

The effectiveness of applying conceptual development teaching strategies to Newton's second law of motion

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Dedication

I would like to dedicate my dissertation to my wife Helen and my children, Ernus and Mannscher. May our God and Father bless you, guide and always keep you safe in His love.

Abstract

School science education prepares learners to study science at a higher level, prepares them to follow a career in science and to become scientific literate citizens. It is the responsibility of the educator to ensure the learners' conceptual framework is developed to the extent that secures success at higher level studies. The purpose of this study was to test the effectiveness of conceptual change teaching strategies on the conceptual development of grade 11 learners on Newton's second law of motion. The two strategies employed were the cognitive conflict strategy and the development of ideas strategy.

A sequential explanatory mixed-method research design was used during this study. The qualitative data were used to elucidate the quantitative findings. The quantitative research consisted of a quasi-experimental design consisting of a single-group pre-test–post-test method. During the qualitative part of the research a phenomenological research approach was utilised to gain a better understanding of participants' learning experiences during the intervention.

The quantitative research made use of an adapted version of the Force Concept Inventory (FCI). The data collected from the pre-test were used to inform the intervention. The intervention was videotaped and the video analysis or qualitative data analysis was done. After the intervention the post-test was written by the learners. Hake's average normalised learning gain $\langle g \rangle$ from pre- to post-scores was analysed to establish the effectiveness of the intervention. The two sets of results (quantitative and qualitative) were integrated. Information from the qualitative data analysis was used to support and explain the quantitative data.

The quantitative results indicate that there was an improvement in the students' force conception from their initial alternative conceptions, such as that of an internal force. Especially the learners' understanding of contact forces and Newton's first law of motion yielded significant improvement. The *qualitative data* revealed that the understanding of Newton's second law of motion by the learners who partook in this study did improve, since the learners immediately recognised the mistakes made when confronted with the anchor concept. The cognitive conflict teaching strategy was effective in establishing the anchor concept of force which proved to be useful as bridging concept in the development of ideas teaching strategy. The data from *both datasets* revealed that the cognitive conflict teaching strategy for the initial part of the intervention was effective. It was evident that for development of the idea teaching strategy the two data sets revealed mixed results. Recommendations were made for future research and implementation of conceptual development teaching strategies.

Keywords relevant to this study are: Newton's second law of motion, teaching strategy, conceptual development, conceptual understanding, learning, cognitive learning theory,

information processing model, cognitive resources, Newton's laws of motion, Sequential Explanatory design, Force Concept Inventory (FCI).

Opsomming

Fisiese wetenskap op skool berei die leerlinge voor om wetenskap op 'n hoër vlak te studeer, 'n beroep te volg en wetenskaplik geletterd te wees. Dit is die onderwyser se verantwoordelikheid om te verseker dat die leerlinge se konseptuele raamwerk so ontwikkel is dat sukses op hoër vlakke verseker kan word. Die doel van die studie is om die effektiwiteit van konseptuele veranderende onderrig-strategieë op die konsepontwikkeling van Newton se tweede bewegingswet op Graad 11 leerlinge te toets. Die twee strategieë wat gebruik is, is die kognitiewe konflikstrategie en die ontwikkeling-van-idees-strategie.

Die sekvensieel verduidelikende gemengde-navorsingsontwerp is tydens hierdie studie gebruik. Die kwalitatiewe data is gebruik om die kwantitatiewe data uit te lig. Die kwantitatiewe navorsing het bestaan uit 'n kwasi-eksperimentele ontwerp bestaande uit 'n enkelgroep voor-toets-na-toets-metode. Tydens die kwalitatiewe deel van die navorsing is 'n fenomenologiese navorsingsbenadering gebruik om die deelnemers se leerervaring tydens die intervensie beter te verstaan.

Tydens die kwantitatiewe navorsing is 'n aangepaste weergawe van die Force Concept Inventory (FCI) gebruik. Die voortoets se data-insameling is gebruik om die intervensie uit te lig. Die intervensie is op videoband opgeneem en ontleed, of kwalitatiewe analise is gedoen. Na die intervensie is die natoets deur die leerlinge geskryf. Hake se gemiddelde genormaliseerde leerwins $\langle g \rangle$ tussen die voor- en natoets is ontleed om die effektiwiteit van die intervensie te bepaal. Die twee stelle data (kwalitatiewe en kwantitatiewe) is geïntegreer. Die inligting van die kwalitatiewe data-analise is gebruik om die kwantitatiewe data te ondersteun.

