. This means that when solving a problem students must be able to interpret and construct different representations, identify their similarities and distinctions, and move between these representations.

2.4.3. Types of representations

2.4.3.1. Computer 3D graphics and simulations as representations

Meyer and van Niekerk (2008) defined simulation as the fake of a real-life situation which is usually in simplified form. Learners are placed in a spot where they can understand aspects of real life by participating in activities that are closely related to it. While not substituting direct involvement with the situation, simulations organise learners for practice by providing them with the opportunities to develop while at the same time testing their cognitive and psychomotor skills in a reasonably risk-free setting, in which the consequences of any mistake are less costly than in the real setting. The simulation used in this study therefore provided an opportunity to learners to work in a reasonably risk-free setting as there could be no explosion of light bulbs. It is also less costly than the real setting as there are no costs of buying electric equipment for these practical tasks; instead, learners construct electric circuits using computer simulations. Vakalisa and Gawe (2011) argued that teachers and learners increasingly use information and communication technology (ICT) in teaching and learning. They further claim that ICT can supplement and simplify teaching and learning. It is for this reason that the researcher decided to use computer simulations as it really simplifies abstract knowledge about electricity and shows how electrons move through the conductor thereby faking abstract and invisible information into concrete and visible information to enrich learning.

Metiouii and Trudel (2012) indicated that simulations help students learn and understand circuit analysis concepts by using electronic workbench software to stimulate actual laboratory experiments on a computer, in that students work with circuits drawn on the screen of the computer and with simulated instruments that act like actual laboratory instruments. Circuits can be modified easily with on-screen editing, and, as a result, analysis provides fast, accurate feedback. Simulations in circuts is ahands -on approach throughout in interactive experiments associated with a series of questions about the results of an experiment. In additionitis more cost effective, safer and more thorough and efficient than hardware experiments.

To provide an environment to facilitate deep, rich learning, researchers employed both computer 3D graphics and simulations to create a multi representative construction model, offering learners more flexible ways to organise their thinking with manipulation (like coordinating, restructuring and comparing operations) and symbolic terms, such as text, graphics and speech. Researchers incorporated translucent multimedia whiteboards into a 3D virtual space, combining Virtual Manipulatives and a Multimedia Whiteboard to facilitate geometry problem solving (to create a new tool called the Virtual Manipulatives and Whiteboard, or VMW). In the VMW system, learners can solve geometry problems by manipulating virtual objects or exploring the problems from various viewpoints in 3D space. The use of computer-based simulations has been recognized as a powerful tool to stimulate students to engage in the learning activities and to construct meaningful knowledge. Whiteside (1986) stated that computer simulation-based instruction is useful to reach the analysis, synthesis, and evaluation in hierarchical levels in Bloom's taxonomy.

2.4.3.2. Connected Chemistry, DEMIST and SMV-CHEM

The use of external representations to help learners come to understand complex scientific concepts is now commonplace. Typical interactive environments such as the three shown below offer learners many different ways to visualize scientific phenomena including video, animations, simulations, and dynamic graphs.

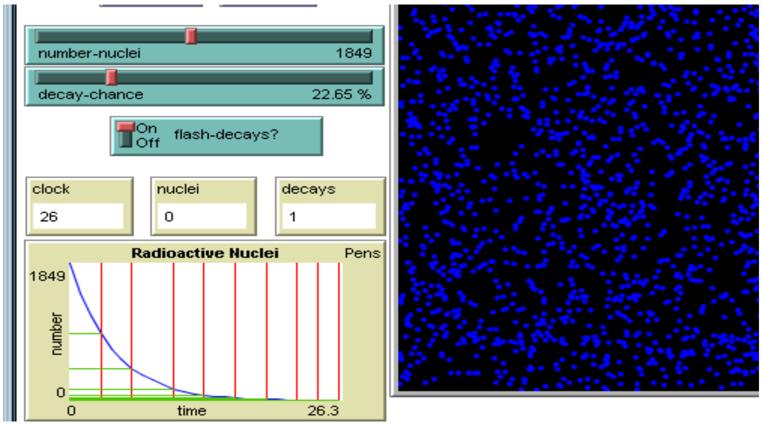

Figure 2. SMV Chem

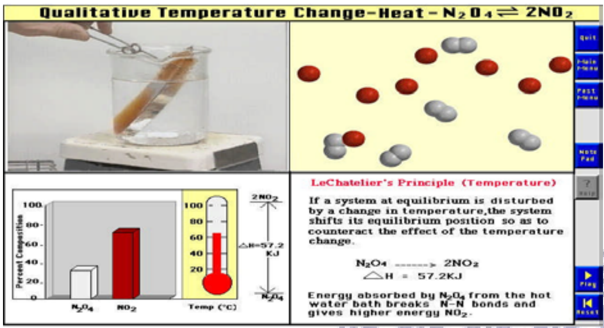

Figure 3. Connected Chemistry

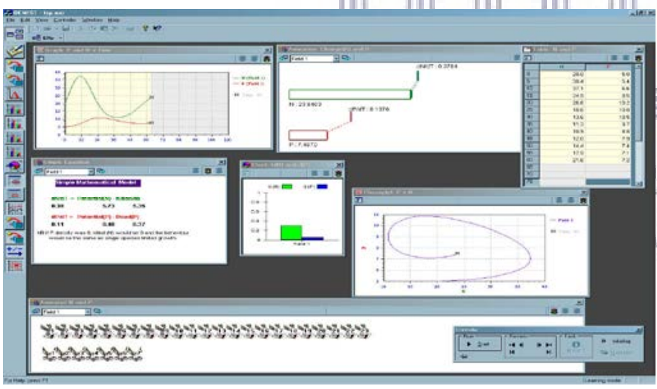

Figure 4. DEMIST

Figures 2 to 4 show three types of representations: Connected Chemistry (figure 2), DEMIST (figure 3) and SMV CHEM (figure 4). According to Stieff (2005) Connected Chemistry is a 'glass box' simulation which provides a graphical representation of simulated molecules as well as dynamic graphs describing their behaviour and simple numerical displays of system variables. The Connected Chemistry is shown in Figure 2. Van Labeke & Ainsworth (2001) defined a DEMIST as a domain-independent multi-representational simulation environment. They further explained that each environment was designed for different, equally important, educational reasons.

These environments can help learners come to understand the complex forms of visualisations required for professional and expert practice (e.g., phase plots in DEMIST). They can be designed to give learners indirect experience of phenomena that is difficult to experience directly in educational settings (such as the video of experiments in SMV-CHEM). They can provide visualisations of phenomena that are impossible to see in the real world yet whose experience will provide understanding that is difficult to achieve without such representation (e.g. molecular simulations in Connected Chemistry). However, all have one thing in common – they don't just provide a single visualisation: instead they provide Multiple Representations simultaneously.

2.4.3.3 Practical work

Practical work also challenges teachers in most cases. The execution of practical work in the classroom is a major challenge. One study conducted by Motlhabane and Dichaba (2013) explored how in-service teachers (adults) acting as learners model practical work in school laboratories. Empirical evidence according to Motlhabane and Dichaba (2013) showed that teachers learn best from one another's lessons. The results of the study show that teachers can acquire valuable skills through role-play.

Role-play benefits both the learners between two and seven years of age according to Charlesworth and Lind (2007) and adults according to Motlhabane and Dichaba (2013). The researcher believes that it is still appropriate for people of all ages including Grade 10 learners to enhance learning. Structured play is used as the greatest vibrant device to construct information in science. Scientific vocabulary is imparted within the limits of the daily plan through structured play concepts.

2.5. Research on vectors

2.5.1 Physical embodiment of vectors

When representing a geometric translation with a vector in an arrow form, the complexity of vector representations comes out in a cognitive sense. According to Aguirre and Erickson (1984); Aguirre, (1988); Hestenes et al. (1992); Heller and Huffman (1995); Knight (1995); Savinainen and Scott (2002); Nguyen and Meltzer (2003); Flores et al. (2004) and Coelho (2010) critical studies on students' experiences with vectors focused on physics education. The studies focused more on the interrelationship among physical quantities. The conclusion derived from these studies was that physical embodiment of vectors like a vector in an arrow form assisted learners understand vectors; however, the same representations blocked progression to advanced and abstract understanding of vectors. This means Multiple Representations can hinder deeper understanding. For example, push, pull, moving vertices and penetration show different meanings but all the vectors represent the same translation of a triangle irrespective of them being scattered and different.

2.5.2. Multiple Representations in geometry as a way of representing vectors

Geometry is one of fundamental methods which people use to understand and to explain the physical environment by measuring length, surface area and volume. Geometric skill is key in the representation and understanding of vectors. Clements and Battista (1992) and Tan (1994) suggested that enhancing geometric thinking is very important for high level mathematical thinking, and it should be developed with spatial interaction and manipulation in daily life. However, in traditional classrooms, geometry learning is usually conducted only through the description of text, 2D graphs and mathematical formulas on whiteboards or paper. Tan (1994) cited that in some important topics, such as measuring the area and volume of 2D or 3D objects, traditional teaching methods often focus too heavily on the application of mathematical formulas, and lack opportunities for students to manipulate the objects under study. Consequently, many students can memorize the formulas and even appear to succeed in their course work without fully understanding the physical meaning of the math formulas or geometry concepts.

2.6. Research on Physics education

2.6.1. Implications of Multiple Representation for physics teaching

Effective physics instruction needs more than lecturing or any single representation method of instruction. According to Styer (1996) effective teaching does not simply teach students what is correct - it also ensures that students do not believe what is incorrect. It requires active involvement of the students in the learning process and that Multiple Representations-based instructions meet this need in the physics classroom. Monk (2004) noted that the aim should be to teach students to use Multiple Representations in a particular scientific context and to use a variety of representations at the same time, rather than to use only one representation for all situations. In physics classrooms, teachers are responsible for designing constructivist situations and concrete connections for students so that scaffolding of knowledge can be achieved. Teachers should also encourage students to think about connections between Multiple Representations. Laughbaum (2003) cited that teachers should spend some time of the physics lesson on the relationships between manipulative and abstract symbols and emphasize applications of Multiple Representations. Moreover, using Multiple Representations in teaching of physics should be emphasised in pre-service teacher education programmes, as well as in in-service teacher education seminars. One further implication can be suggested for the physics textbooks and other teaching materials. In the traditional physics classroom, there is a need to encourage students to think more deeply on physics concepts, to intrinsically motivate them for learning, to make students appreciate the nature of physics by getting rid of rote memorization, and to avoid over-emphasising rules and algorithms. In fact, new instructional methodologies like Multiple Representations-based instructions might address this need.

2.6. Recent studies on Multiple Representations, vectors and and physics education

2.6.1. How Multiple Representations can be used to improve learner performance

Maries (2013) recommended that Multiple Representations can assist introductory physics students to improve their problem solving performance. Maries (2013) specifically mentioned a type of representation known as 'diagrammatic representation' in mathematics. Diagrammatic representations can play a particularly important role in the initial stages of conceptual analysis and solution planning. The Victorian Curriculum Report (2010) came up with the findings that when we want to compare two or more approaches in order to establish a method to prove that learners' understanding can be improved, findings on the assessment suggest students drawing productive diagrams are more successful problem solvers even if their approach is primarily mathematical. Furthermore, students provided with a diagram sometimes exhibited deteriorated performance. Think-aloud interviews suggest this is partly due to reduced conceptual planning time as students jump to implementation. Maries (2013) investigated two interventions aimed at improving introductory students' consistency between mathematical and graphical representations and revealed that excessive scaffolding can have a detrimental effect due in part to increased cognitive load. Students exhibiting representational consistency also showed improved problem solving performance. In putting measures in place to address a challenge of underperforming in a subject, it is also proper to look at concepts that are contributing to the failure rate of the subject, hence many scholars believe that one practice that can assist is Multiple Representation. The physics education research community in the area of Multiple Representations highlight the overlying trend on how Multiple Representations help learners learn concepts and skills and assist them in problem solving. Kohl (2001) argued that about two trends that developed from the latter, namely, how learners use Multiple Representations when solving problems and how different representational formats affect student performance in problem solving.

We show how our work relates to these trends and provide the reader with an overall synopsis of the findings related to the advantages and disadvantages of Multiple Representations for learning physics. This area of research investigates the relationship between learners' success and the representational format in which a problem is posed. The first question relates to learners' choices of the problem format: if they are given this choice, what will they choose? Kohl and Finkelstein (2013) found that more learners prefer the problem statement to be represented with a picture than with words, graphs or mathematical equations. However, this does not necessarily make them more successful in solving the problem. For example, on a question in wave optics students who chose a pictorial format did significantly better than the control group. However, in atomic physics the students who chose a pictorial format did significantly worse than learners in the control group. There was no clear pattern as to what format made the problem more difficult. However, Finkelstein et al. (2008) suggested that students who learned physics with the instructor who used lots of representations were less affected by the representational format of the problem.

Therefore, if we want our learners to be able to reason flexibly, it appears that the use of Multiple Representations when they are learning new material helps. Even though the use of Multiple Representation is highly recommended, we must be careful, because it is not a cut and dry problem solving approach. Kohl et al. (2007) stated that skill with different representations and Multiple Representations is highly valued in physics, and prior work has shown that novice physics students can struggle with the representations typically used in solving physics problems. There exists work in examining student use of representations and Multiple Representations, but there have been no comprehensive attempts to understand what factors influence how introductory students succeed or fail in using representations in physics. Having said that, skills with different representations and Multiple Representations are highly valued in physics, both as tools for understanding basic concepts and to solve difficult physics problems.

2.7 Conclusion

This chapter provided the theoretical framework used to underpin the research. It also considered multiple representation research that served as the source for the study. The following chapter will provide an outline of the methodology used in this study.

CHAPTER 3

Research Methodology

3.1. Introduction

The previous chapter dealt with the theoretical frameworks and literature that underpin this study. This chapter provides an outline of the data collection procedures and the reasons certain instruments were used to collect the data. The data collection plan was developed to answer the following main research question:

How can a Multiple Representation approach be used to teach vectors in Grade 10 Physical Sciences?

To address the main research question, the following sub-questions were posed:

- What was learners' understanding of vectors prior to the Multiple Representation lessons?
- How was the Multiple Representation lesson implemented?
- What was learners' understanding of vectors after the Multiple Representation lessons?
- What was the perception of learners on the use of Multiple Representations to learn vectors in Grade 10 Physical Sciences?

3.2. Research approach

Data collection methods refer to a variety of techniques that could be used for gathering information. The choice depends on the appropriateness of the approach in the study. The method that was used to conduct the investigation was a mixed research method. According to Tashakkori and Teddie (2003) a mixed method research involves the use of both quantitative and qualitative methods. Qualitative research methods are means of data gathering whereby first-hand information through the utilisation of different tools is gathered. Qualitative methods allow for information and data to be collected symbolically representing reality as it is termed 'underneath the logic'. It addresses reality through meaning, context, words, images, impressions and so forth. It includes "any type of research that produces findings not arrived at by means of statistical procedures or other means of quantification" (Strauss and Corbin, 1998, pp. 10-11). Creswell (2003) explains that the mixing of methods focuses on quantitative and qualitative data being collected, analysed and interpreted in a single study.

3.3 Case study

This study used a case study design. The case study was the best choice for the study because, according to Yin (1989), a case study contributes uniquely to the knowledge of individual, organisational, social and political phenomena.

3.3.1 Advantages of a case study

Case study arises out of the desire to understand the feelings of individuals; therefore, because perceptions are such a difficult behaviour to gather, this method of data collection was essential. A single case study was conducted at a senior secondary school at Libode-Mega District in the Eastern Cape. The focus group was Grade 10 Physical Sciences learners. The reason for the choice of the case study was that the school is in an area where the researcher teaches and Grade 10 is the class the researcher teaches. These two aspects helped the researcher to access the respondents. It also helped the researcher to gather up-close, in-depth and detailed information for the study.

3.3.2. Disadvantages of a case study

According to Yin (2009) case studies cannot be generalised to populations or universally, but can be generalised in the theoretical propositions. Disadvantages are that single and multiple case studies have been viewed as a less desirable form of inquiry and its greatest concern is the lack of rigour of case study research. Bias and equivocal evidence presents itself and it influences the direction of the findings and its conclusions. Yin (1982) described the case study method as providing little basis for scientific generalisation. This means the results of my study are not applicable to similar cases and unless the issues of reliability and validity are thoroughly looked at the results are not likely to be flawless.

3.4. Sample

3.4.1. Population and sample

The research site was a secondary school in rural Ngqeleni, Eastern Cape. The place is deep rural and learners in the area are really struggling with Physical Sciences. The selection process fell in the category of convenient sampling, because the participants were all conveniently in one class of 45 learners where the data was collected. This type of sample is a non-probability technique where participants are selected for convenience, with respect to the accessibility and proximity of the researcher (Castillo, 2009). The total number of Grade 10 Physical Sciences learners in the school is 160. The sample consisted of 45 Grade 10B Physical Sciences learners. The class has been taught with mostly 'traditional' representations, i.e. equations, graphs and tables. Of 45 learners, 24 learners participated in the pre-test. The same learners participated in the lesson (intervention). In the interviews and the questionnaires, the focus group was the Grade 10B Physical Sciences learners who were involved in the Multiple Representations.

All the 24 learners who participated in the test and in the lesson turned up for the interviews. That means 100% of the learners who participated in the pre-test and intervention turned up for both the interviews and filling of questionnaires. All the 24 questionnaires issued to learners were returned. In three questionnaires learners made more than one choice in an item and some items were left blank. For richness of my data I decided not to discard any questionnaires but I analysed each item based on the number of responses. So, all the 24 questionnaires qualified for analysis. The reason for incomplete questionnaires was the three learners filled the wrong spaces, e.g. instead of filling 2.2, 2.3, 2.4 they would make three 2.2 and leave 2.3 and 2.4 blank. The other ticks in 2.2 were mistakenly put there instead of being put in 2.3 and 2.4. These learners complained about not having enough time to complete the questionnaires so they had to rush hence the mistakes. The aim of the test was to check the learners' level of knowledge and their misconceptions about vectors. In the interview the sample of the learners gave their perceptions on Multiple Representations in relation to responding to questions, arousal of interest, willingness to work longer periods, participation in activities, their level of attention, usage of resources, and their impact on improving the level of understanding of vectors. The questionnaire was to quantify the perceptions of learners towards the use of Multiple Representations to teach vectors.

3.5. Data collection plan

The data collection was preceded by a pilot study.

3.5.1 Pilot study

In order to gain maximum benefit from using questionnaires, it was crucial that the instrument be piloted. Bryman (2008) advises that it is always desirable to conduct a pilot study before administering a self-completion questionnaire: it will ensure that the survey questions operate well (e.g. for clarity, eliminate ambiguities, target audience readability levels). For expert validation, I gave the questionnaire to my supervisor to check its fitness-for-purpose. The researcher then used the learners from a neighbouring school who were also doing Physical Sciences in Grade 10. I allowed them to respond to the items on the questionnaire. The students provided feedback on the clarity of the questionnaire items, instructions and layout. They also highlighted areas that needed to be revisited. I then revised the questionnaire.

3.5.2 Research data collection

The researcher conducted the research in the school where learners are schooling and the teacher is teaching. That allowed the researcher to gather a high level of detail about the participants and their actual experiences. The methodological framework is shown in Table 3. The steps followed to collect the data responded to the research sub-questions.

3.5.2.1 What was learners' understanding of vectors prior to the Multiple Representation lessons?

In step 1 a pre-test was given to the Grade 10B learners. 24 learners participated in the test. 24 is 60% of the total population of rade 10 B. Participation was voluntary. The aim of the pre-test was to assess students' prior knowledge and to gather the level of understanding and interest in vectors based on the method that was used before the Multiple Representations. A memorandum was used to mark the test. The scores were recorded and analysed in the form of a graph.

3.5.2.2 How was the Multiple Representation lesson implemented?

Step 2 consisted of a lesson on vectors where Multiple Representations was used. For the lesson plan refer to Appendix H. In the lesson, YouTube clips, practicals, tables and graphs, drawings, words, demonstrations and simulations were used. The aim of the lesson was to expose learners to Multiple Representations of vectors. The presentations were aimed at making learners respond to questions, arouse and maintain their interest, make them participate in activities, improve level of attention, enable them to use resources, and to improve their level understanding of vectors. The lesson was videotaped for analysis.

3.5.2.3 What was learners' understanding of vectors after the Multiple Representation lessons?

The third step was a post-test comparison. The aim of the post-test was to compare the performance of the learners before and after the use of Multiple Representations. This test was also marked using a memorandum.

3.5.2.4 What was the perception of learners on the use of Multiple Representations to learn vectors in Grade 10 Physical Sciences?

In step 4 the learners were given a questionnaire to fill. The aim of the questionnaire was to gather and quantify the learners' perceptions on the use of Multiple Representations in teaching and learning of vectors in Grade 10 Physical Sciences. The responses in the questionnaire were compared to the learners' performance in the pre-test and post-test. The questionnaire had four themes of 4 to 5 items each. The themes were interest, confidence, appropriateness of Multiple Representations, and attitudes. The whole data collected from the questionnaire was put into a spread sheet for analysis. The numbers collected in responses were converted into percentages.

In this step the learners were also interviewed based on their responses on the questionnaire. The learners were informed of the topic of the interview and that happened within a reasonable time. The learners were interviewed in groups of four. Six groups of learners were interviewed. The aim of the interview was to find out what their perceptions were on Multiple Representations based on the aims of the lesson. It was also used to determine the final state of the learners in terms of their perceptions towards Multiple Representations of vectors after the lesson was conducted. But the most important aim was to triangulate the results from the other four instruments, i.e. the pre-test, the lesson, the post-test and the questionnaire. The interview responses were recorded on an audio tape for analysis. The recording was followed by transcribing and translation of the responses. The data was then cleaned to leave out what was not related to the research.

Table 3: Methodological framework

Research question	Method	Respondents	Instrument	Sample size	analysis
How can a Multiple Representation approach be used to teach vectors in Grade 10 Physical Sciences?					
Step 1: What was learners' understanding of vectors prior to the Multiple Representation lessons?	Pre-test	Learners	Test	24	Memo marking
Step 2 How was the Multiple Representation lesson implemented?	Learners taught vectors in Multiple Represen tations	Learners	Lesson plan	24	Thick descriptions
Step 3 What was learners' understanding of vectors after the Multiple Representation lessons?	Post-test	Learners	Test	24	Memo
Step 4: What was the perception of learners on the use of Multiple Representations to learn vectors in Grade 10 Physical Sciences?	Survey Interview	Learners Learners	Questionn aire Focus group Interview schedule	24 24	Stats coding

3.6. Data collection instruments

3.6.1 Interviews

According to Castillo (2009) interviews are a systematic way of talking and listening to people. It is a method of collecting data from individuals. A structured interview, also known as a standardised interview, provides the same questions to all respondents. This is an interview in which all respondents are asked the same question with the same wording an in the same sequence.

A structured interview was conducted at the school. The focus group was 24 Grade 10B learners. An interview schedule was drawn up and learners were interviewed during the school hours to maximise the chances of their availability. The 24 learners were grouped into six focus groups of four each. The aim of the interview was to gather what the perceptions of learners are towards Multiple Representations. They responded to questions on their feelings about Physical Sciences before and after Multiple Representations. Learners could discuss answers so that the interviewer could come up with rich data. Same questions were asked to all the learners to ensure consistency of responses. Open ended questions were used for learners to express their views. Responses were recorded on an audio tape. The data was translated, transcribed and cleaned. The data was then analysed. The data collected from the interview complemented the results of the questionnaire which is a quantitative data collection tool.

David and Sutton (2004) claim that the advantages of a structured interview include the researcher having control over the topics as well as format of the interview. Prompting may be included regarding questions and if an inappropriate question is asked, data on why no responses were made may be recorded. Disadvantages of interviews, according to David and Sutton (2004), include interviews adhering too closely to the interview guide and may be the cause of not probing for relevant information. Since there is a set interview guide, respondents may hear and interpret or understand questions in a different manner.

Design Tool: focus group interviews

A focus group interview represents a more natural environment than that of a one-to-one interview because participants in a focus group are influencing and are influenced by the other participants in the group – just as they are in real life. Kreuger and Casey (2000) and Travers (2006) describe the focus group as the word suggests: *focus* having a limited focus of interest and *group* pointing to a number of participants occupied in the interview. Morgan (1998) goes further to explain that a focus group is a form of group interview that depends on the interaction within the group as they discuss a topic supplied by the interviewer.

The focus groups interview was conducted with the focus group to obtain a sample of learners' views on Multiple Representations. It took place at a time convenient to the learners who were interviewed. The interview was conducted in a school library to minimise 'power play' as the school library is a neutral venue that learners are used to. The choice of group interview was based on making learners discuss their answers and be at ease so they could give honest answers. That helped the researcher to gather rich data from the learners.

3.6.2 Questionnaire

According to Johnson and Christensen (2012) questionnaires provide information about thoughts, feelings, perceptions, beliefs and values. Propper (1959) cited that the advantages of a questionnaire are its practicality; the researcher is able to collect a large amount of information from a large number of people in a short period of time and at a relatively low cost. He further suggested that the results of the questionnaire can be quickly and easily quantified and analysed, even more scientifically. It can be used to compare and contrast other research and may be used to measure change. The questionnaire was a set of items tabulated on a Likert scale thus closed-ended questions were used. The purpose of the closed-ended questionnaire was to determine the level of agreement on the learner perceptions towards the use of Multiple Representations in teaching vectors. Questionnaires were anonymously self-administered and learners participated of their own free will. Learners were advised of their rights as respondents. The questions were of the same order and were structured to minimise bias. The wording was kept simple with no ambiguity, allowing the respondents to choose categories to fit their situations. The questionnaire was designed so that it covered a lot of information relating to learners' perceptions towards the use of Multiple Representations in teaching vectors. There were five categories with five items each. The five categories were as follows: level of interest, confidence, appropriateness of approach, understanding of learners, and attitudes of learners. Each category had five items that were rated from rating 1 to 5. The ratings were as follows: strongly agree, agree, not sure, disagree, and strongly disagree. Strongly agree was rated as 5 and strongly disagree was rated as 1.

3.7. Data analysis

The tests (pre- and post-) were marked looking at their misconceptions by using a memorandum. The marks from the tests were recorded and marks were analysed. The analysis was based on the level of understanding of the learners through the marks they obtained. The analysis was in the form of marks 0-9, 0-19, 20-29, 30-39, 40-49, 50-59, 60-69 and 70-80. The interviews were recorded, translated and transcribed and cleaned. The data from the interview responses were then grouped into themes for analysis. This means an interview schedule was used to collect data. The responses were necessarily a true reflection of the learners' understanding, feelings and practice of Multiple Representations. The data from the questionnaires was coded and put on an Excel spread sheet. The graph was drawn. The spread sheet and the graph were used to analyse the data.

Coding was done as follows: focus groups were given a letter F, an interview was given letter I and the learners were each given a number. For example, [FI4 L1] means a quote from focus group interview 4, learner number 1.

3.8. Validity and reliability

Reliability is the degree to which an instrument produces stable and consistent results. Validity on the other hand refers to how well a test measures what it is supposed to measure. According to Lincoln and Guba (1985), trustworthiness is an important aspect of qualitative research; it is equivalent to the concepts of reliability and validity.

3.8.1 Validity

To ensure validity the researcher made sure that the aims of the research and the research questions were aligned by looking at the key words of some of the questions and those of the heading of the topic. The researcher then used a test and the questionnaire to triangulate the results. The test questions, questions of the interview and the questionnaire were sent to an expert to ensure their validity. Members were allowed to check their responses before they were used.

3.8.2 Reliability

To ensure reliability the instrument was piloted. The class which was not part of the study was interviewed. The piloting helped the researcher to detect if the language was clear and the questions were understood and unambiguous. The unclear questions were reworded. The interviews were conducted by the researcher. The data was scanned, put into themes and the themes were categorised.

3.9. Ethics

In order for the interviews to take place permission was required from the University of the Western Cape, the Eastern Cape Education Department, the Circuit Manager (circuit 1), the principal and the educators (Appendices 4-7). Parents of the learners who took part in the study completed the consent form. The researcher protected the anonymity of the participants by dissociating the names during coding. The ownership of the data was clarified in the meeting between those who were involved and a resolution was sought to designate ownership of the data and to prevent sharing of data with those not involved. A copy of the research will be forwarded to the Department of Education, the school principal and the university in order to prevent the misuse of results to the advantage of one group or another.

3.10 Conclusion

This chapter outlined the rationale for the research design for this research project. The choice of methodology used as well as the data collection instruments was provided. The next chapter will present the findings of the study after the data collection process was completed.

CHAPTER 4

Findings and Discussion

4.1. Introduction

The previous chapter outlined the rationale for the research design for this research project. The choice of methodology used as well as the data collection instruments were made in order to answer the research question: How can a Multiple Representation approach be used to teach vectors in Grade 10 Physical Sciences? The chapter provided an in-depth discussion of the sample, the instruments used and the data analysis process. This chapter provided findings on each of the research sub-questions.

4.2 How can a Multiple Representation approach be used to teach vectors in Grade 10 Physical Sciences?

In order to address the main research question the following sub-questions were posed:

(i) What was learners' understanding of vectors prior to the Multiple Representation lessons?

(ii) How was the Multiple Representation lesson implemented?

(iii) What was learners' understanding of vectors after the Multiple Representation lessons?

(iv) What was the perception of learners on the use of Multiple Representations to learn vectors in Grade 10 Physical Sciences?'

Table 4 below shows the level descriptions of percentage levels as specified by the CAPS document. This table also includes achievement descriptions. The levels range from 1 to 7. The percent ranges are as follows: 0-29, 30-39, 40-49, 50-59, 60-69, 70-79 and 80-100.

Table 4: The percentage range against achievement description

Level	% range	Achievement description
1	0-29	Not achieved
2	30-39	Elementary achieved
3	40-49	Moderate achieved
4	50-59	Adequate achieved
5	60-69	Substantial achieved
6	70-79	Meritorious achieved
7	80-100	Outstanding achieved

4.2.1. Methodological framework steps

4.2.1.1. What was learners' understanding of vectors prior to the Multiple Representation lessons?

The pre-test was given to determine learners' understanding of vectors before they were taught in Multiple Representations. As a baseline the test was given to gather what learners already know in Grade 10 about vectors as the topic was already dealt with in class in the same grade earlier (not through Multiple Representations). Learners were taught vectors previously using the traditional chalk-and-talk method. The second reason for the pre-test was to allow a better linking of their pre-knowledge with the anticipated depth of content in vectors with the use of Multiple Representations. The test was designed to look at the learners' knowledge of the key concepts in vectors and vectors manipulations. The test was comprised of four questions in order of cognitive demands from simple recall in question one to vector constructions with scale in question four.

The following tables show the findings from the pre-test in the form of question by question analysis. For the test questions refer to appendix A. Each question is analysed in the form of a table that shows ratings as well as the percentage of learners in a rating.

(i) Question 1 analysis

Question 1 was on basic concepts and basic vector identification. This question was mostly based on level I of Bloom's taxonomy. Bloom's taxonomy describes the cognitive levels for learners. When question papers are set the examiners these cognitive levels. This level is about knowledge. The question expected learners to recall. Recalling includes defining, listing, identifying and recognising. The table 5 shows the performance of learners in question 1 in the pre-test.

Table 5: Rating and percentage of learners for performance in question 1 of the pre-test

Rating	Percentage of learners
1	9
2	22
3	50
4	13
5	5
6	1
7	0

Table 5 above shows the rating and percentage of learners who performed in each rating. From the table the majority of learners fell in level 3. This makes a total of 50% of learners in the level. 6% of the learners fell in ratings 5 to 6. The majority of learners could not recall which includes define, list, identify and recognise. For example, learner 1 defined displacement in question 1.1.2 of appendix A as 'a quantity that is defined by magnitude and size'. Learner 6 defined a positive vector as 'a vector that is going to the right'. The whole of question 1.2 posed a challenge to the majority of learners. For question 1.2.1 learner 21 differentiated between an acceleration of -10 $m.s^{-2}$ and a temperature of -36°C as 'hot and cold temperatures'.

(ii) Question 2 analysis

Question 2 focussed on construction vectors where learners used the mathematical instruments where necessary. Mostly this part was skill based since learners had to demonstrate their ability to use mathematical instruments. This question was mostly based on levels II III and IV of Bloom's taxonomy. Here learners were expected to comprehend, apply and analyse scientific knowledge

Table 6: Rating and percentage of learners for performance in question 2 of the pre-test

Rating	Percentage of learners
1	33
2	32
3	23
4	19
5	5
6	0
7	0

Table 6 shows that the majority of learners (about 33%) fell in level 1. No leaners went up to level 6. More than 50% of the learners scored below 40%. These learners cannot calculate or construct vectors satisfactorily even most basically. Only 5% of learners managed to score above 49% in the test. Most learners could not find the resultant by construction.

(iii) Question 3 analysis

This question was mostly based on levels II III and IV of Bloom's taxonomy. Here learners were expected to comprehend, apply and analyse scientific knowledge. Learners had to calculate and construct vectors. The constructions in question 3 were of a higher order than those in question 2. Learners had to manipulate more than one vector in each sub-question because they were dealing with resultant vectors.

Table 7: Rating and percentage of learners for performance in question 3 of the pre-test

Rating	Percentage of learners
1	25
2	25
3	23
4	20
5	7
6	0
7	0

Table 7 shows that an equal number of learners (about 25%) fell in level 1 and level 2. No learners went up to level 6. About 50% of the learners scored below 40%. These learners could not calculate or construct vectors satisfactorily even most basically. 7 % of learners managed to score above 49% in the test. The performance of learners in question 3 was not very different from their performance in question 2 though they performed better in question 3 than in question 2. Most learners could not find the resultant by construction but at least they could calculate.

(iv) Question 4 analysis

This question was mostly based on levels IV, V and VI of Bloom's taxonomy. Here learners were expected to comprehend, apply, synthesise, analyse and evaluate scientific knowledge. Learners had to calculate and construct vectors. Unlike question 3, this question expected learners to analyse statements since the questions were presented in words.

Table 8: Rating and percentage of learners for performance in question 4 of the pre-test

Rating	Percentage of learners
1	50
2	32
3	18
4	0
5	0
6	0
7	0

Table 8 shows that half of the learners' responses fell in level 1. No learners went up to level 4. The highest level obtained was level 3 which was obtained by 18% of the learners. The other 50% of learners were distributed among levels 2 and 3. The majority of learners could not interpret word equations. Some had a problem dealing with the resultant of simultaneous vectors.

Some of the learners did not know where and how to use mathematical instruments. Twenty-four (24) learners participated in the test and they were marked. Their marks were recorded and grouped. The number of learners who got marks in each group were counted. The table below shows the number of learners in each group. The data is also represented in the form of a bar graph.

(v) Overall performance of learners in the pre-test

Table 9: Table showing the overall performance of learners in the pre-test

Number of learners	Marks ranges
7	0→9
6	10→19
5	20→29
4	30→39
1	40→49
1	50→59
0	60→69
0	70→80

Table 9 shows that most learners scored in the range of 0-19 marks in the pre-test. These learners scored less than 24%. The percentage of the learners in this bracket is about 54% of the test participants. The next 9 learners scored from 20 and 39 marks. This translates to about 38% of the participants who scored between 25% and 49% in the test. A total of 22 learners scored in the range 0-39 marks. Thus about 92% of participants scored less than 50% in the test. The last two learners scored in the range of 40 to 59 marks. These learners scored between 50% and 74%. This means about 8% of participants scored above 50%. No learners scored above 59 marks. This translates to 0% of learners who scored above 74% in the test. About 54% of participants did not understand vectors when they were taught without the use of Multiple Representations, and a very low percentage (about 8%) understood half or more of the work in vectors. Figure 4 below shows this performance.

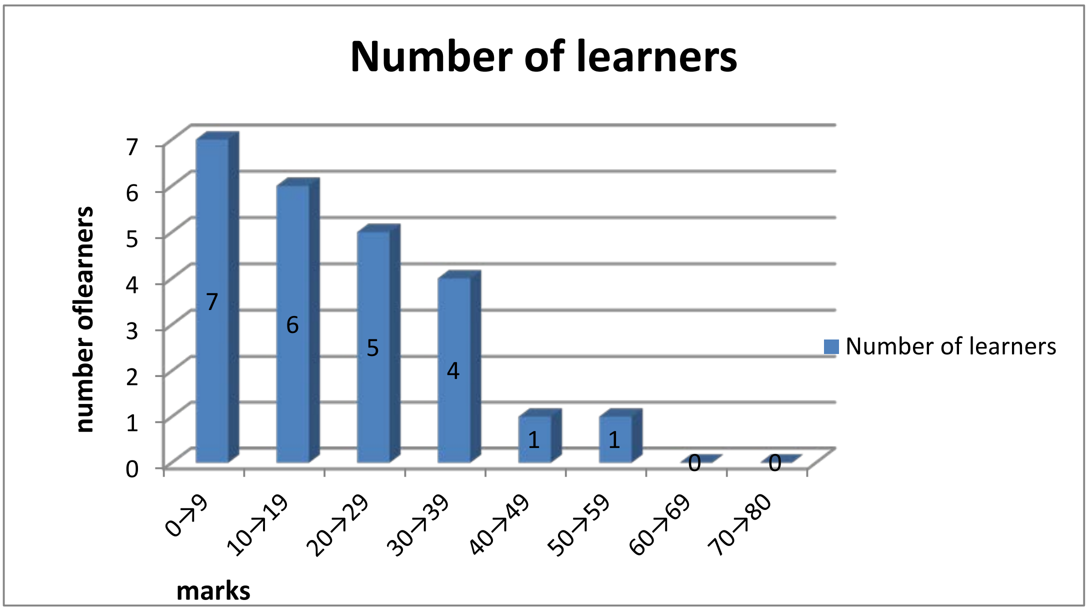

Figure 5: Graph showing marks for the learners in the pre-test

Figure 5 above shows results from the table. The vertical column shows the marks in ranges whilst the horizontal axis shows the number of learners that belong to each range of marks. The total for the test was 80 marks. About 28% of learners scored less than 10% of the total marks. The last six learners got 30 to 59 marks. This means only 25% of the learners got more than 38% with only about 8% of the total number of learners scoring above 50% of the total marks. No learners scored above 59 marks in the test. This means no learners scored above 74% in the test.