Die kwantitatiewe resultate het getoon dat daar 'n verbetering van die leerlinge se kragkonsep sedert die leerlinge se aanvanklike alternatiewe kragkonsep, soos dié van 'n interne krag, was. Dit was veral die leerlinge se begrip van die kontakkragte en Newton se eerste wet van beweging wat beduidend verbeter het. Die kwalitatiewe data toon dat leerlinge Newton se tweede bewegingswet verstaan het, aangesien hulle onmiddellik hulle foute agtergekom het wanneer hulle met die ankerkonsep gekonfronteer is. Die kognitiewe konflik-onderrigstrategie is effektief tydens die vaslegging van die ankerkonsep van krag, wat op sy beurt baie handig gebruik is as oorbruggingskonsep tydens die ontwikkeling van idees-onderrigstrategie. Die data van beide datastelle toon dat die kognitiewe-konflik-onderrigstrategie vir die aanvanklike deel van die intervensie effektief was. Dit is duidelik in die data geblyk dat die ontwikkeling-van-idees-onderrigstrategie gemengde resultate toon. Aanbevelings aangaande toekomstige navorsing en konseptuele ontwikkelingonderrigstrategie is gemaak.

Sleutelwoorde relevant to die studie is: Newton se tweede bewegings wet, onderrig strategie, konseptuele ontwikkeling, konseptuele verstaan, leer, kognitiewe leer teorie, inligtings prosseserings model, kognitiewe hulpbronne, Newton se bewegings wet, Sekwensieële verduidelikings ontwerp, Krag Konsep Register [Force Concept Inventory (FCI)].

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CHAPTER 1

ORIENTATION, MOTIVATION AND STATEMENT OF PROBLEM

1.1 INTRODUCTION

The pass rate of learners taking Physical Sciences is currently an issue of major concern nationally and internationally (Department of Education, 2010; Redish, 2006:1). Therefore, it becomes imperative to pay more attention to the teaching of Physical Sciences due to technological advancement and to supply in the labour market needs (Redish, 2006:1).

Although much research has already been conducted in science teaching that deals with the problems that learners experience with physics, educators also need to study their learners and their responses to instruction in order to understand what is happening in the classroom (Redish, 1999:1). Staver (2007) indicated that learners need a strong coherent conceptual framework in order to solve problems in Physical Sciences. It is also well known that Physical Sciences learners often form alternative conceptions before or during the learning process. To address the afore-mentioned, appropriate teaching strategies need to be applied to change the novice conceptions of learners into a scientific correct conception and, in so doing, prevent or reduce alternative conceptions, sometimes called misconceptions, from forming.

In this introductory chapter a problem statement and motivation for the research are provided, the literature is reviewed and the concepts are explained. The general research aims, specific research objectives and hypotheses for the study are provided and the method of study is discussed. A preview of the content of the dissertation is also given.

1.2 STATEMENT OF THE PROBLEM AND MOTIVATION FOR RESEARCH

Science can be considered a body of evidence that emphasises the integration of scientific inquiry and knowledge (Staver, 2007:6). Science education prepares learners to study science at a higher level, follow a career in science and become scientific literate citizens. 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 (Duit, 2007).

When one looks at the recent history of Physical Sciences Grade 12 results for the past six years during the National Senior Certificate (NSC) examinations in South Africa, the results are not very encouraging (Department of Education, 2014). The statistics for Physical Sciences accentuate the need for improved Physical Sciences education by researching learners' conceptual knowledge in South-Africa's multi-cultural environment.

The problem of poor performance in Physical Sciences is however not only restricted to South Africa. Learners around the globe seem to struggle learning Physical Sciences, more specifically the physics part thereof (Redish, 2006:1). Learners who are unable to understand physics concepts often label the subject as difficult, 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 a career in sciences (Hobden, 2005:307; Mugler, 2010:11). Redish (2006:1) stresses the importance of paying more attention to the facilitation of physics to all learners given that applicable skills are needed in an increasingly technological world and demanded in the labour market. Therefore, any country, including South Africa, can ill afford not to have enough learners entering into a Physical Sciences study field. Unfortunately the Physical Sciences curriculum is filled to capacity with limited time for learners to conceptualise difficult and related concepts such as Newton's laws of motion (Hobden, 2005:305).