4.2.1.2 How was the Multiple Representation lesson implemented?

The lesson was conducted in order to expose learners to learning through Multiple Representations. The lesson was divided into three sections: the introduction, the body and the conclusion. A total of six representations were used, i.e. verbal representations, simulations, drawing, calculations, YouTube and demonstrations. The focus was on how the participants responded to each representation.

Step 1: Introduction of the lesson

The introduction was designed to gather the learners' level of knowledge of vectors. In this section learners were asked to define the basic concepts in vectors, to give examples of vectors, their symbols and units. The teacher introduced the lesson by explaining to the learners that they would be taught vectors using Multiple

Representations. He explained Multiple Representations as a form of representation where the same information would be represented in different ways. This part was in the form questions and was done orally. Learners responded to questions as individuals. Learners were also given an opportunity to ask questions from one another. The teacher asked questions to learners (as they appear in appendix A). There were no responses at first so the teacher tried to ease them by pointing at them randomly to respond.

Define a vector

Response 1: A vector a quantity that is defined by magnitude and size [Learner 1]

Response 2: um…… A vector a quantity that is defined by one dimension and size [Learner 14]

Write the symbolic representations of speed and velocity

Response 1: **v** is a symbol for velocity [learner 6]

Response 2: V is a symbol for velocity [learner 21]

Response 3: *v* is a symbol for velocity [learner 14]

The teacher tried to prompt learners by opening a discussion session on the correct symbol of a velocity. At the end of the discussion the teacher had to clear some misconceptions. An example of these misconceptions was in the symbols for scalars and vectors like the symbols of velocity. The following symbols came up for velocity **v**, **V**, *v*, v, and V. Learner [6] argued strongly that the correct symbols for velocity was **v.** Learner [21] countered that by arguing that you cannot write a bold letter with a pen, so her argument was that the correct symbol should be V. The teacher cleared the misconceptions but, since the misconceptions around these symbols had nothing much to do with Multiple Representations, discussions were not allowed to go too far. The teacher then consolidated the learners' responses and gave solutions to all the question as reflected in appendix B

Step 2 Body of the lesson

i. Displacement and distance as examples of vectors and scalars

Representation 1: Power point presentation

The teacher explained to the learners the difference between displacement **(**as a change in position in a straight line) and distance (as the actual path taken) using a power point presentation. He used figure 5 below to show the difference between distance and displacement.

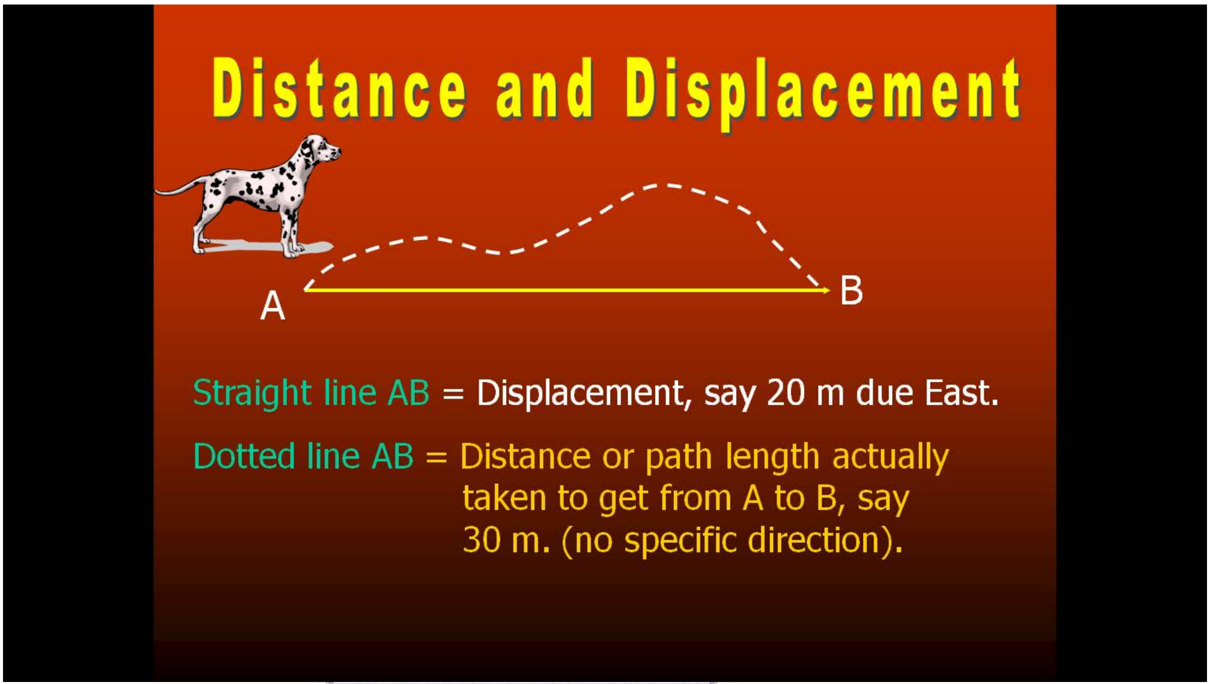

Figure 6: Distance and displacement

In Figure 6 the dog is about to move following the path as shown with dotted lines. The teacher allowed learners to participate by asking them some questions:

How do you use the word 'displace' or 'displacement' outside Physical Sciences?

Um…. Like substitution [learner 13]

It's like……. Putting something away or far like when government remove amatyotyombe (shacks) [learner 6]

Representation 2: boxes and arrows on the chalkboard

As step 2 of representing displacement and distance as examples of vectors and scalars the teacher used arrows and boxes. The aim was to show the vector nature of the motion (arrows to the left or to the right). Figure 7 shows the representation of displacement using the box and arrow method.

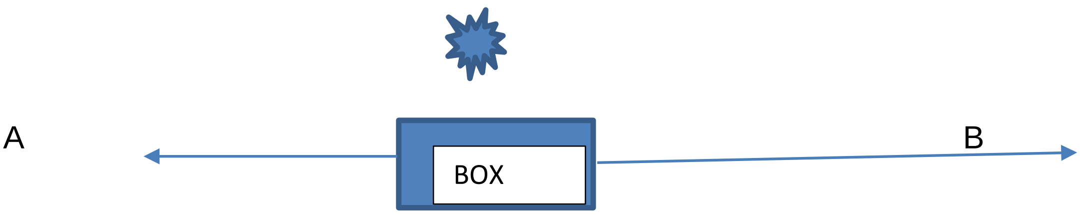

Figure 7: Representation of displacement using the box and arrow method.

Using one of their understandings of the word ‘displacement’, the teacher let learners explain the possible horizontal ‘displacements’ of the box.

In horizontal directions how can the box be moved?
The box can be displaced to A or displaced to B. [learner 5]

The teacher explained to the learners that the box maybe displaced towards A or towards B. He then added that if we take the direction towards B as eastwards and the direction towards A as westwards, then any position on the side of B will be given an eastwards direction and any position on the side of A from the star will be given a westwards direction. The teacher further referred to the sizes of arrows to explain that a longer arrow shows a greater displacement. Learners seem to follow this example very well.

Representation 3: Simulations

To emphasise his point the teacher showed the learners simulations for the motion of the walking man. This is shown in figure 4. For each position the learners had to tell the distance from the starting point and the displacement from the starting point. Simulations further allowed the teacher to introduce speed (as a rate of change of distance without a direction). The teacher also introduced velocity as a rate of change of displacement (with a specified direction).

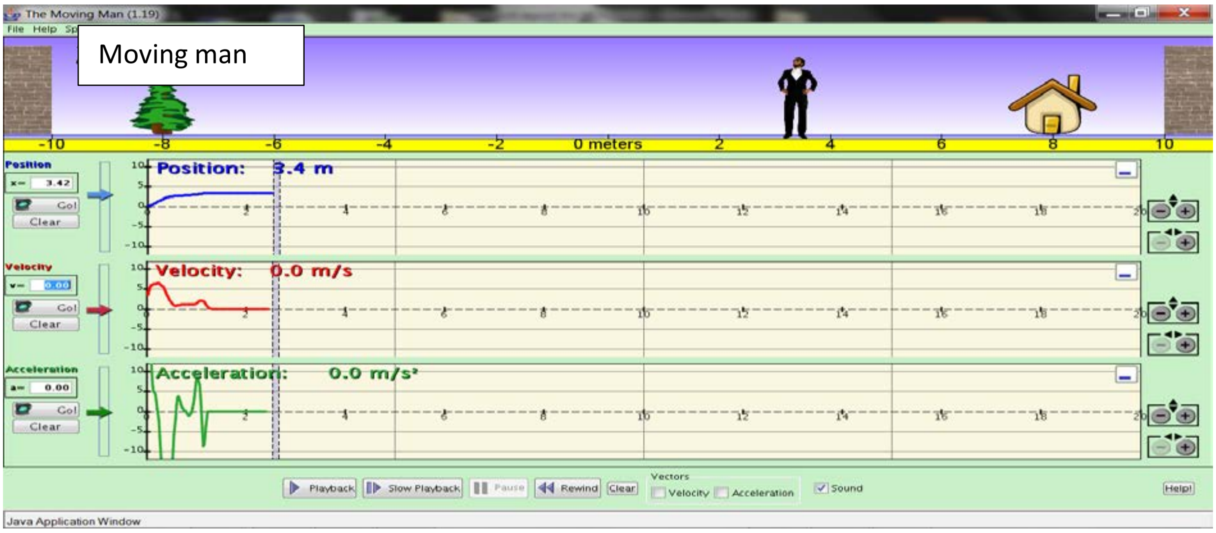

Figure 8: Distance and displacement, vectors and scalars, and resultant using a simulation of a walking man.

Figure 8 shows the simulation of a walking man on top. Below the walking man there are graphs that show the motion of the man. These are graphs of displacement versus time, velocity versus time and acceleration versus time.

Why is the velocity 0 at the position as shown in the simulations? [learner 1]

It shows that the person is stationary (not moving) [teacher]

But why is the displacement not 0? [learner 1]

The displacement will only be 0 if the object has gone back to the starting point. [teacher]

The teacher explained the meaning of each line and value that appears on the simulation. The walking man was allowed to move to different positions and the distance and displacement were determined. The position of the man in figure 8 above is 3.4.m. The man walked from 0 to the home to the position shown above. The position is shown as 3.4 m but the direction is not shown so learners were made to decide on the direction with respect to zero position as well as the distance travelled by the man. Learners had to focus on the motion (and not the position) of the man to decide on the distance travelled by the man. One learner's response to the position above was that both displacement and distance were 3.4 m but other learners corrected him. A lot of discussion was held in relation to the reference position that learners never thought was important. An example here was when the referenced position was changed from origin (0) to the tree or the home. This brought some confusion to some learners.

With the same simulation the teacher brought up the concept of velocity (speed with a direction). The speed was introduced as the rate of change of distance while velocity was introduced as the rate of change of displacement in construction. Unlike in construction this representation would show a zero velocity whenever the man was stationary. Whenever the man was fast the value of the velocity increased irrespective of direction. This meant that velocity does not necessarily depend on displacement. This was more evident when the value of position was decreasing but the speed was increasing. Sometimes the value of position was higher but the velocity was actually zero. This representation seemed to complicate these vectors since learners were so comfortable with the relationship between the displacement and velocity from the definition of velocity.

Representation 4: Scale drawing for a vector

A vector

Representing a vector by scale drawing

The teacher introduced learners to scale drawing to represent the size of a vector and that an arrow shows the direction of a vector and he used this explanation to further differentiate between a vector and a scalar. The teacher restricted himself to distance and displacement. In additional, the teacher explained how a vector is represented through a drawing and that symbols for vectors are typed in bold letters or with an arrowhead above the symbol, e.g. ***v***, ***F*** and **a.** He used an example below to drive his point home. Figure 8 below shows how to represent a vector using a scale drawing and a bearing.

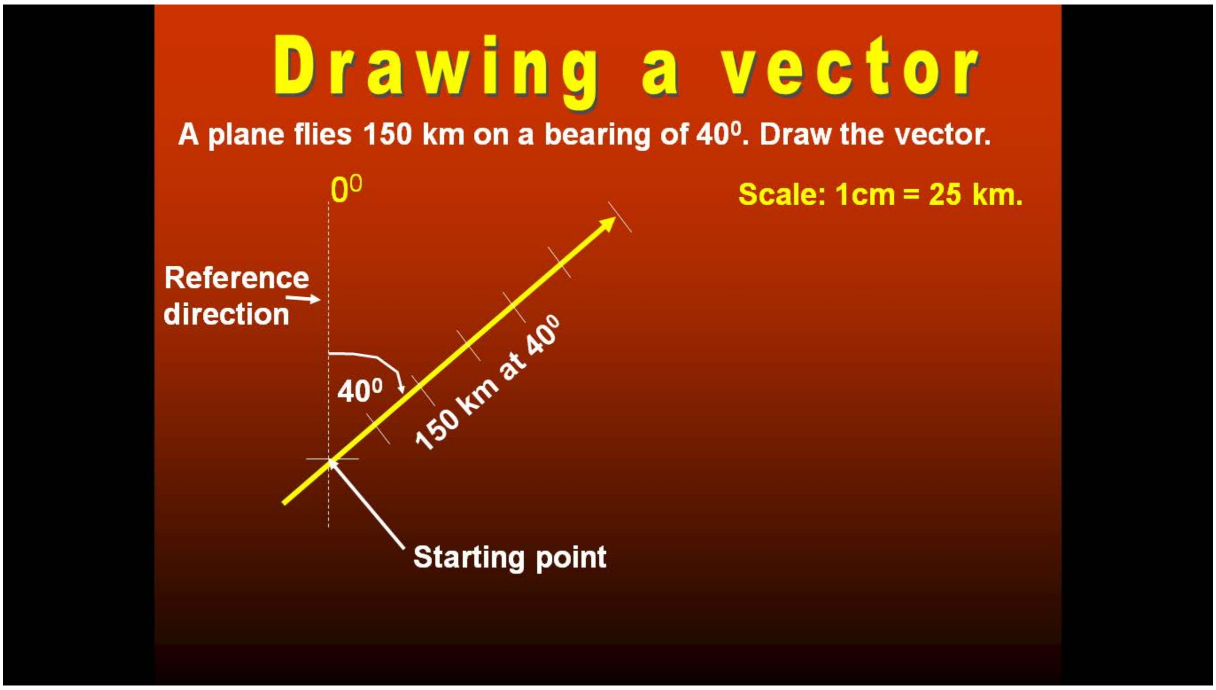

Figure 9: Representation of a vector using a scale drawing and a bearing.

Resultant vector

The educator introduced a resultant vector as a combined effect of a number of vectors. He referred to the resultant on a straight line and the perpendicular vectors only for explanations.

Finding resultant by scale drawing

The first representation that the teacher used to represent the resultant vectors was a scale drawing and the focus was on resultant of vectors on a straight line first. The teacher emphasised that when representing a resultant vector through scale drawing you always draw it from the tail of the first vector to the head of the last. The teacher restricted resultant vector to only two vectors. Figure 9 below was used to show how to find a result and vector in a straight line.

(a) Finding the resultant of vectors on a straight line

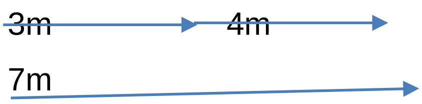

Figure 10: Resultant vector in a straight line

The representative above was used to tackle both displacement and velocity. The time was given as 2.6 seconds. Velocity was introduced as the rate of change in position (displacement). This definition meant that learners had to focus on the change in position and the time taken for that change. This representation made learners participate. A lot of learners seemed to understand it though there were a few learners who did not recognise the difference between a resultant vector and just a vector. Learner [6] asked the following question:

Why do we have to add vectors instead of just focussing on one vector'? Learner [6] *Um….. for example, if someone has been sent to a shop but decides to take some rests with every group of friends he would meet on the way from each stopping to each stopping, it would be one complete vector. [learner 8]*

Learners tried to explain the importance of a resultant vector to each other. Learner [6] even came up with an example of 'stop and go' in cars during traffic jams. The learners emphasised that if you combine the stopping distances from one stopping to the next you will be able to come up with a resultant vector.

Learners represented different straight line resultants with a scale drawing. They worked out both displacement and velocity. The example shown in table 10 was used to explain scale conversions.

Table 10: table showing scale conversions for book versus real ground

	Book	Real ground
Scale	1cm	10 m
Given value and the value that needs to be calculated	x	100 m

The teacher explained how you get the value of the unknown using mathematical skills of 'cross multiplying' where they multiply 'book' with 'real'. For example, here it was:

$10 \cdot x \cdot m = 1 \cdot 100 \cdot cm \cdot m$

X = 10 cm

The teacher then explained that the answer means learners had to measure 50 cm on the paper to represent 100 m. This did not look simple to the learners that some even felt there should be a better way for scale conversion. They even described how they deal with scale conversion in Geography where they have a constant scale for South Africa of 1:50000. For example, the following suggestions came up:

But sir…….. in Geography if we are given a map we just measure the distance on the map and divide it by 2 then we know the real distance. [learner 8]

In Geography you use a scale of 1:50000 only but in Physical Sciences we use any scale. [teacher]

The scale issue became a 'hot' issue because of the inclusion of x that they did not like. The teacher suggested that they should cross the scale and divide by the given number. In the example above the teacher showed the learners the alternative way of scale conversion.