Staver (2007:23) ascribes the difficulty of learning Physical Sciences to the wide range of prior knowledge, experiences, cognitive resources and interests the learners bring to the classroom. According to Staver (2007:23), educators should integrate the core body of scientific knowledge and scientific enquiring as to clarify science and its applications. He furthermore claims that teaching is aimed at the facilitation of learning and if learners fail to learn, the educator should carry part of the responsibility. This implies that educators have to be sensitive to their learners' needs and adjust their teaching strategies and techniques to assist learners. Once learners understand scientific principles and are able to apply their scientific knowledge to the world they live in, they gain a lifetime of thirst for knowledge and the acquisition of skills that can be learned and developed on their own (Staver, 2007:23).

One of the main contentious issues that science teachers currently face is the inability of learners to understand Newton's laws of motion (Hart, 2002:14). The core of this problem lies in the complexity of describing motion, given that Isaac Newton basically refined the various types of motions to three fundamental laws (cf. Annexure A). This problem is furthermore complicated by learners' alternative conceptions that often hinder the learning of Newton's laws of motion. The alternative conception that has probably been researched most is the notion that a continuous action of a force is necessary to keep an object in motion (Palmer, 1997:681). Moreover, learners' intuitive ideas of force and motion do not account for all different types of motion (e.g. linear, projectile, circular, free fall) as the Newtonian concept does (Rowlands, Graham, Berry & McWilliam, 2007: 21).

Against this background, the researcher wished to find answers to the following research questions:

- To what extent has the Grade 11 learners' understanding of Newton's second law improve through teaching strategies that focus on conceptual development?
- What is the effectiveness (the learning gain) of conceptual change teaching strategies on the conceptual development of grade 11 learners on Newton's second law of motion?

1.3 REVIEW OF LITERATURE AND EXPLANATION OF CONCEPTS

1.3.1 Introduction

Physical Sciences education is considered as an interdisciplinary field (Duit, 2007). Although the subject of Physical Sciences is the major reference discipline, competencies in various other disciplines are also needed. Reference disciplines for science education include philosophy and history of science, pedagogy, neuroscience and psychology. These integrated fields form a theoretical framework for doing research. For instance, the information-processing model that resulted from recent research in neuroscience, psychology and education can be used as foundation when conducting research on conceptual development as suggested by Redish and Hammer (2009). When teaching science, it is important to consider the cognitive processes in the brain and how concepts are formed. The ways in which the memory and the mind operate, as well as their roles during the learning process are considered in order to enlighten and motivate a conceptual development teaching approach. In this study the conceptual development teaching strategy was tested, more specifically the cognitive conflict method and the development of ideas method.

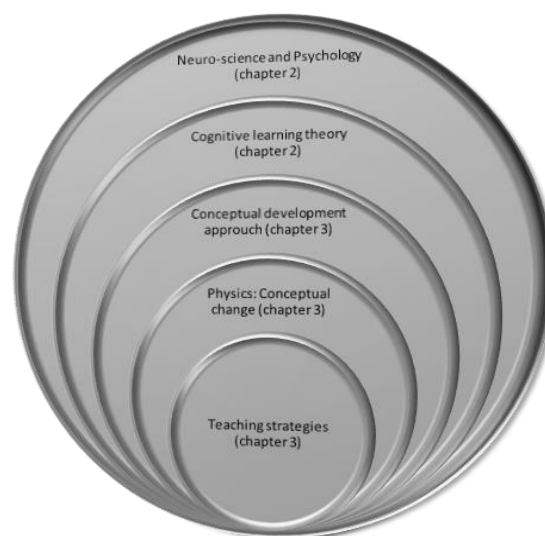


Figure 1.1: Central premise: Schematic representation of the theory on which this research is based.

Figure 1.1 gives a schematic representation of the theory on which this research was based. The research started in Chapter 2, with main disciplines psychology and the neuroscience underpinning the theory. The cognitive learning theory, that forms the basis of conceptual developments, was then discussed in Chapter 2. In Chapter 3 conceptual development and the role it plays in achieving conceptual change, were considered. Conceptual development teaching strategies are the tools through which conceptual change will be achieved.