Value = (1 x 100) /2

Value = 50

(b) Finding the resultant of perpendicular vectors

Since vectors are not always on a straight line, the teacher also introduced vectors that act at right angles to each other. Figure 11 below was used to show how to find a resultant vector using a tail to head method (a triangle method).

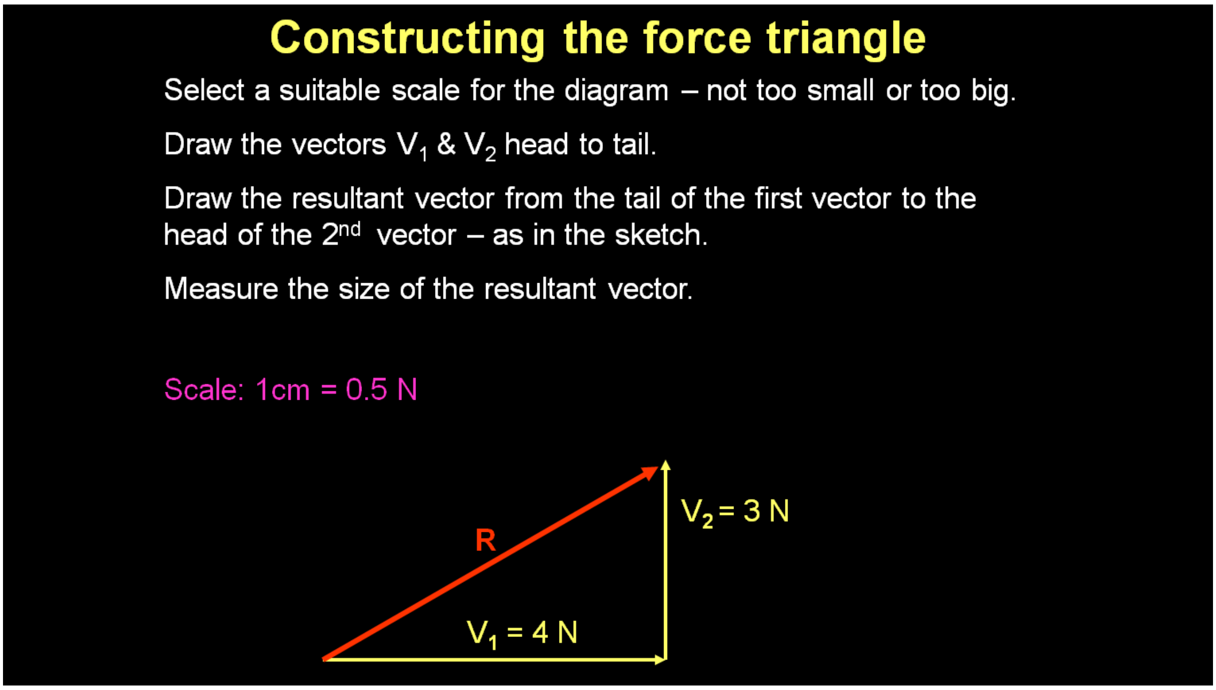

Figure 11: Shows how to find a resultant vector using a tail to head method (a triangle method)

Some learners got confused when perpendicular vectors were introduced. The teacher dealt with questions that related to the angle and how to draw a vertical vector. For example:

How do you find the direction of a resultant if vectors are not acting on a straight line? [learner 5]

The direction is given as an angle and since you have a vertical and a horizontal value you use tangent of an angle like Tanα = opposite/adjacent.

Then α = $\tan^{-1}$(opposite/adjacent. In the example above α = $\tan^{-1}$(3/4), α = 45□

Representation 5: Calculations

(a) Calculating a resultant vector of vectors on a straight line

+3 + (+4) = +7

Since the directions were explained in dealing with vectors this part did not pose any questions. The teacher explained a positive and a negative vector. Resultant vectors on a straight line never posed challenges.

(b) Perpendicular vectors

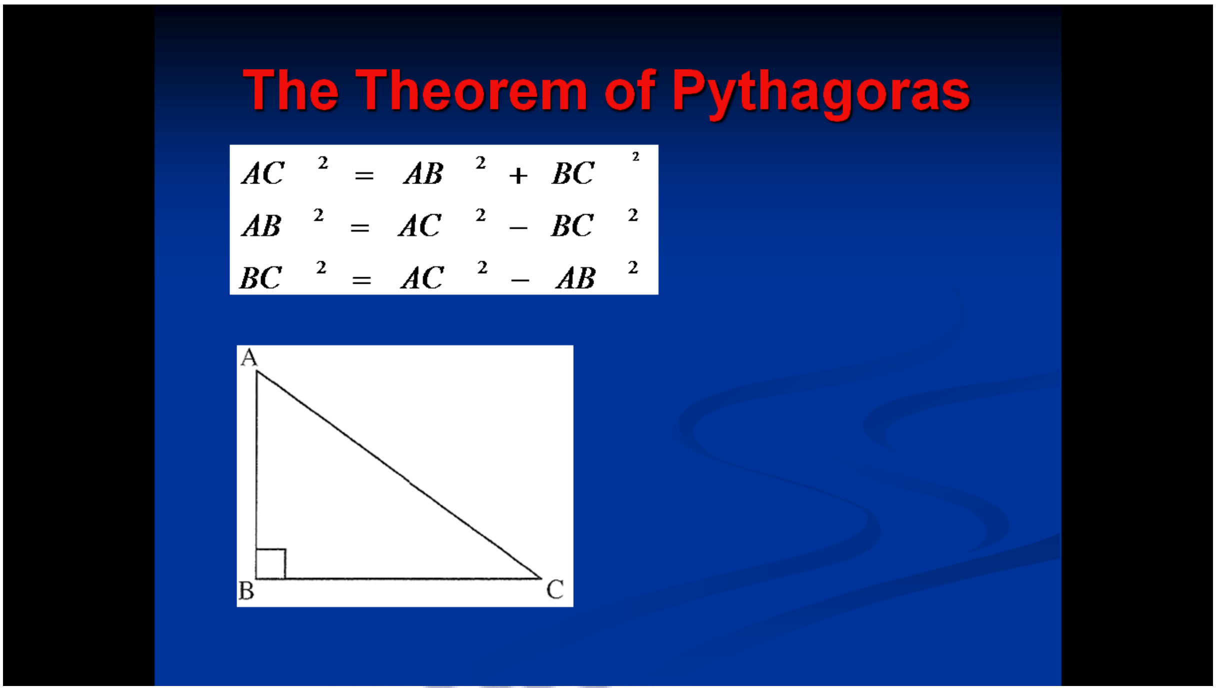

Figure 12: Shows how to use calculations to find a resultant vector

To find a resultant vector you may either use a construction like in figure 11 or calculations like in figure 12. The teacher explained perpendicular vectors in calculations using figure 12. This resultant needed Pythagora's theorem.

Representation 6: YouTube

To emphasise the issue of resultant the teacher allowed learners to view a YouTube clip of athletes running a marked field as shown in figure 13. He instructed the learners to work out the resultant of the athletes at different positions, i.e. between the first corner and the second corner, between the second corner and the third corner and between the third corner and the first corner. They did the activity using construction and calculations with the guidance of the teacher. One learner asked whether one should observe the path to the end to decide on how much distance was actually covered. The response to the question was that the path will always be shown and the length of the path will be given. When learners were watching the YouTube they realised that participants can be on the same sport from the same starting point but, depending on the paths chosen, they will have different distances but the same displacements from the starting points. A good example was a case of two athletes who ran on the field taking the paths shown below both running to position B.

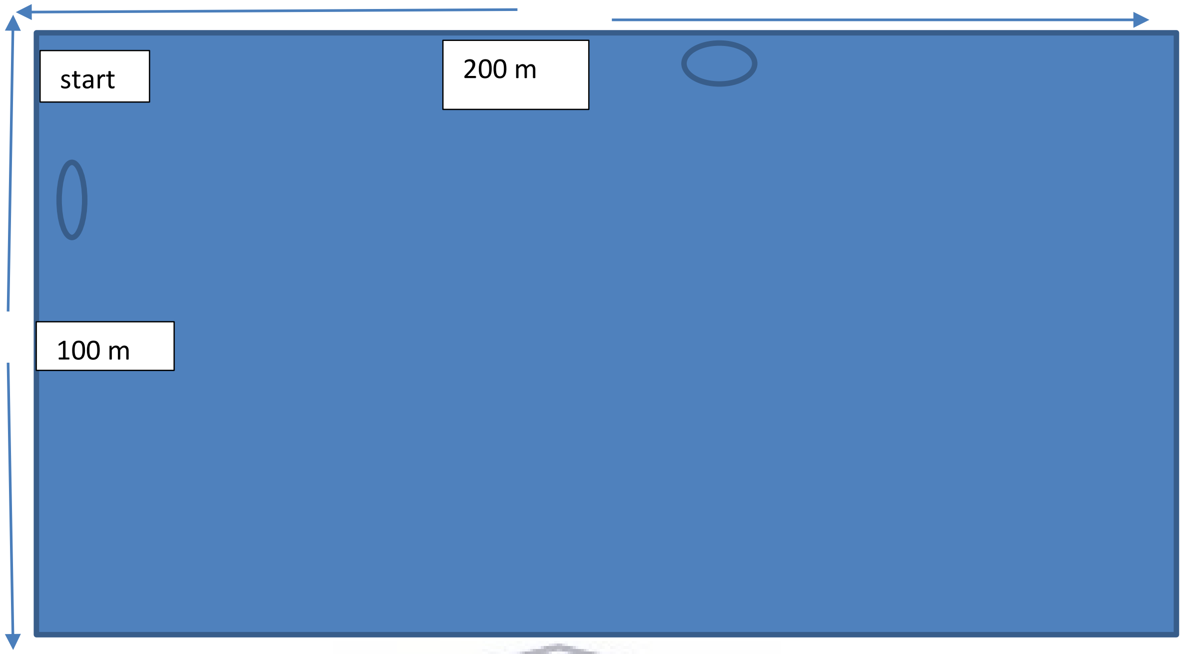

Figure 13 Representation of vectors using a YouTube clip.

Representation 7: Learner demonstration

The teacher let learners demonstrate in the class what they have observed in the YouTube clip. The learners were allowed to run around the class. They were stopped on positions that corresponded to the positions that they observed in the YouTube clip. Figure 14 shows representation of the learners running.

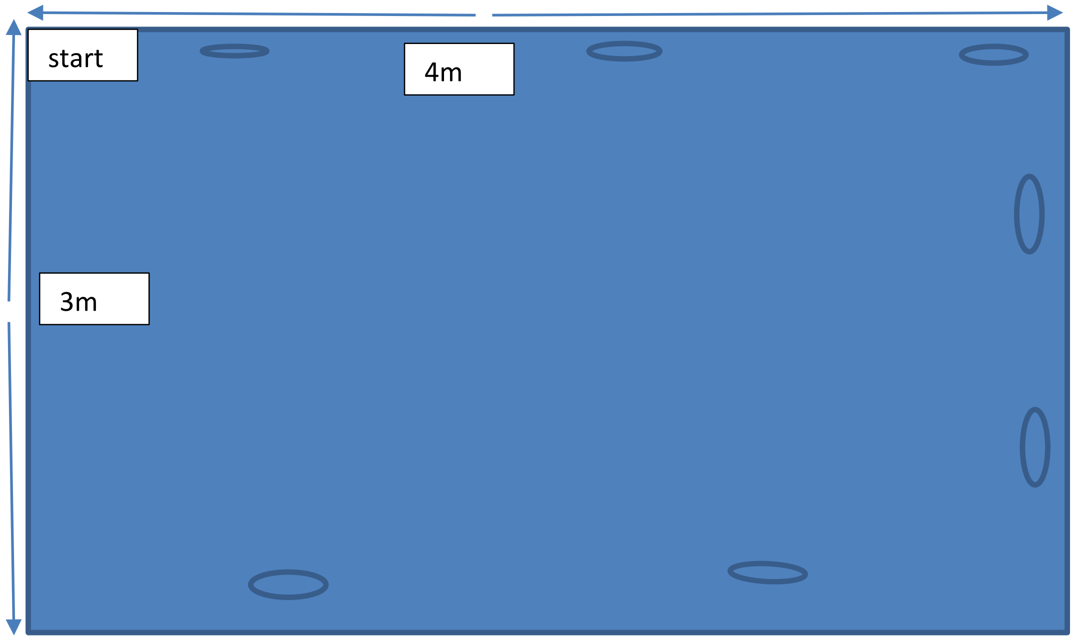

Figure 14: Representation of learners running in the class

Learners would calculate both displacement and velocity using their various positions and times. Learners realised that when they were stationary in the same position from the starting point in their 'stops and goes' their displacements and times were the same. This meant that their velocities were the same. One learner asked, "If velocity is a speed with a direction, why do you have a non-zero velocity when you are stationary?" The learner further asked, "How come that though some learners were fast and some were slow that we have the same velocity?" This learner conceded that the only clear representation to her was the construction because there was no fast and slow arrow.

More discussion had to be held on the confusion brought by terms: slow, fast, stationary, towards the house and towards the tree. From these three representations (simulations, YouTube clip and learner demonstration) these terms were bringing more confusion to vectors. Both the constructions and calculations made a lot of sense to learners because they would see the individual vectors, the final positions and the total time taken to get to those positions. This meant that though the teacher was not prepared to bring more concepts into the basics of vectors he had to introduce the concepts like instantaneous velocity and average velocity. Instantaneous velocity focuses on speed and direction at a specific point. This means that even though your displacement from the starting point might be towards the tree the instantaneous velocity might be away from the tree. Without doubt these representations caused confusion in terms of the signs as in the example below:

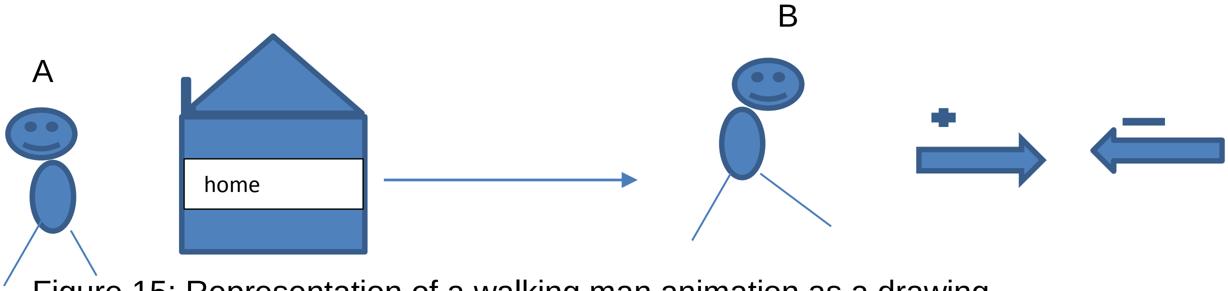

Figure 15: Representation of a walking man animation as a drawing

In figure 15 above towards the right is positive and towards the left is negative. In position A the man's displacement from home is negative but at position B the man's displacement from home is positive. These positive and negatives are irrespective of the direction of motion of the man. If we relate the velocity and displacement, we conclude that the sign of the velocity should be the same as that of the displacement. This was explained nicely with the use of construction and there were no confusions. But when it comes to simulations, YouTube and learner demonstration the direction of the motion of the man was important when dealing with velocity. This is so because when dealing with velocities you deal with aeroplanes and ships. You cannot say the ship's velocity is eastwards while in fact the ship is moving westwards. This is a case even though we can agree that the displacement of the ship is westwards (with respect to the starting point). This whole thing made real life vectors and book based vectors not to link according to some students. One learner said, "I like the construction and calculations for my understanding because they do not have any tricks. You simply calculate or construct the resultant displacement and you divide your answer with time and you get your velocity." She further continued to say, "even the direction is easy because you take the direction of the displacement."

At the end of the body of the lesson learners were given an activity to consolidate what they had learnt. The teacher also tried to clear out some misconceptions. Multiple Representation proves to improve understanding but it may create confusion. This improvement of understanding and creation of confusion were evident in the lesson. The activities were discussed and solutions were given. The activities were on basic terms, drawing and calculations based on vectors (including resultant vectors). The use of Multiple Representations for the class left the teacher with uncertainty around interpretation of vectors.

Step 3: Conclusion of the lesson

As conclusion the teacher reinforced the lesson with oral questions and summarised the main aspects of the lesson. At the end of the question session the educator gave the learners a few questions to answer at home by giving an exercise from the prescribed textbook.

4.2.1.3 What was learners' understanding of vectors after the Multiple Representation lessons?

In order to examine perceptions of learners on Multiple Representations learners were given a post-test. Tables showing question-by-question analysis were constructed followed by a table and graph showing the overall performances in the post test. The following tables show the findings from the pre-test in the form of question by question analysis. For the test questions refer to appendix C. Each question was analysed in the form of a table that shows ratings as well as the percentage of learners in a rating.

(i) Question 1 analysis

Question 1 was based on basic concepts and basic vector identification. This question was mostly based on level I of Bloom's taxonomy. Bloom's taxonomy describes the cognitive levels for learners. When question papers are set the examiners these cognitive levels. This level is about knowledge. The question expected learners to recall. Recalling includes defining, listing, identifying and recognising. Table 11 shows the performance of learners in question 1 in the post-test.

Table 11: Table showing question one learner performance in the post-test: rating and percentage of learners

Rating	Percentage of learners
1	0
2	6
3	7
4	15
5	10
6	13
7	50

From table 11 the majority of learners fell in level 7. A total of 50% of learners are in this level. 13% of the learners fell in ratings 1 to 3. The majority of learners could recall which includes define, list, identify and recognise. There were a few misconceptions. For example, learner [1] defined a negative vector in question 1.1.5 of appendix C as “a vector that is going to the left” just as learner [6] defined a positive vector as a vector going to the right in the pre-test. The whole of question 1.2 posed no challenges to the majority of learners.

(ii) Question 2

Question 2 focussed on construction vectors where learners used the mathematical instruments where necessary. Mostly this part was skill based since learners had to demonstrate their ability to use mathematical instruments. This question was mostly based on levels II III and IV of Bloom’s taxonomy. Here learners were expected to comprehend, apply and analyse scientific knowledge. Table 11 shows the performance of learners in question 2 in the post-test

Table 12: Table showing question two learner performance in the post-test: rating and percentage of learners

Rating	Percentage of learners
1	13
2	2
3	0
4	6
5	5
6	20
7	54

Table 12 shows that the majority of learners fell in level 7 in the question. More than half the number of learners fell in this level. A total of 79% of learners scored above level 4. Only a total of 15% of the learners scored below 5%. This means learners can construct vectors satisfactorily including the complicated ones.

(iii) Question 3

This question was mostly based on levels II III and IV of Bloom's taxonomy. Here learners were expected to comprehend, apply and analyse scientific knowledge. Learners had to calculate and construct vectors. The constructions in question 3 were of a higher order than those in question 2. Learners had to manipulate more than one vector in each sub-question because they were dealing with resultant vectors.

Table 13: Table showing question three learner performance in the post-test: rating and percentage of learners

rating	Percentage of learners
1	4
2	4
3	2
4	11
5	8
6	18
7	53

Table 13 shows that an equal number of learners (about 25%) fell in level 1 and level 2. No learners went up to level 6. About 50% of the learners scored below 40%. These learners could not calculate or construct vectors satisfactorily even the basic ones. 7% of learners managed to score above 49% in the test. The performance of learners in question 3 was not very different from their performance in question 2 though they performed better in question 3 than in question 2. Most learners could not find the resultant by construction but at least they could calculate. Most learners could find the resultant by both calculations and construction.

(v) Question 4

This question was mostly based on levels IV, V and VI of Bloom’s taxonomy. Here learners were expected to comprehend, apply, synthesise, analyse and evaluate scientific knowledge. Learners had to calculate and construct vectors. Unlike question 3, this question expected learners to analyse statements since the questions were presented in words.

Table 14: Table showing question one learner performance in the post-test: rating and percentage of learners.

Rating	Percentage of learners
1	36
2	10
3	12
4	5
5	5
6	35
7	0

Table 14 shows that 36% of learners fell in level 1. No leaners went up to level 4. A total of 45% of the learners achieved above 3. In the 55% of learners that achieved below level 4, 22% achieved between level 2 and 3. The majority of learners could interpret word equations. Some had a problem dealing with the resultant of simultaneous vectors.

(vi) Overall performance

24 learners participated and they were marked. Their post-test marks were grouped and recorded in the table below. The data was also represented in the form of a bar graph.

Table 15: Table showing the overall performance of learners in marks in the post-test

Number of learners	Mark ranges
2	0→9
2	10→19
3	20→29
6	30→39
5	40→49
3	50→59
2	60→69
1	70→80

Table 15 shows that only five learners scored in the range of 0-19 marks in the pre-test. These learners scored less than 24% in the test. The percentage of the learners in this bracket is about 21% of the test participants. The next nine learners scored in the range 20-39 marks. This translates to about 38% of the participants who scored between 25% and 49% in the test. A total of 14 learners scored on a range of 0-39 marks. This means less than 60% of participants scored below 50% in the test. A total of ten participants scored above 50% in the range 40-80 marks. This translates to about 42% of participants who scored above 50% in the test. Of the 10 participants in the range 40-8, three of them scored in the range 60-88. This translates to more than 10% of participants who score above 75% in the test. Of the three participants who scored above 75% in the test one of them scored above 80. There was a significant improvement in the performance of participants in vectors after the intervention lesson.

Deeper analysis of results by percentage of learners in the lowest ranges and in the highest ranges as in table16 shows clearly where Multiple Representations is most effective and where Multiple Representation is not so effective.

Table 16: Table showing question by question analysis against Bloom's taxonomy for the pre-test and the post-test

Question	Bloom's taxonomy Level	Percentage range of performance	Percentage of learners that performed in each range in the pre-test	Percentage of learners that performed in each range in the post-test	difference	Comment
1	I Knowledge	0-39	31	6	-25	Positive
1	I Knowledge	70-100	1	63	+62	Positive
2	II-IV Comprehension Application Analysis	0-39	65	15	-50	Positive
2	II-IV Comprehension Application Analysis	70-100	0	70	+70	Positive
3	II-IV Comprehension Application Analysis	0-39	50	0	-50	Positive
3	II-IV Comprehension Application Analysis	70-100	0	71	+71	Positive
4	IV- VI Analysis Synthesis Evaluation	0-39	82	46	-36	Positive
4	IV- VI Analysis Synthesis Evaluation	70-100	0	35	+35	Positive

Comparing the pre- and post-test there is a general decrease in the percentage of learners who scored in the percentages 0-39% and an increase in those who scored 70-100%. Questions 1 and 4 show the lowest difference of -25% and -36% respectively in percentages of learners who scored in the range 0-39%. Questions 2 and 3 show the highest difference of -50% of learners who scored in the range 0-39%. This shows that generally the most reduction in percentages of learners who scored in the range 0-39% was questions 2 and 3. The least reduction in percentage of learners who scored in the range 0-39% was in question 1. The reduction in question 4 was above question 1 but below questions 2 and 3. In questions 2 and 3 there is the highest difference of +70% and +71% respectively in percentages of learners who scored in the range 70-100%. This means an increase in the percentage of learners who can apply scientific knowledge and those that can comprehend. For question 1 learners who scored in the range of 70-100% increased by 62%. The least increase in percentage of learners who scored in the range 70-100% was in question 4 at +35%. However, not all the learners showed improvement with the use of Multiple Representations. Though the number of learners in the range 0-39% has decreased, there are still learners who got marks in this range in the post-test.

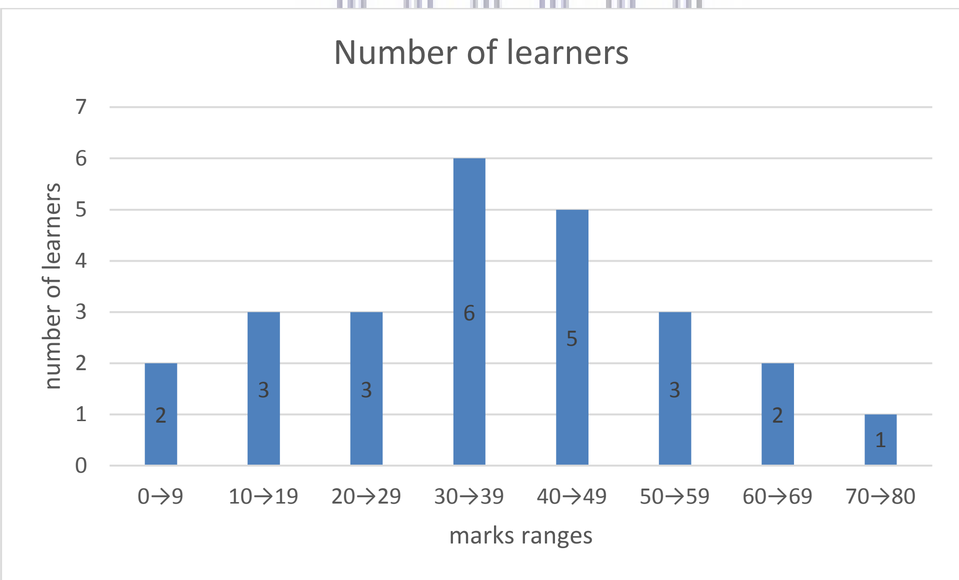

Figure 18: Graph showing the marks learners got in the post-test

The graph above shows results from table 15. The horizontal axis shows the marks in ranges whilst the vertical column shows the number of learners that belong to each range of marks. The total for the test was 80 marks. Most learners got in the range of 30-49 marks in the post-test. The number of learners in this bracket is 11 which constitutes 45.8% of the test participants. Unlike the pre-test results only eight learners got below 29 marks. This translates to about 33 % of the participants. These are the only learners who got below 40% in the test.

4.2.1.4 What was the perception of learners on the use of Multiple Representations to learn vectors in Grade 10 Physical Sciences?

i) Questionnaire

Learners were given questionnaires to fill as individuals. Learners were expected to complete the questionnaire over the weekend. All of the learners had the questionnaire with the same themes, same items and same Likert scale. Their responses were collected and recorded on a spread sheet. The actual numbers of learners we converted into percentages for analysis. Below is a figure that shows their responses in percentages.

I. Interest

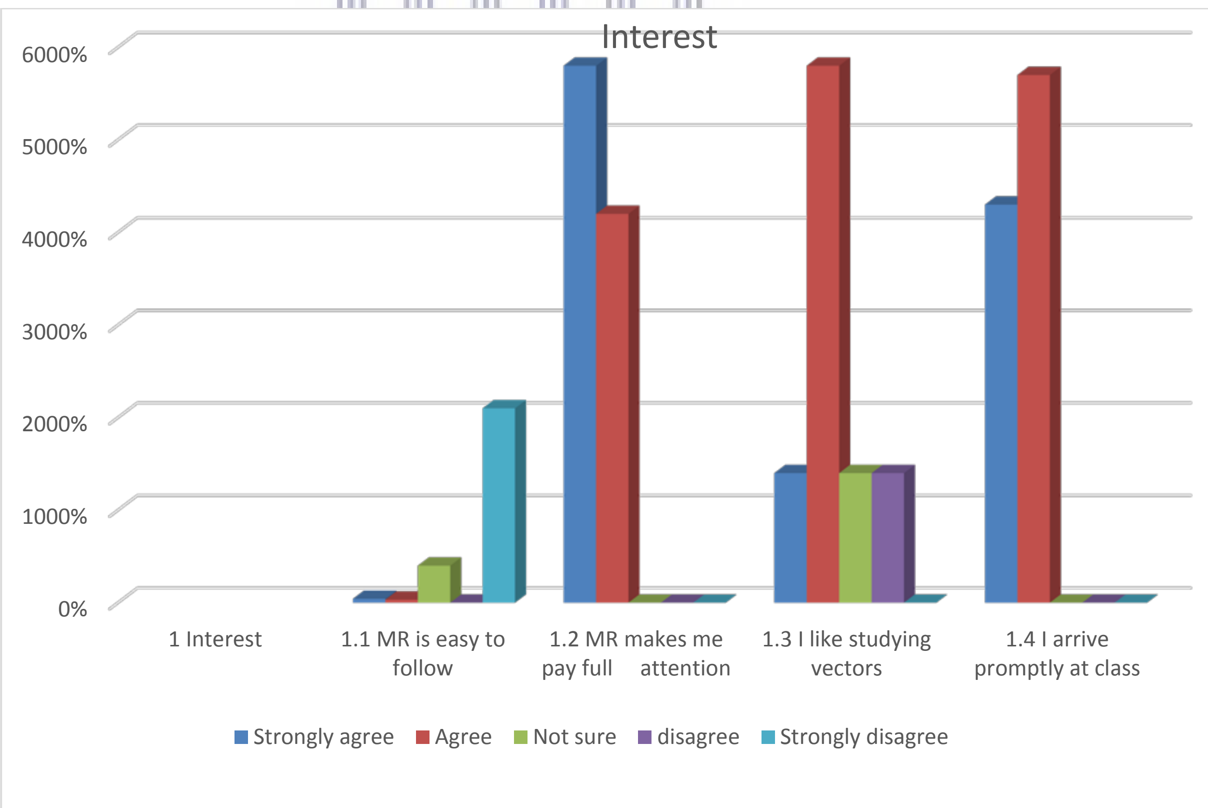

Figure 17: A graph showing results of learners' interest in Multiple Representations

The figure above shows that 75% of responses highlighted that Multiple Representations is easy to follow. This 75% is composed of 42% of participants who strongly agreed that Multiple Representations is easy to follow. However, 21% strongly disagreed. All the learners agreed that Multiple Representations make them more attentive. 58% of those strongly agreed. 72% of learners agreed that they like vectors with 14% of them strongly agreeing that they love the subject. However, 14% of participants were not sure that they love vectors while 14% disagreed that they loved vectors. All the participants agreed that they arrive promptly in class. 43% of those participants strongly agreed that they arrive promptly in class.

II. Confidence

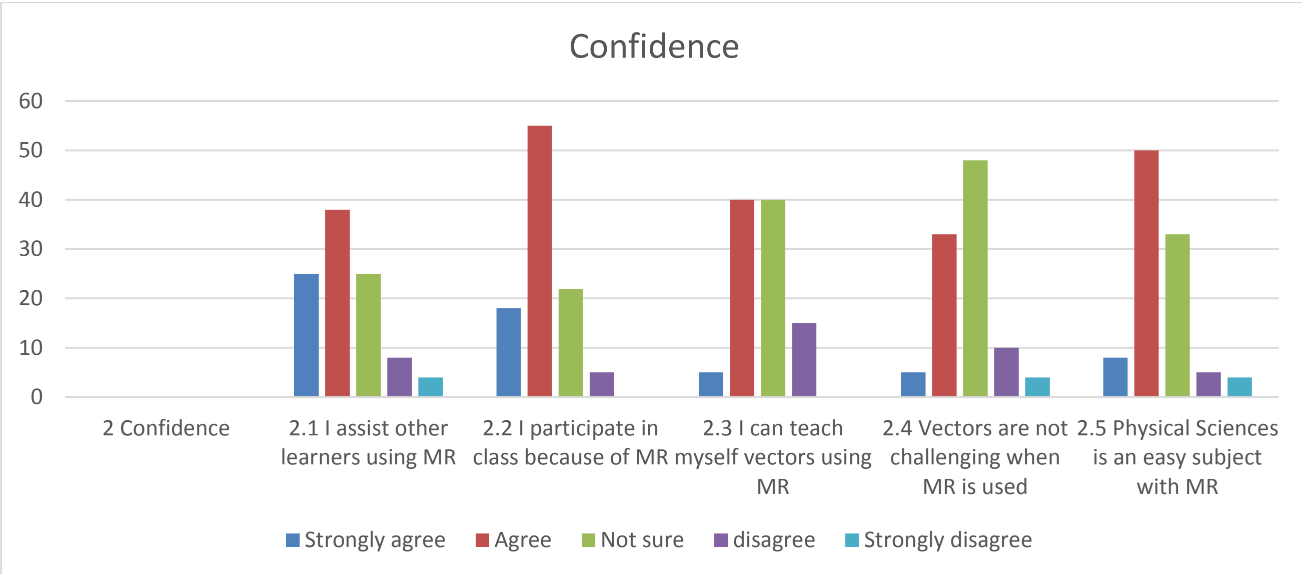

Figure 18: A graph showing results of learners' confidence due to use of Multiple Representations

63% of participants were confident that they can assist other learners using Multiple Representations. 12% of participants disagreed that they can assist other learners using Multiple Representations. 4% strongly disagreed that they can assist other learners. 73% of learners agreed that Multiple Representations improves participation in class. However, 5% strongly disagreed that Multiple Representations improves participation in class. Just less than 50% of participants were confident that they can teach themselves using Multiple Representation. 40% were unsure while 15% disagreed that they can teach themselves using Multiple Representations. The majority of learners were not sure that vectors are not challenging. 38% of participants agreed that vectors are not challenging. 14% of participants felt that vectors are challenging and 4% of the participants felt strongly that vectors are challenging. About 58% of participants felt that Physical Sciences is an easy subject when Multiple Representations was used. However, 33% were unsure while 9% disagreed.

III. Appropriateness of Multiple Representations

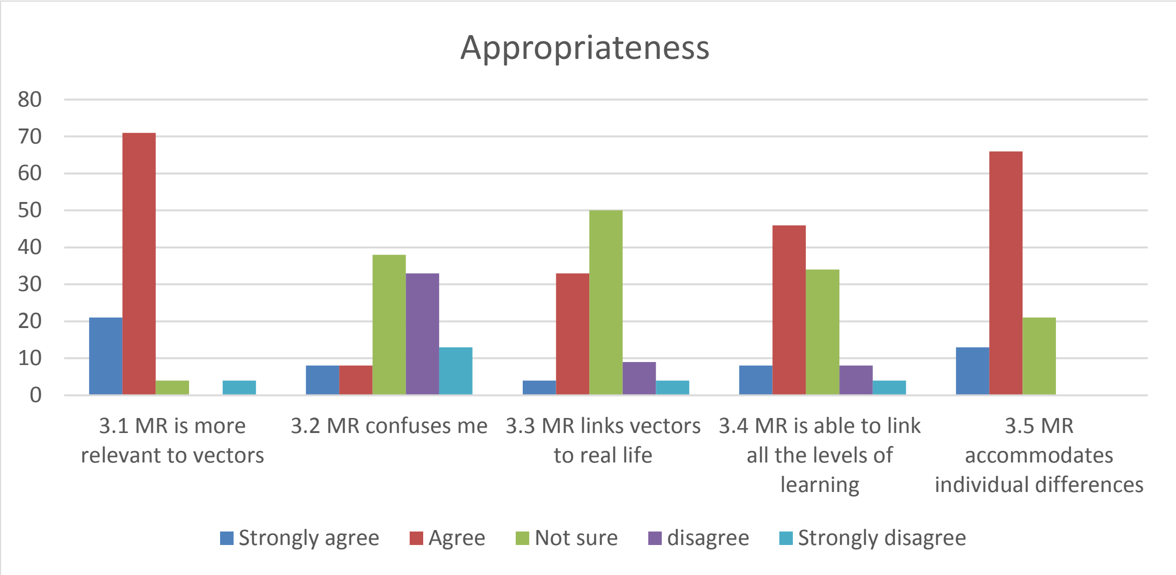

Figure 19: A graph showing results of appropriateness of the Multiple Representations to leaners

The graph above shows that more participants agree that Multiple Representations is more relevant to vectors and that Multiple Representations accommodates individual differences at about 70% and 65% respectively. But more learners are not sure if Multiple Representations links vectors to real life. More than 30% of learners disagree that Multiple Representations confuses them with just below 40% of learners not being sure whether Multiple Representations confuses them. More than 10% of participants feel that Multiple Representations confuses them. 92% of participants (agree and strongly agree) agreed that Multiple Representations is more relevant in the teaching and learning of vectors. Only 4% disagreed while 4% of participants were unsure. Only 16% felt that Multiple Representations confused them while 38% of the participants were unsure. 49% of participants felt that Multiple Representations did not confuse them. 37% of participants highlighted that Multiple Representations linked vectors with real life. However, 50% were unsure if Multiple Representations linked vectors with real life and 13% disagreed that Multiple Representations linked vectors with real life. 54% of participants highlighted that all levels of knowledge are linked when teaching or learning through Multiple Representations. 12% disagreed while 34% of participants were unsure. The majority of participants (79%) felt that teaching and learning through Multiple Representations caters for individual differences with 21% being unsure. No participants disagreed with that.