In this study, Educational Psychology teaches how conceptual development takes place, whilst physics education indicates what alternative conceptions may hinder conceptual development and how conceptual resources may be progressively refined to develop an understanding of Newton's second law of motion. Pedagogy contributes with regard to teaching-learning strategies for conceptual change of alternative conceptions and refinement of learners' conceptual resources.

1.3.2 Educational Psychology and learning theories

The aim of Educational Psychology is to understand content taught by a teacher to a learner in a certain setting (Woolfolk, 2010:14). It is important for educators to be aware of the work done by educational psychologist to enrich the learning experience of the learners and to be more effective educators. Since Educational Psychology is anchored in two subject disciplines, namely education and psychology, it has much to offer educators who want their learners to pass and pass well (Woolfolk, 2010:18). Educators should understand how teaching and learning works and the complexities in the achievement of these goals in order to be more effective teachers (Redish, 2006:1). Educational Psychology deals with the whole human development, but only some aspects are relevant for this study, which will be discussed briefly.

Woolfolk (2010:16-18) postulates that there are three groups of theories significant for Educational Psychology and teachers. These theories include the Stage theories, the Learning and Motivational theories and the Contextual theories. Firstly, the **Stage theory** is based on the ground work of three predominant scientists. Jean Piaget (1896–1980) described four qualitatively different stages of cognitive development that are considered important for learning; Freud (1856–1939) coined the five stages of psychosexual development, and Eric Erikson (1902–1994) developed the psychosocial theory, which states that humans go through different stages of development, with each stage posing unique challenges. Secondly, the **Learning and Motivational theories** include three learning theories, namely the Behaviourist theory of learning, that focuses on behaviours, antecedents and consequences thereof (Champion, 2013:7); the Information Processing theory that focuses on important concepts in the cognitive information-processing theories of learning, perception, working memory, long-term memory and types of knowledge; and the Social Cognitive theory that focuses on the

interactions between behaviour, environment and personal characteristics, and includes self-regulated learning. Thirdly, the **Contextual theories** include the work of Lev Vygotsky (1896–1934), who claimed that activities cannot be understood apart from their cultural background and that all mental processes in humans can be traced back to or are formed through social interactions with others; and the bio-ecological model of development by Urie Bronfenbrenner (1917–2005) that is extensively used today. Bronfenbrenner developed a framework that maps the network of social contexts that affect development (Woolfolk, 2010:18).

The information processing model of the group of Learning and Motivational theories serves as a framework for this study. **Cognitive** development, **conceptual** development and the **learning** of physics within this framework will be elucidated on in the next paragraphs. Aspects of the other applicable learning theories will also be incorporated.

1.3.3 Cognitive development

Cognitive development is described by Redish (2003:3) and Woolfolk (2010:26) as gradual and orderly changes whereby mental processes become more complex and sophisticated. Cognitive development is based on three principles, the first of which is that people develop at different rates, secondly development progresses orderly or logically, and thirdly development progresses gradually. During this development structural changes take place in the brain of the learner. Without these structural changes, learning cannot occur.

Learning is directly linked to neurons in the brain which are responsible for storage and transmission of information (Woolfolk, 2010:28). Networks of connected neurons represent cognitive elements of knowledge and memory (Sabella & Redish, 2007). What learners know is situated in their memories and can be used for future learning. The cognitive view of learning furthermore views learners as having resources like plans, intentions, goals, ideas and memories that are used to select and construct knowledge from stimuli obtained through experience (Ormrod, 2011:182; Woolfolk, 2010:233). Because of the influence of learning on the development of the brain we find that learners are especially able to integrate former and current experiences. According to the cognitive perspective, knowledge consists of more than what resulted from previous learning, as knowledge also serves as a guide to the next level of learning. Knowledge can also be domain-specific, pertaining to a specific subject or topic, or general, referring to learners' skills such as reading, writing or using apparatus (Woolfolk, 2010:234).

The most commonly researched view of memory according to Slavin (2009:158) and Woolfolk (2010:237) is the information-processing system. Woolfolk (2010:237) describes the information-processing system as follows; *“Information is encoded in the sensory memory where perception and attention determine what will be held in the working memory for further*

use. In working memory, new information connects with knowledge from the long-term memory. The thoroughly processed and connected information becomes part of the long-term memory, and can be activated to return to working memory. Implicit memories are formed without conscious effort”.