IV. Attitude of learners towards and towards multiple representations

The graph below analyses the attitude of learners towards Multiple Representations

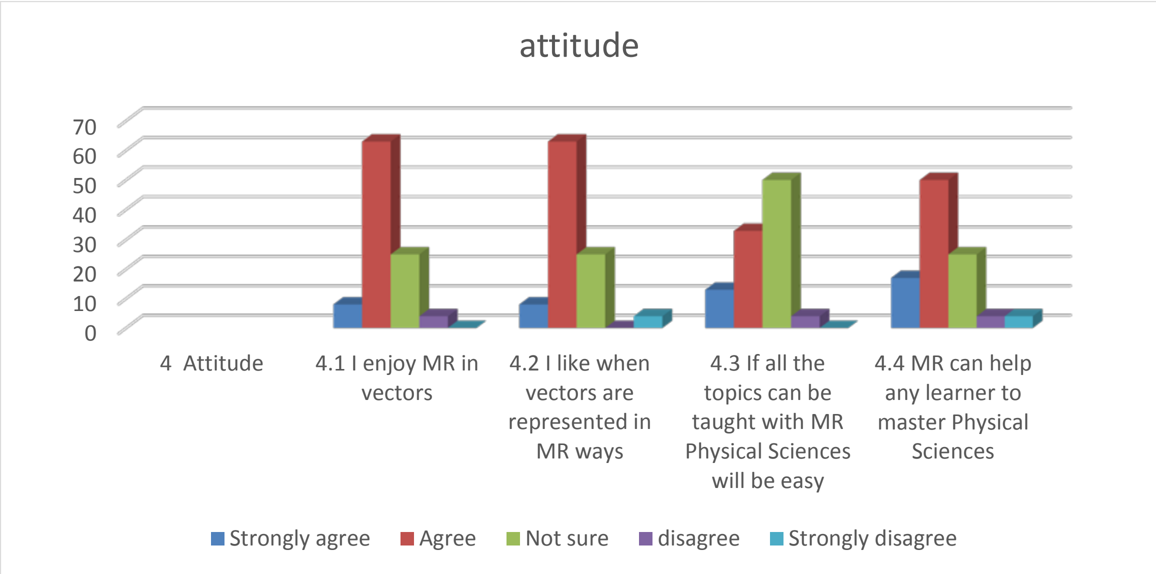

Figure 20: A graph showing results of learners' attitude towards the use Multiple Representations in teaching vectors.

71% of participants highlighted that Multiple Representations makes them enjoy Physical Sciences. 4% of the participants disagreed while 25% were unsure. 71% of participants liked vectors when Multiple Representations was used. 4% of participants disagreed that they liked vectors when Multiple Representations was used. 49% of participants agreed that Multiple Representations can be used in other topics while 50% of participants were unsure. Only 4% disagreed that Multiple Representations can be used in the teaching and learning of other topics. 67% of participants highlighted that Multiple Representations could help them master Physical Sciences. 25% were unsure while 4% strongly disagreed.

ii) Interviews

Learners were interviewed in groups of four learners each. All of the groups were asked the same questions. Their responses were recorded. The data was transcribed, translated and cleaned. Below are some of their responses.

During the interview learners indicated that vectors are challenging. One learner indicated that:

Vectors are not easy because you need to understand the language, calculations, drawing and operating instruments. I get confused when I have to construct and calculate resultant vectors. [FI_1, L5] (Focus group Interview 1, Learner 5)

During the interviews learners indicated that the lessons using Multiple Representations were presented in more interesting and challenging ways which improved their understanding of the concepts dealing with vectors. One of the learners indicated:

I found the new way of lesson presentation using different information to make sense of the topic more interesting. If I can be given another test on vectors I cannot get less than 80% because the new method made the meaning of 'distance' and 'displacement very clear. [FI_1, L1]

During the interview learners indicated that Multiple Representations develop confidence in vectors: One of the learners indicated:

I did not feel confident when I was writing the test because I did not understand the vectors when they were taught in words and calculations only, now I have a lot of confidence that if we can be given another test I will get all the questions correct.

[FI3, L4]

During the interview learners indicated that Multiple Representations complement each other to improve and deepen understanding and to develop many problem solving strategies. One learner indicated that:

I am not good with calculations but the new way of representing vectors has made me to understand construction of resultant and I can now easily use Pythagoras theorem after constructions. *[FI4 L1]*

Cognitive flexibility theory highlights the ability to construct and switch between multiple perspectives of a domain as fundamental to successful learning (Spiro & Jehng, 1990). Dienes (1973) argues that perceptual variability (the same concepts represented in varying ways) provides learners with the opportunity to build abstractions about mathematical concepts. It also can be the case that insight achieved in this way increases the likelihood that it will be transferred to new situations (Branford & Schwartz, 1999). This all agrees with my findings that the representations complement one another.

During the interview learners indicated that Multiple Representations improves their achievement scores in vectors. Two learners indicated that:

After the vector were represented in different way all the question that were in the test seem very easy and I hate that I got such a low mark in the pre-test. The reason I missed them is that I am not good with calculations but now I can combine construction with Pythagora's theorem to find the resultant vector. [FI2 L4]

I got less than 25% in the first test, which was so bad because the test was really difficult. The second time we wrote, I did pass, I got 63% and I was fine. Maybe the way you taught us is the one that made me to cope. [FI2 L3]

During the interviews learners indicated that the lessons using Multiple Representations were presented in more interesting and challenging ways which improved their understanding of the concepts dealing with vectors. A learner indicated:

I found the new way of lesson presentation using different representations to make sense of the topic more interesting. That is why in the second test on vectors I got more than 80%. The new method made the meaning of 'distance' and displacement very clear. [FI3 L1]]

During the interview learners indicated that Multiple Representations develop confidence in vectors: One of the learners indicated:

I did not feel confident when I was writing the test because I did not understand the vectors when they were taught in words and calculations only, now I have a lot of confidence that if we can be given another test I will get all the questions correct.

[FI2 L1]*]*

During the interview learners indicated that Multiple Representations complement each other to improve and deepen understanding and to develop many problem solving strategies. One learner indicated that:

The calculation and the use of the simulation helped me understand better because as the man was going towards home again the simulation showed a negative value which made it easier to see how the value decreases as the vector moves backwards from the front. The calculations made it even clearer. [FI1 L1]

4.3 Comparing the pre- and post-tests results

The pre-test was designed to guage the level of understanding of vectors by learners. The post-test, on the other hand, was designed to show the impact of the intervention using Multiple Representations on the understanding of vectors by the learners. The results of the performance of learners in the pre-test and the post-test are tabulated below. Tables 16 and 17 show the marks and percentages respectively that learners obtained in the pre-test and the post-test.

Table 17: Table showing the numbers of learners in the marks ranges for the pre-test and the post-test

Marks ranges	Pre-test	Post-test
0→9	7	2
10→19	6	2
20→29	5	3
30→39	4	6
40→49	1	5
50→59	1	3
60→69	0	2
70→80	0	1

Table 18: Summary in percentages for pre-test and post test

Percentage range	Percentage of learners in the pre-test	Percentage of learners in the post--test	Difference
0-39	63	29	-34
70-100	4	25	+21

As shown in table 18 the pre-test shows how learners performed before they were exposed to Multiple Representations. The performance of the learners in the pre-test shows that learners lacked understanding of vectors before Multiple Representations was used. No learners got above 59 marks and the majority of learners obtained marks in the range of 0-19. In the post-test, however, there was a lot of improvement in that the learners' marks went up to the range 70-80. In the post-test the majority of learners got marks in the range 30-49 marks. Table 14 summarises the picture in percentages by focussing on the differences between the performance in the pre-test and the post-test in the ranges 0-39 and 70-100. It is clear that there was a general decrease in percentages of learners in the range 0-39% and an increase in the percentage of learners in the ranges 70-100. This shows that Multiple

Representations improved the level of understanding of vectors by learners for all the cognitive levels as proposed by Bloom.

4.4 Examining the results in terms of Bloom's levels

Table 19: Question by question analysis against Bloom's taxonomy difference between the performances in the pre-test and the post-test

Question	Bloom's taxonomy level	Percentage range of performance	Percentage of learners that performed in each range in the pre-test	Percentage of learners that performed in each range in the post-test	Difference	Comment
1	I Knowledge	0-39	31	6	-25	Positive
1	I Knowledge	70-100	1	63	+62	Positive
2	II-IV Comprehension Application Analysis	0-39	65	15	-50	Positive
2	II-IV Comprehension Application Analysis	70-100	0	70	+70	Positive
3	II-IV Comprehension Application Analysis	0-39	50	0	-50	Positive
3	II-IV Comprehension Application Analysis	70-100	0	71	+71	Positive
4	IV- VI Analysis Synthesis Evaluation	0-39	82	46	-36	Positive
4	IV- VI Analysis Synthesis Evaluation	70-100	0	35	+35	Positive

Each question represented a level of Bloom's taxonomy as shown in table 18. Question 1 was on basic concepts and basic vector identification. The question expected learners to recall, define, list, identify and recognise. Question 2 focussed on construction vectors where learners used the mathematical instruments where necessary. Mostly this part was skill based since learners had to demonstrate their ability to use mathematical instruments. Question 3 required learners to comprehend. Learners had to calculate and construct vectors. The constructions in question 3 were of a higher order than those in question 2. Learners had to manipulate more than one vector in each sub-question because they were dealing with resultant vectors. In question 4 learners had to comprehend. Learners had to calculate and construct vectors. Unlike question 3 this question expected learners to analyse statements since the questions were presented in words.

In the pre-test the majority of learners performed in the percentage range of 0-39 in all the questions. However, the percentage of learners in this range was lowest in question 1. Comparing the pre- and post-test there is a general decrease in the percentage of learners who scored in the percentages 0-39% and an increase in those who scored 70-100%. This shows a generally positive response of learners towards Multiple Representations. Questions 1 and 4 show the lowest difference of -25% and -36% respectively in percentages of learners who scored in the range 0-39%. Questions 2 and 3 show the highest difference of -50% of learners who scored in the range 0-39%. This shows that generally the most reduction in percentages of learners who scored in the range 0-39% was questions 2 and 3. The least reduction in percentage of learners who scored in the range 0-39% was in question 1. The reduction in question 4 was above question 1 but below questions 2 and 3. This shows that Multiple Representation was most effective for those learners who already had a certain level of skills and comprehension. This further shows that Multiple Representations was more effective for those learners who were already at the highest level of thinking than those who were at the lowest level of thinking.

In questions 2 and 3 there is highest difference of +70% and +71% respectively in percentages of learners who scored in the range 70-100%. This means an increase in the percentage of learners who can apply scientific knowledge and those that can comprehend. This again shows that Multiple Representation was most effective for acquiring and application of skills and comprehension. For question 1 learners who scored in the range of 70-100% increased by 62%. Again this one shows that Multiple Representations is more effective for enabling learners to define, recall, recognise, define, list and identify. The least increase in percentage of learners who scored in the range 70-100% was in question 4 at +35%. This shows that Multiple

Representation could not help learners to analyse, comprehend, evaluate and apply scientific knowledge.

However, not all the learners showed improvement with the use of Multiple Representations. Though the number of learners in the range 0-39% has decreased, there are still learners who got marks in this range in the post-test. This shows that not all learners responded positively to the implementation of Multiple Representation. There are no clear reasons to the researcher for some learners to lack improvement after the use of Multiple Representations. One of the possible reasons, according to the researcher, might be the confusion that various representations might bring to learners' level of motivation. The confusion, lack of interest and motivation can be based on how the teacher implemented Multiple Representations and how the researcher integrated the concepts of motivation and development of interest in learners in the lessons.

4.5 Implementation of Multiple Representation in class

Learners really enjoyed multiple presentations and made them participate fully. The teacher found Multiple Representations to be very interesting as he had to use various ways of representation. This use of various representations was quite challenging because it needed a lot of creativity and time management from the side of the teacher. The majority of learners were so involved in the intervention and some were excited with the use of Multiple Representations The fact that learners were excited during the MR indicates that the learning environment was stimulating for learners hence it inspired them to learn science. Dhurumraj (2013) argued that a stimulating environment inspires learners to learn. This resulted in a lot of improvement in performance after the intervention as shown by the post-test outcomes. They asked a lot of interesting questions. These are examples of the questions that learners asked:

> Why is the velocity 0 at the position as shown in the simulations? [learner 1]
> *It shows that the person is stationary (not moving) [teacher]*
>
> But why is the displacement not 0? [learner 1]

The displacement will only be 0 if the object has gone back to the starting point. [teacher]

Some learners did not show much improvement though. If I were to do the research again I would reduce the number of representations in one intervention and either use only the ones that are similar or only the ones that show real variety in representations. This would depend on the learners' performance in the pre-test. Similar representations tend to help learners master a concept if it is asked in a 'one sided manner' but it restricts learners to that one side of understanding of a concept. Representations that tend to look contradictory tend to confuse learners but it makes them flexible. An example is words, tables and graphs. Words and tables tend to complement each other but words and graphs tend to contradict.

Not all learners improved after the intervention and the possible cause is the confusion that a combination of representations for one concept may bring. This confusion can be caused by lack of creativity on the side of the teacher to relate the representations. Multiple Representations is an interesting approach to use in teaching learners; however, it must be done in a manner that may not end up confusing learners. This can be achieved in various ways including minimising the number of representations for one concept or grouping representations that are not likely to look contradictory to learners. To manage the class, I kept learners involved in activities. I would ask questions and allow them to ask questions.

4.6 Learners' perceptions

From the interviews the learners did not have the same perceptions about the use of Multiple Representations and vectors. Some learners found Multiple Representations very interesting while some learners found Multiple Representations confusing. The majority of learners agreed that vectors are challenging. The possible reason for vectors to be challenging is that most of our learners have poor mathematical skills and the bigger part of vectors need mathematical manipulations. During the interview learners indicated that vectors are challenging. Learner 1 indicated that:

Vectors are not easy because you need to understand the language, calculations, drawing and operating instruments. I get confused when I have to construct and calculate.

It is clear here that despite all efforts made by the researcher some learners still found it very difficult to understand vectors.

4.7 Coincidental issues

Multiple Representations is influenced by the level of knowledge that already exists in the learner. Motivation and interest came up as a coincidental issue. Learners complained that their educators were the reasons that they lacked base for sciences. Blame was for example apportioned to educators who were teaching other subjects or other grades as well.

4.8 Conclusion

This chapter looked at the detailed analysis of results of the research. The researcher analysed the data from the five instruments: the pre-test, the intervention, the post-test, the questionnaire and the interview. The next chapter will be looking at detailed discussion of the findings. The chapter further provided the findings and a discussion of the findings. The following chapter will provide a summary and conclusions drawn from the research.

Chapter 5

Summary and conclusions

5.1. Introduction

The previous chapter focussed on the discussions of the findings. In this chapter the researcher will look at the summary and conclusions. Each chapter will be summarised. This will be followed by recommendations, limitations of the study and conclusions of the study

5.2. Overview of the scope of the thesis

5.2.1. Introduction to the study

The study is about the use of Multiple Representations to teach vectors in Grade 10. The study was conducted by a well experienced teacher who has taught in poor deep rural areas for more than 13 years. The school where the research was conducted is also a poor, deep rural school. Learners perform very poorly in higher order questions in Physical Sciences. Problem-solving questions, scientific enquiry questions and application based questions seem to pose even more problems for learners. The district where the researcher did his research performs below both the provincial and national average in Physical Sciences. Some of the general problems that cause the district to perform poorly in the subject are: Shortage of suitable and skilled teachers for the subject, and lack of resources and lack of motivation on the side of learners in relation to learning the subject. The rationale for the study was based on the effectiveness of Multiple Representations in improving learner performance in Physical Sciences. This was motivated by the continued underperformance in the subject in Grade 12. Some topics seem more challenging to learners than others. Not only the content in those topics is to blame but the teaching strategies pose a lot of challenges to learners. The problem of poor performance in South Africa calls for improved teaching strategies among other things. Positive perceptions generally improve understanding and performance of learners in a subject. The researcher is looking at various representations to help improve learner understanding. Different ways to represent vectors may improve learner understanding if they are done carefully.

5.2.2. Literature Review

This chapter outlined the theoretical framework that underpins the study. It also looked at the relevant literature that supports and elucidates the study. This study is underpinned by the theory of constructivism and pedagogical content knowledge. The theory of constructivism emphasises the importance of existing knowledge before learners can construct new knowledge.

Pedagogical content knowledge makes the transformation of disciplinary content into forms that are accessible and attainable by students possible. This includes knowledge of how particular subject matter topics, problems, and issues can be organised, represented, and adapted to the diverse interests and abilities of learners and presented for instruction. It distinguishes the teacher from the content specialist. Teacher's personal class experience plays a big role in pedagogical content knowledge.

A lot of literature was reviewed in dealing with vectors and multiple representations. This literature combined local and international literature. There was a special focus on the recent literature on the topic. Multiple Representations was simply defined as the many ways in which physical concepts and situations can be communicated. Some representations can be in the learners' minds and some in the learners' environments. Generally what teachers use in class represent the representations in the learners' environment. Abstractions and mathematical concepts are built with multiple ways of representing scientific knowledge. Multiple representations commonly supports learning of complex scientific topics. To maximise the benefit of multiple representations a person must consider the use of a minimum number of representations in a topic, carefully assessing the skills intended for learners, sequencing representations, identification of whether learners need additional help relating the representation to the domain and the pedagogical functions the multiple representational system is designed to support. Representing the same concepts in varying ways support the construction of deeper understanding.

5.2.3 Methodology

A sample consisting of 45 Grade 10 learners from a total of 160 Grade 10 Physical Sciences learners participated in the study. Both the quantitative and qualitative data were collected and analysed. Learners were first given a pre-test to establish their initial understanding of vectors. This pre-test was followed by an intervention in the form of a lesson. The lesson was conducted in order to expose learners to learning through Multiple Representations. A post-test was then administered to determine the impact of the intervention. To gather and quantify the learners' perception on the use of Multiple Representations in teaching and learning of vectors in Grade 10 Physical Sciences learners were given questionnaires to complete. The last step was interviewing of learners to triangulate the results from the three instruments

5.2.4 Findings

The study found that that learners were struggling with understanding of vectors and their perceptions towards vectors were negative. The study also found that Multiple Representations can improve understanding and develop positive perception of learners towards the teaching and learning of vectors. This improvement only occurs if Multiple Representations is used correctly. The study further found out that the use of Multiple Representations does not guarantee improvement and in understanding of vectors as other factors may affect learner understanding as well as interest in vectors.

5.2.5 Discussion

The literature that was reviewed shows that Multiple Representations can drastically improve both the interest in vectors and understanding of vectors by learners. The literature, however, suggests that improper use of Multiple Representations may confuse learners in understanding vectors. The literature further suggests that Multiple Representations may even limit deeper understanding by learners. The findings by the researcher agree with the literature used as it also came out from the research that interest and understanding of vectors improves with the use of Multiple Representations. This came from the results obtained from the instruments. Because of the level at which the research was used by the researcher, he could not establish if the use of Multiple Representations may block deeper understanding of learners in vectors. The researcher suggests that Multiple Representations should not be used blindly. Any person who wants to use it must first establish which areas Multiple Representations will fit best and which representations fit best in line with the cognitive levels as suggested by Bloom's taxonomy. The proper use of Multiple Representations would be to connect what is in the learners' minds with what is in their environments. Multiple representations include the following: simulations, videos, dynamics, graphs and practical work amongst other things and each representation plays an important role in motivating learners and improving their understanding.

5.3. Major findings of the study

(i) The pre-test highlighted that learners had very limited understanding of vectors when they were taught using the traditional talk-and-chalk method. This includes how to define them, how to represent them, calculations, and constructions based on vectors (refer to section 4.2.1).

(ii) The implementation of Multiple Representations as a teaching strategy allowed participation and understanding by learners at different cognitive levels. PowerPoint presentations, box and arrows, simulations, scale drawing, calculations, YouTube and learner demonstrations were used as representations (see section 4.2.2). Representations need to allow complementary information or complementary processes. An example of this is when you use a scenario of changing quantities and quantities that do not change. Using numerical representation for values that do not change and a table for values that change made a lot of sense. Learners seemed to enjoy the different representations as there was an increased discussion and interaction in the lesson. Previously learners would only respond and ask questions when prompted to do so.

(iii) Learners showed a lot of improvement after the use of Multiple Representations. The results of a post-test in section 4.2.3 show that using different representations generally helped learners improve on understanding of vectors. This is evident in their performance in question by question and in their overall performance as shown in sections 4.2.3.1 to 4.2.3.4

(iv) Learners were exposed to interviews and they were given questionnaires to fill. The interviews were based on the pre-test, intervention and post-test.

From their responses it shows clearly that there was an improvement in interest and learners developed confidence to participate in class, to teach themselves using Multiple Representations and to even assist other learners. Learners felt that Multiple Representations made them enjoy vectors. Even though there were still some learners that indicated that they were not convinced of their improved understanding of vectors, there was a greater level of involvement of learners and discussion in groups regarding the topic.

5.4. Implications of the study

Learners from other schools who are doing the same topic could also benefit from the approach. If there is a benefit of the approach then teachers teaching the subject in the same school may benefit. In my capacity as a deputy principal who is a curriculum head I could also advise other teachers who are doing other subjects from my school to adopt the approach for the benefit of their learners.

Subject advisors, university lecturers, private tutors and other education stakeholders may benefit from the approach in their own fields. These stakeholders will benefit if they view the approach as being of benefit to them and they implement it. The implications are summarised below:

1. The study has implications for fellow physical science teachers as it provided an example of the application of Multiple Representations. It could be used as a guide for other science teachers on how to use this approach.
2. The MR approach in this study demonstrated that learners' achievement generally improves as they are allowed to see a topic through different lenses or representations. It provides a greater perspective for learners to understand or to interrogate the topic under discussion. This has implications for education department officials like curriculum advisors who can advise science teachers based on this study how to approach challenging areas of the curriculum.
3. The study also has implications for writers of science textbooks on how to use different representations and how it could be used

effectively. The study also cautions writers on areas where learners can become confused if too many representations are used.

4. This study provides baseline data for further studies using multiple representations as a teaching approach. This is especially relevant in rural areas where schools do not always have the necessary resources to provide too many representations.

5.5 Limitations of the study

The research was a case study. Only one school was involved in the research. This means the findings might not necessarily be used in other contexts. For example, the school was a poor rural school and circumstances in the school might be different from those of a school in town.

In a school of more than 500 learners doing Physical Sciences 24 Grade 10 learners were involved in the research. The 24 learners were chosen from a population of about 200 Grade 10 learners. If more learners were involved in the research more ideas and opinions might have come up.

The questionnaire was piloted in the neighbouring school. Only one set of learners was used for the piloting of the questionnaire. Other instruments were not piloted. This means an extensive pilot test that couldn't be done to cover most of the possibilities.

The topic was dealt with before without the use of Multiple Representations. The Grade 10 learners come from different junior secondary schools. This means not all learners that were involved in the research had the same background on the topic that was dealt with. This could have influenced their responses, their understanding and their perceptions in both Multiple Representations and vectors.

As it is stated in the background, the school in which the research was conducted is a school in a deep rural area of the former Transkei. The learners here predominantly use isiXhosa as a home language. This isiXhosa has many dialects within itself. Physical Sciences is taught in English and this may pose a problem to the learners who are doing English as first additional language and not a home language. This could have affected both the understanding of the learners and their responses.

The learners were given a pre-test before the intervention and a post-test after the intervention. Each test was given only once. The results from one test might not be reliable.

5.6 Recommendations for future research

The research was a case study which means only one school was involved. The context was a poor deep rural school. In future more schools could be involved. The schools may be chosen based on set criteria which would give more reliable results. For example, rural and urban schools could be chosen for the research.

The intervention was based on one topic, vectors. The intervention could be extended to other topics in Grade 10 Physical Sciences. Other grades and even other subjects could be exposed to this approach. A bigger number of learners could be involved in the study and more schools could be involved.

5.7 Conclusion

This chapter outlined an overview of the scope of the study, summary of the results and findings discussed in chapters 4 and 5, implications pertaining to the study, conclusions drawn as well as recommendations for future studies.

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APPENDICES

APPENDIX A: PRE-TEST

INSTRUCTIONS

. Leave one line between two sub-questions, for example, between QUESTION 4.1 and QUESTION 4.2.

The formulae and substitutions must be shown in ALL calculations.

. Round off your answers to TWO decimal places where applicable.

.

QUESTION 1

1.1 Define the following terms:

1.1.1	scalar	(2)
1.1.2	displacement	(2)
1.1.3	speed	(2)
1.1.4	positive vector	(2)
1.1.5	equal vectors	(2)

1.2 Differentiate between:

1.2.1	A temperature of -25°C and a temperature of 25°C	(4)
1.2.2	a -10 m.s^{-2} acceleration and a temperature of -36°C.	(4)
1.2.3	+3 N and -3 N	(4)
		/22/

Question 2

2.1 Represent the following graphically:

2.1.1 10 N in the direction 300° (4)

2.1.2 25 N in the direction 240° (4)

2.1.3 30 N at 110° (4)

2.2 What is the value of the following:

2.2.1 3kg + 7kg (2)

Question 3

3.1 Determine the following by calculations and graphical representations:

3.1.1 4N East + 3N West

(5)

3.1.2 5N East and 3N North

(5)

3.1.3 10 N and 15 N if the angle between them is 70° (no calculations)

(5)

Question 4 (use graphical representations)

4.1 A tourist pushes his car with a force of 40 N north and then 30N west to locate a petrol pump at the filling station. Find his resultant force. (5)

4.2 A car travels 30 km, south, and then 13 km at 270°. Determine the resultant displacement using a scale drawing. (5)

4.3 A ship steams at a distance of 110 km in a direction of 45° E of N while the ocean current displaces it 50 km to the east. Determine the resultant displacement graphically. (5)

4.4 An aircraft undergoes a displacement of 60 km at 60° due to the crosswinds while actually wanting to fly in an easterly direction. Determine the easterly and northerly displacement components which could have caused the resultant displacement.

(5)

4.5

4.5.1 Define a resultant vector. (2)

4.5.2 In a scale of 10mm: 20 N, explain the meaning of this ratio. What will be the length of line representing a force of 140 N? (2+2)

APPENDIX B

Lesson plan for vectors in Grade 10

1. PRE-KNOWLEDGE:

Learners need understanding of the following:

I. Definitions of a vector and a scalar
II. Examples of vectors and scalar and representing vectors
III. Define, calculate and draw a resultant vector

QUESTIONS for the **BASELINE ASSESSMENT**

i) Define a vector quantity

ii) Give two examples of a vector quantity and two examples of a scalar quantity

iii) Write the symbolic representation of a speed and velocity

iv) Write down the meaning of a resultant vector

c) **Do corrections**

i) A vector is a physical quantity with magnitude and direction

ii) Vectors: Force and acceleration , Scalar : time and distance

iii) Speed (v) and velocity ($\vec{v}$)

iv) A resultant vector is a combined effect of a number of vectors

2. He explains **displacement** as a change in position in a straight line.

- He uses figure 1 below to show the difference between distance and displacement.
- He then uses arrows and boxes to show the vector nature of the motion (arrows to the left or to the right).
- Demonstrates with a video from YouTube

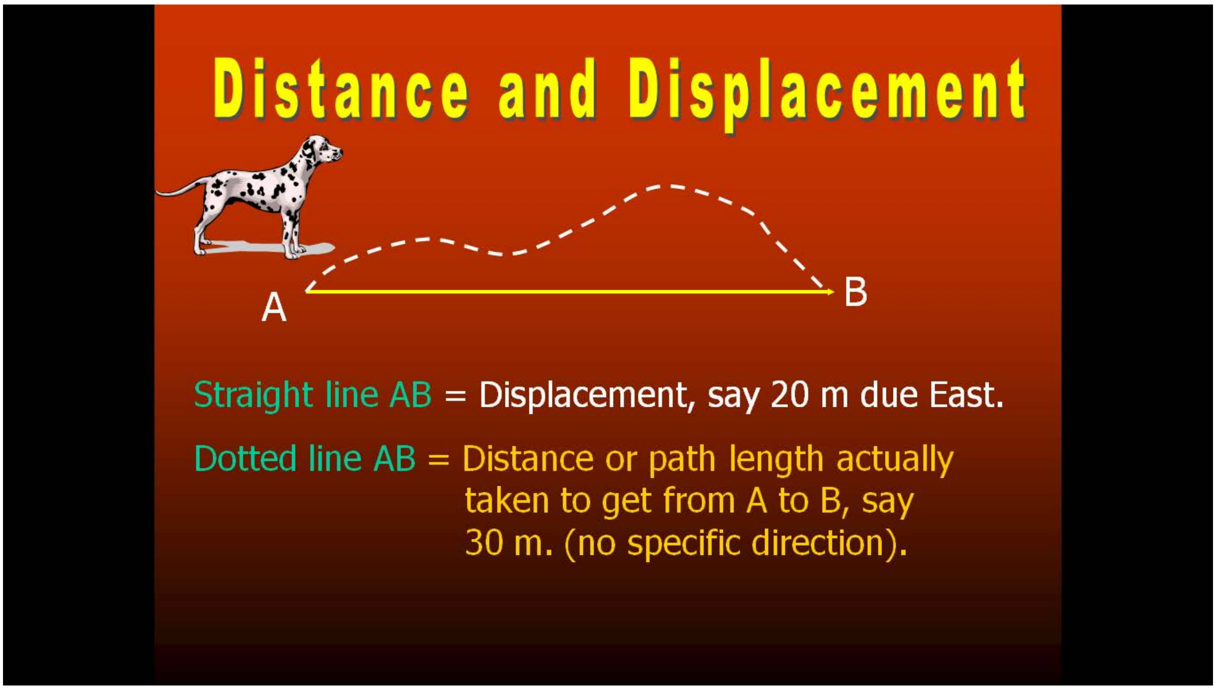

Figure 1: Displacement and distance

- He further shows simulations for the motion of the block and how to represent a resultant. This is shown in figure 3.

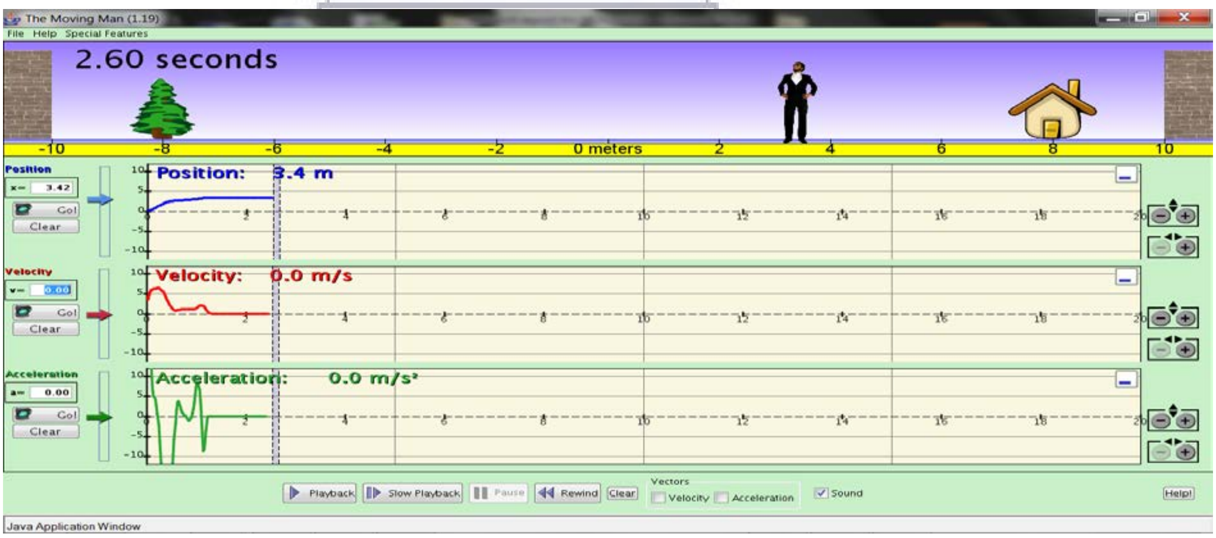

Figure 3: Distance and displacement, vectors and scalars, and resultant using a simulation of a walking man.

Figure 3 shows a simulation of a walking man on top. Below the walking man there are graphs of displacement versus time, velocity versus time and acceleration versus time.

A vector is a physical quantity with magnitude and direction. Symbols for vectors are typed on bold letters or with an arrowhead above the symbol. e.g. $\vec{v}$, $\vec{F}$ and $\vec{a}$.

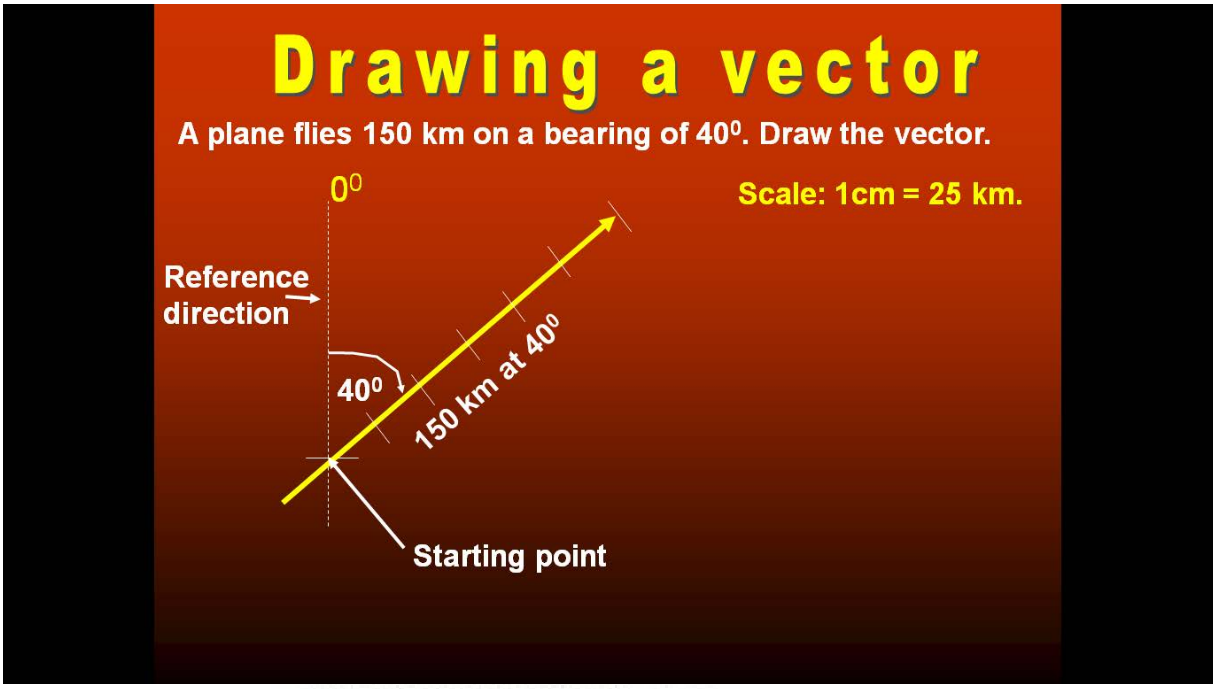

Figure 4: How to represent a vector

The teacher demonstrates vectors by using arrow drawing and simulations as shown in figure 3 and figure 4.

3. **The educator introduces a resultant vector** as a combined effect of a number of vectors. He demonstrates it practically and uses a YouTube video.