1.3.4 Conceptual development

The Oxford Advanced Learners Dictionary (2010:299) defines a “concept” as “an idea or a principle that is connected to something” and the adjective “conceptual” as “related to or based on ideas”, for example “a conceptual framework within which children’s needs are assessed” or a “conceptual model”. In the context of this study, Baron (2001:222) and Woolfolk (2010:246) describe “concepts” as mental categories for events that are stored in the brain in a network reflecting the relationship with other concepts, known as a propositional network, also called a “conceptual framework” (Baron, 2001:222; Woolfolk, 2010:246).

The term “development” refers to “the growth of something so that it becomes more advanced, stronger” (Oxford Advanced Learner’s Dictionary, 2010:299). In the context of this study conceptual development refers to the development of the learners’ concepts of force into a scientifically correct concept. Woolfolk (2010:476) states that the two main features of the conceptual development model of teaching are:

1. teachers’ commitment to learner understanding and not just covering syllabi and
2. learners’ own involvement by making sense of new concepts through their existing knowledge.

In this study conceptual development refers to the development of knowledge of Newton’s second law of motion as the outcome of the progressional development of science concepts and relations.

1.3.4.1 Teaching and teaching sequence

Science teaching is a decisive means to an essential end, learning (Starver, 2007:8). Starver continues to mention that during the teaching process the attitude of the educator should be one of respect to the learners and consider their existing knowledge and opinions. The educator beliefs in the ability of the learners and maintain high expectations in the learners within a challenging but non-threatening learning environment. Woolfolk (2010:455) mentions that the educator should align the curriculum with the context, tasks and problems that the learners can relate to and use guided inquiry and the necessary teaching strategy that lead learners to continuously develop and modify their knowledge.

According to Gunter, Estes and Mintz (2007:34), a teaching sequence refers to the order in which subject matter is placed. For instance, the skills in fundamental subjects are usually sequenced from the simplest to the most complex. Learning could also be sequenced according to interest and variety. The sequence of learning should however follow a logical order and obvious connections should be included between parts to be learned and what is already known by students (Gunter *et al.*, 2007:34).

Learners' prior knowledge and their particular difficulties in understanding the different concepts and explanations of phenomena should guide the selection of the content and the instructional interventions (Vosniadou, Ioannide, Dimitrakopoulou & Papademetriou, 2001). A great deal of attention should be paid to the sequence in which the concepts are introduced and developed in order to avoid the formation of new misconceptions and to overcome existing ones.

Misconceptions exist when the construct in the brain of a learner is incorrectly linked between neurons in the conceptual framework of the learner. When new work is learned misconceptions form when incorrect links or associations are formed between neurons in the conceptual framework of the learner (Woolfolk, 2010:251; Dekkers & Thijs 1998:30). Alternative concepts are formed when learners' brain do not make an association between say an existing conceptual framework of force and the new explained concept of force. In so doing a new alternative conceptual framework of force forms in the mind of the learner that is completely separated from the existing concept of force (Vosnaidou & Ioannides, 1998:1213). Conceptual development takes place when firstly the links between neurons are correctly rearranged and misconceptions are changed into the correct conceptual framework. Secondly, conceptual change will occur when the alternative conceptual framework is correctly linked with the existing conceptual framework and is further developed into a correct scientific framework.

Another option is the most difficult to achieve and it is advisable that a teaching sequence is developed in such a way that learners do not develop alternative concepts (Jensen, 2008:173). Learners do have misconceptions about scientific concepts due to their novice conceptual framework. It is advisable that these novice conceptual frameworks are developed correctly into a correct scientific conceptual framework through a well-planned teaching sequence and by using the correct teaching strategies.

1.3.4.2 Guidelines for conceptual development

From the Cognitive Learning theory (cf. par. 1.3.3) some guidelines are mentioned the educator should keep in mind when teaching for conceptual development (Gunter *et al.*, 2007:4):

1. Each level or grade achieved by a learner improves the learner's cognitive ability (intelligence).
2. As a learner learns, the patterns of cognition change (elaboration).
3. Synapse forming in the brain of each learner is unique. Not all learners understand all the work all of the time or in the same way.
4. One should teach with the memory functions of learners in mind (working and long-term memory).
5. Teach for deep understanding (knowledge should be understood and applied).
6. Learners must understand concepts and place it into their existing conceptual framework (organisation).
7. Meta-cognition enhances learning.
8. Fear fails while challenges succeed.
9. Every learner's brain is unique. The teacher should try to reach every one (context).