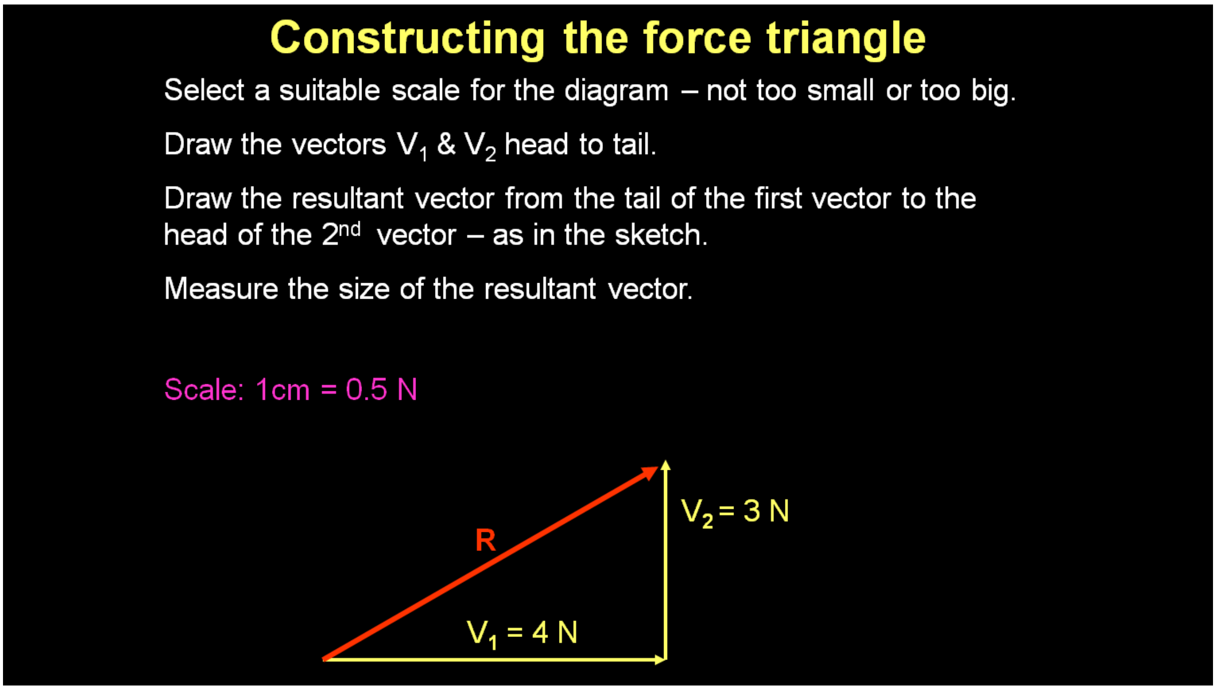

Figure 5: Shows how to find a resultant vector using a tail to head method (a triangle method)

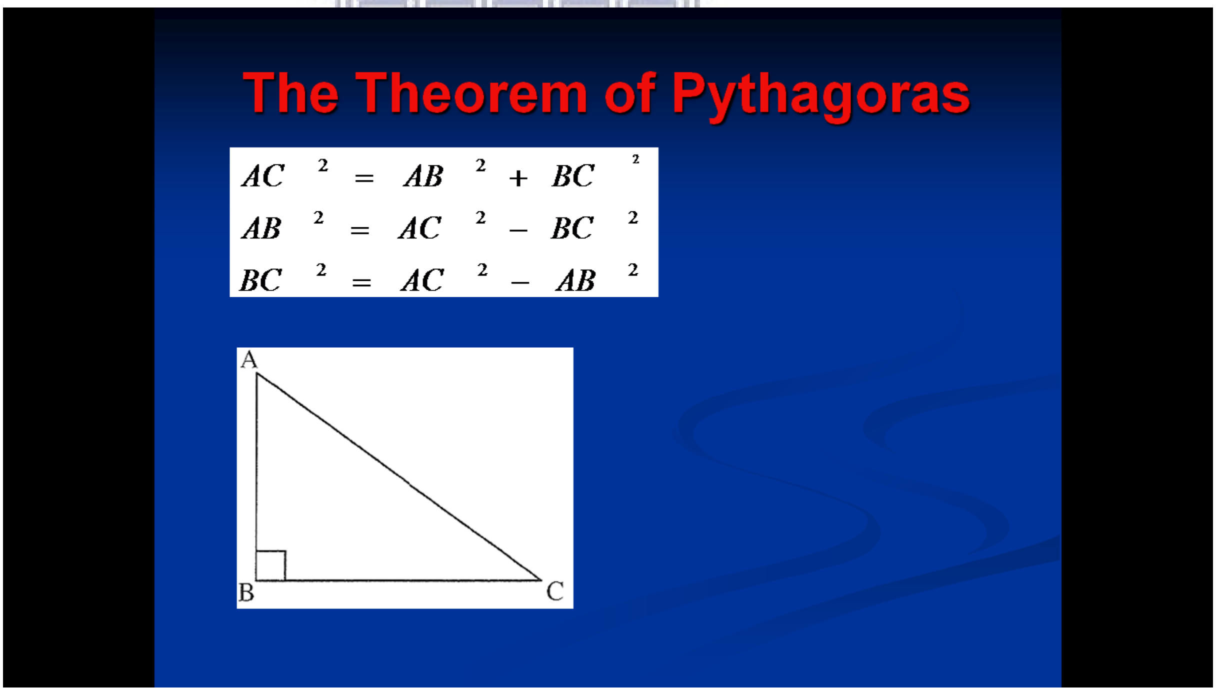

Figure 6: Shows how to use calculations to find a resultant vector

To find a resultant vector you may either use a construction like in figure 5 or calculations like in figure 6.

4. **Vector nature of forces is explained by the teacher**

A force can be in the direction of motion or in a direction against the motion. If a direction of the force is not given in the question, it is advisable not to include it in the answer. The safer way would be to write forward or backwards, in the direction of motion, in the direction opposite the direction of motion, etc. A question that asks for the magnitude of a vector, e.g. calculate the magnitude of velocity, requires the answer to be a magnitude, without a direction. Examples of contact and action-at-distance (non-contact) forces are listed in the table below.

Contact forces and non-contact forces

CONTACT	NON-CONTACT
Applied force	Gravitational force
Tension force	Magnetic force
Drag force	Electrostatic force
Normal force	
Spring force	
Frictional force	

The forces are represented by blocks and arrows. Learners are allowed to play with simulations to show the directions of forces and the net force on an object.

A scalar is a physical quantity with magnitude only, e.g. t, m and v . These symbols are for time, mass and speed respectively.
m = 3 kg , t = 32 s and D = 33 m. If a question asks for a scalar, don't attach a direction to the answer.

Learners' activities 10 min
2.2.1 What is the difference between $\vec{F}$ and F?

2.2.2 On two different occasions during a high school soccer game, the ball was kicked simultaneously by players on opposing teams.

Case 1: one player kicks it and the opposing team stops it.

Case 2: a player kicks it and the opposing team kicks it back.

In which case (Case 1 or Case 2) does the ball undergo the greatest acceleration? Explain your answer.

2.2.3 What is meant by the contact forces? Give three examples.

2.2.4 What is the sum of all forces acting on an object called?

B: reaction force

C: acceleration

D: net force

2.2.5 In a tug of war, when one team is pulling with a force of 100 N and the other 80 N, what is the net force?

A: 20 N

B: 80 N

C: 100 N

D: 180 N

Corrections [7 min]

3. Conclusion

Activity to re-enforce lesson (Educator summarises the main aspects of the lesson). [**5 min**.]

HOMEWORK QUESTIONS/ACTIVITY (educator gives learners a few questions to answer at home by giving an exercise from the prescribed textbook) [30 min]. All the questions will be shown through simulations in class.

APPENDIX C

POST-TEST

INSTRUCTIONS

. Leave one line between two sub-questions, for example between QUESTION 4.1 and QUESTION 4.2.

The formulae and substitutions must be shown in ALL calculations.

. Round off your answers to TWO decimal places where applicable.

.

QUESTION 1

1.1. Define the following terms:

1.1.1. vector (2)

1.1.2. distance (2)

1.1.3. velocity (2)

1.1.4. force (2)

1.1.5. negative vector (2)

1.2. Differentiate between:

1.2.1. A temperature of -36°C and a temperature of 36°C (4)

1.2.2. a -10N of a force and a temperature of -36°C. (4)

1.2.3. +3 $m.s^{-2}$ and -3 $m.s^{-2}$ (4)

Question 2

2.1. Represent the following graphically:

2.1.1. 25 N in the direction 225 (3)

2.1.2. 30 N in the direction 270° (3)

2.1.3. 60 N at 100° (3)

2.2. What is the value of the following:

2.2.1. 3kg + 4kg (1)

Question 3

3.1 Determine the following by calculations and graphical representations:

3.1.1 3N East + 4N West (5)

3.1.2 3N East and 4N North (5)

3.1.3 13 N and 25 N if the angle between them is 70° (no calculations) (5)

Question 4 (use graphical representations)

4.1 A tourist pushes his car with a force of 30 N north and then 40 N west to locate a petrol pump at the filling station. Find his resultant force. (4)

4.2 A car travels 20 km south, and then 12 km at 270°. Determine the resultant displacement using a scale drawing (4)

4.3 A ship steams at a distance of 100 km in a direction of 30° E of N while the ocean current displaces it 50 km to the east. Determine the resultant displacement graphically. (4)

4.4 An aircraft undergoes a displacement of 50 km at 30° due to the crosswinds while actually wanting to fly in an easterly direction. Determine the easterly and northerly displacement components which could have caused the resultant displacement.

(4)

4.5

4.5.1 Define a resultant vector (2)

4.5.2 In a scale of 1cm : 20 N, Explain the meaning of this ratio. What will be the length of line representing a force of 130 N? (2+2)

APPENDIX D

QUESTIONNAIRE

	Strongly agree	Agree	Not sure	disagree	Strongly disagree
1 Interest					
1.1 MR is easy to follow					
1.2 MR makes me pay full attention					
1.3 I like studying vectors					
1.4 I arrive promptly at class					
2 Confidence					
2.1 I assist other learners using MR					
2.2 I participate in class because of MR					
2.3 I can teach myself vectors using MR					
2.4 Vectors are not challenging when MR is used					
2.5 Physical Sciences is an easy subject with MR					
3 Appropriateness of MR					
3.1 MR is more relevant to vectors					
3.2 MR confuses me					
3.3 MR links vectors to real life					
3.4 MR is able to link all the levels of learning					
3.5 MR accommodates individual differences					
4 **Attitude**					
4.1 I enjoy MR in vectors					

4.2 I like when vectors are represented in MR ways					
4.3 If all the topics can be taught with MR, Physical Sciences will be easy					
4.4 MR can help any learner to master Physical Sciences					

APPENDIX E

Interview Schedule: Ngwane Maxhoba

<u>Interview questions</u>

School :___________________________________

Code :____________________________________

Age :___________________________________

Sex :___________________________________

Grade :___________________________________

Years in Grade 10 :___________________________________

<u>Interview questions</u>

1. Do you think doing Physical Sciences can help you achieve your goals in life? Explain.
2. Which topics in Physical Sciences challenge you the most?
3. Would you categorise vectors as a challenging topic in Physical Sciences? Explain.
4. What made you not to get 100% in the pre-test?
5. In our lesson we presented vectors in Multiple Representations. Was it valuable to you? Explain.
6. Has Multiple Representations improved your confidence? Explain.
7. Do you feel Multiple Representations have improved your level of attention in class?
8. Have Multiple Representations changed your attitude towards Physical Sciences lessons? Explain.
9. Do you think Multiple Representations are relevant to learning Physical Sciences?
10. In what ways do Multiple Representations accommodate you as an individual in the class?
11. What would improve your performances in tests generally?
12. Would you prefer one type or Multiple Representations for your learning of vectors? Why?

University of the Western Cape
Faculty of Education, Private Bag X17, Bellville, South Africa

APPENDIX F:

Background information sheet

Dear Sir/Madam,

My name is Maxhoba Ngwane, Masters Student in the Education Department of the School Science Maths Education at the University of the Western Cape. I am conducting research on the use of Multiple Representations to teach vectors in Physical Sciences in Grade 10.

Research Title: The use of Multiple Representations to teach vectors in Physical Sciences in Grade 10.

The research study is guided by the following research question/s: What are the perceptions of learners on the use of Multiple Representations to teach vectors in Grade 10 Physical Sciences?

The research participants will comprise Grade 10 Physical Sciences learners. Data collection will be in the form of tests, questionnaires and interviews. Participation in this study is voluntary. Participants have the right to withdraw from the research at any stage of the research process without having to give any explanations. Participants are guaranteed utmost confidentiality regarding all information collected from them. Pseudonyms or a system of coding will be used to protect their identity. Should you wish to find out more about the research, you are welcome to contact my supervisor, Professor Hartley, whose contact details are provided below or indeed me.

Yours sincerely

Researcher: Mr. Ngwane Maxhoba Supervisor: Prof. Shaheed Hartley
Contact number: 0797940745 Tel. 021-9592680
Email: maxngwane@gmail.com Email: shartley@uwc.ac.za

Signature of the researcher: ………………………….. Date:……………………………

University of the Western Cape

Faculty of Education, Private Bag X17, Bellville, South Africa

APPENDIX G: PERMISSION LETTER

THE EASTERN CAPE EDUCATION DEPARTMENT (ECDoE)

X Secondary School
Stepping Stone Weg
7550
Durbanville

The Research Director
Eastern Cape Education Department
P/B X 0032
Bisho
5605

Dear ________________

Re: Permission to conduct research at X School

My name is **Ngwane Maxhoba,** a Masters student in Science Education Department in the SSE of the Faculty of Education at the University of the Western Cape. I would like to request your permission to interview learners in grade 10 in Physical Sciences in one of the schools in Libode district.

I am conducting research on the application of Multiple Representations to teach vectors in grade 10 physical sciences. The target group will be Grade 10 Physical Sciences learners, in the FET Phase.

The research will not interfere in any way with the functioning of the school or with learning in the classroom. In addition, participation will be voluntary and so participants will be free to withdraw at any time without giving reasons should they feel uncomfortable with my research. Their participation in the study will remain anonymous. Information received as part of the study will be used for research purposes only. It will not be used in any public platform for any purposes other than to understand how the application of Multiple Representations will be used teach vectors in Grade 10 Physical Sciences class.

Should you wish to find out more about the research, you are welcome to contact my supervisor, Professor Hartley, whose contact details are provided below or indeed me.

Yours sincerely

Researcher: Mr. Ngwane Maxhoba   Supervisor: Prof. Shaheed Hartley
Contact number: 0797940745   Tel. 021-9592680
Email: maxngwane@gmail.com   Email: shartley@uwc.ac.za

Signature of the researcher: ………………………….. Date:……………………………

University of the Western Cape

Faculty of Education, Private Bag X17, Bellville, South Africa

APPENDIX H: PERMISSION LETTER

THE PRINCIPAL
X Primary School
Stepping Stone Weg
7550
Durbanville

Dear ___________________

Re: Permission to conduct research in your school

My name is **Ngwane Maxhoba** a Master's student in the SSME Department of the Faculty of Education at the University of the Western Cape. I am conducting research to understand how the application of Multiple Representations will be used to teach vectors in a Grade 10 Physical Sciences class.

I would like to request your permission to interview learners to understand how the application of Multiple Representations will be used teach vectors in Grade 10 Physical Sciences class.

The research will not interfere in any way with the functioning of the school or with learning in the classroom. In addition, participation will be voluntary and so participants will be free to withdraw at any time without giving reasons should they feel uncomfortable with my research. Your participation and that of the learners in the study will remain anonymous. Information received as part of the study will be used for research purposes only. It will not be used in any public platform for any purposes other than to understand how the application of Multiple Representations will be used teach vectors in Grade 10 Physical Sciences class. Should you wish to find out more about the research, you are welcome to contact my supervisor, Professor S. Hartley, whose contact details are provided below or indeed me.

Yours sincerely

Researcher: Mr. Ngwane Maxhoba
Contact number: 0797940745
Email: maxngwane@gmail.com

Supervisor: Prof. Shaheed Hartley
Tel. 021-9592680
Email: shartley@uwc.ac.za

Signature of the researcher: …………………………….. Date:……………………………

University of the Western Cape

Faculty of Education, Private Bag X17, Bellville, South Africa

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APPENDIX I: PERMISSION LETTER

THE FET GRADE 10 TEACHER(S)
X Primary School
Stepping Stone Weg
7550
Durbanville

Dear ___________________

Re: Permission to conduct research in your Grade 10 Physical Sciences classroom

My name is **Ngwane Maxhoba** a Master's student in the SSME Department of the Faculty of Education at the University of the Western Cape. I am conducting research on to understand how the application of Multiple Representations can be used to teach vectors in a Grade 10 Physical Sciences class.

I would like to request your permission to interview learners to understand how the application of Multiple Representations can be used teach vectors in Grade 10 Physical Sciences class.

The research will not interfere in any way with the functioning of the school or with learning in the classroom. In addition, participation will be voluntary and so participants will be free to withdraw at any time without giving reasons should they feel uncomfortable with my research. Your participation and that of the learners in the study will remain anonymous. Information received as part of the study will be used for research purposes only. It will not be used in any public platform for any purposes other than to understand how the to understand how the application of Multiple Representations will be used teach vectors in Grade 10 Physical Sciences class Should you wish to find out more about the research, you are welcome to contact my supervisor, Professor S. Hartley, whose contact details are provided below or indeed me.

Yours sincerely

Researcher: Mr. Ngwane Maxhoba
Contact number: 0797940745
Email: maxngwane@gmail.com

Supervisor: Prof. Shaheed Hartley
Tel. 021-9592680
Email: shartley@uwc.ac.za

Signature of the researcher: …………………………….. Date:……………………………

University of the Western Cape

Faculty of Education, Private Bag X17, Bellville, South Africa

APPENDIX J: PERMISSION LETTER

THE PARENTS

X Primary School,

Stepping Stone Weg,

7550

Durbanville

Dear ________________

Re: Permission for your child's participation in a research

My name is **Ngwane Maxhoba** a Masters student in the SSME Department of the Faculty of Education at the University of the Western Cape. I am conducting research on to understand how the application of Multiple Representations will be used teach vectors in grade 10 physical sciences class.

I would like to request your permission to interview your child to understand how the application of Multiple Representations will be used teach vectors in grade 10 physical sciences class.

The research will not interfere in any way with his/her learning in the classroom. In addition, participation will be voluntary and so participants will be free to withdraw at any time without giving reasons should they feel uncomfortable with my research. The participation of your child in the study will remain anonymous. Information received as part of the study will be used for research purposes only. It will not be used in any public platform for any purposes other than to understand how the application of Multiple Representations will be used teach vectors in grade 10 physical sciences class

Should you wish to find out more about the research, you are welcome to contact my supervisor, Professor S. Hartley, whose contact details are provided below or indeed me.

Yours sincerely,

Researcher: Mr. Ngwane Maxhoba
Contact number: 0797940745
Email: maxngwane@gmail.com

Supervisor: Prof. Shaheed Hartley
Tel. 021-9592680
Email: shartley@uwc.ac.za

University of the Western Cape

Faculty of Education, Private Bag X17, Bellville, South Africa

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APPENDIX K:

Participants' Informed Consent Form

I agree to be part of the study and I am aware that my participation in this study is voluntary. If, for any reason, I wish to stop being part of the study, I may do so without having to give an explanation. I understand the intent and purpose of this study.

I am aware the data will be used for a master's thesis and a research paper. I have the right to review, comment on, and/or withdraw information prior to the paper's submission. The data gathered in this study are confidential and anonymous with respect to my personal identity, unless I specify or indicate otherwise. In the case of classroom observations and interviews, I have been promised that my personal identity and that of the school will be protected, and that my duties will not be disrupted by the researcher.

I have read and understood the above information. I give my consent to participate in the study.

____________________ ____________________

Participant's signature Date

____________________ ____________________

Researcher's signature Date

Study Title: The use of Multiple Representations to teach vectors in Physical Sciences in Grade 10.

University of the Western Cape

Faculty of Education, Private Bag X17, Bellville, South Africa

APPENDIX L:

Parents' Informed Consent Form

I agree that my son/daughter be a part of the study and I am aware that his/her participation in this study is voluntary. If, for any reason, I wish to stop him/her being part of the study, I may do so without having to give an explanation. I understand the intent and purpose of this study.

I am aware the data will be used for a master's thesis and a research paper. I have the right to review, comment on, and/or withdraw information prior to the paper's submission. The data gathered in this study are confidential and anonymous with respect to my son/daughter's personal identity, unless I specify or indicate otherwise. In the case of classroom observations and interviews, I have been promised that my son/daughter's personal identity and that of the school will be protected, and that my duties will not be disrupted by the researcher.

I have read and understood the above information. I give my consent for my son/daughter to participate in the study.

____________________ ____________________

Parent's signature Date

____________________ ____________________

Researcher's signature Date

Study Title: The use of Multiple Representations to teach vectors in physical sciences in grade 10.

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