The above-mentioned guidelines are also essential when deciding on a teaching strategy to develop a learner's concept from a novice to a scientific correct concept.

It emerges from the conceptual development model of learning that learners learn more effectively through assimilation than through accommodation (Redish, 1994:9; Dekkers & Thijs, 1998:33). Through the process of assimilation a new concept fits into an existing mental model. Therefore, a new concept should be explained in terms of existing concepts in a well-known context so that more effective learning takes place through analogy. Analogies in the earlier grades or everyday life should be chosen so as to build learners' new and more sophisticated mental models in later grades. It is therefore important to build a framework or a structure for the course, in this case Physical Science in the Further Education and Training (FET) phase, around well selected concepts and context. According to Redish (1994:11) **accommodation** is more difficult to accomplish since it is very difficult to replace an established existing mental model. To replace an existing mental model the new concept must be understandable, plausible and strongly contradict the existing mental model or construct and must be useful. Teachers should keep in mind that each learner enters a class with preconceptions as foundation for the new concepts in addition to cognitive skills and prior knowledge that can be used to build the new concepts into the existing conceptual framework (Redish, 1994:11).

1.3.4.3 Conceptual change when teaching for conceptual development

Conceptual change is described as a learning process in which students' alternative conceptions transform or reconstruct into the intended scientific conception (Vosniadou, 2008). Conceptual change is that result of the conceptual development process. Teaching for conceptual change in Physical Sciences is a method of teaching that strives to help learners understand the concepts rather than memorising them. The learners' intuitive knowledge of

physics concepts that differ from the accepted scientific concepts are challenged (Lemmer, 2011:2). Intuitive knowledge is also known as mental schemas or cognitive resources and is basic statements about how the physical universe functions. These schemas may be considered as obvious and irreducible by the learner (Redish, 2003:16).

There are basically two types of conceptual change. Firstly, conceptual change could take place through knowledge restructuring, assimilation or conceptual capture. Secondly conceptual change could take place through strong or radical knowledge restructuring, accommodation or conceptual exchange (Duit & Treagust, 2003:672). In general, conceptual change denotes learning pathways from students' pre-instructional conceptions to the science concepts to be learned. In order to promote conceptual change, lessons should be comprehensible, conceivable, rational and convincing. Conceptual change can only take place when learners directly examine their own theories and confront their shortcomings (Donovan & Bransford, 2005:401).

The role of the educator is to facilitate the process of conceptual change by choosing the appropriate content and context for learners and by considering the cognitive tools of the learners (such as their tools for making sense of the world around them). Once the educator has established the content and context, the focus of the learners should be placed on the critical aspects of the content, keeping in mind that learners' experiences differ (Vosniadou, 2008:539).

Teachers should design learning experiences so that the learners can distinguish critical aspects of the content taught (Gregory & Parry, 2006:61). Once the critical aspects of the content are established, teachers could introduce additional aspects to learners to promote a deeper understanding of a concept. The learners should be actively involved in constructing a new conceptual framework or changing their existing one or at least identifying shortcomings in their conceptual framework. Learners should be guided during the learning process to make sense of experiences and to develop concepts into a coherent and consistent framework of knowledge (Scherr & Redish, 2005:41).

1.3.4.4 Scientific and alternative conceptions regarding Newton's laws of motion

Newton's laws deal primarily with the concept of force. Newton's second law of motion states that the **acceleration** of an object is dependent on two variables namely the **net force** acting on an object and the **mass** of the object. The acceleration of the object is directly proportional to the force and inversely proportional to the mass of the object. The object accelerates in the direction of the net force.

The following is a mathematical expression of Newton's second law of motion:

$$a = \frac{F_{net}}{m}.$$

(F_{net} – net force in Newton, a – acceleration in m.s^{-2} , m – mass in kilogram)

Since the early 1980's alternative conceptions have been investigated in physics education research. Such conceptions were seen as weakly organised cognitive resources (Redish, 2003:18). The following are a few examples of alternative conceptions related to force and Newton's laws of motion (Hestenes & Halloun, 1995):

1. If an object is at rest, no forces are acting on the object.
2. Only animate objects can exert a force. Thus, if an object is at rest on a table, no forces are acting upon it.
3. Force is a property of an object. An object has force and when it runs out of force it stops moving.
4. The motion of an object is always in the direction of the net force applied to the object.
5. Large objects exert a greater force than small objects.
6. A force is needed to keep an object moving with a constant speed.
7. Friction always hinders motion. Thus, you always want to eliminate friction.
8. Rocket propulsion is due to exhaust gases pushing on something behind the rocket.
9. Velocity is another word for speed. An object's speed and velocity are always the same.
10. Acceleration is confused with speed.
11. Acceleration always means that an object is speeding up.
12. Acceleration is always in a straight line.
13. Acceleration always occurs in the same direction as an object is moving.
14. If an object has a speed of zero (even instantaneously), it has no acceleration.
15. The only "natural" motion for an object is to be at rest (Hestenes & Halloun, 1995).

Many of these afore-mentioned alternative conceptions are closely linked to the theories constructed by the natural philosophers. For example, Aristotle organised physical phenomena into a coherent conceptual system that remained unchanged for decades before the flaws were detected (Halloun & Hestenes, 1985:1). These alternative conceptions play a major role during the learning process. When handled correctly, teachers can use the alternative conceptions as cognitive resources to develop the new concept without creating too much conflict in the learners.

Another aspect in developing an understanding of Newton's second law of motion is the learners' prior learning that can be used as resources for further learning. Examples of prior learning include the basic concepts of kinematics in one direction that learners have developed in lower grades, their perception of force and the skills that they have acquired through the years (Scherr & Redish, 2005:45). In this study the focus is firstly on the concept of acceleration and the relation that the greater the unbalanced force the larger the acceleration. Secondly the focus is placed on deceleration, followed by combinations of different motions. Finally Newton's second law of motion is defined. Once the law is established exercises were given as enrichment of the concepts.

Concept development teaching strategies were used to address the above-mentioned aspects to facilitate learning of the difficult concepts and relations incorporated in Newton's second law of motion. The strategies are the cognitive conflict strategy and the development of ideas strategy.

1.4. RESEARCH AIM AND OBJECTIVES OF STUDY

1.4.1 General research aims

- The first aim of this study is to determine extend Grade 11 learners' understanding of Newton's second law of motion improves through teaching strategies that focuses on conceptual development.
- The second aim of this study is to determine the effectiveness that conceptual change teaching strategies has on grade 11 learners' conceptual development of Newton's second law of motion.

1.4.2. Specific research objectives

The specific objectives of this study were to:

1.4.2.1 Compile a theoretical framework through a literature study on

- how learners form concepts in their memories;
- conceptual development strategies for facilitating the development of science concepts;
- learners' alternative conceptions related to Newton's laws of motion.

1.4.2.2 Perform a baseline study to determine the Grade 11 learners' alternative conceptions and conceptual resources for the learning of Newton's second law of motion.

1.4.2.3 Design an intervention that utilises conceptual development teaching strategies to elaborate and transform learners' existing knowledge structures through accommodation (cf. par. 1.3.4.2) and association (cf. par. 1.3.4.1) of new knowledge.

1.4.2.4 Determine the effectiveness of the intervention to facilitate Grade 11 learners' understanding of Newton's second law of motion.

1.5 HYPOTHESES

1.5.1 The teaching strategies are effective in the development of scientific concepts on Newton's second law of motion in Grade 11 learners.

1.5.2 The learners gain knowledge of Newton's laws of motion and achieve a medium normalised learning gain of $g > 0.3$.

1.6 METHOD OF STUDY.

1.6.1 Research procedure

The research question and aims were realised as follows:

1. A literature study was undertaken in education, education psychology, neuroscience, and Physical Sciences to compile a theoretical framework on how learners form concepts in their memories, which conceptual development strategies can be used for facilitating the development of science concepts and which alternative conceptions related to Newton's laws of motion have been reported.
2. A pre-test given to the learners on Newton's first two laws of motion was undertaken to determine the Grade 11 learners' alternative conceptions and conceptual resources for the learning of Newton's second law of motion.
3. Previous literature was used as a springboard to design an intervention that utilises conceptual development strategies to elaborate and transform learners' existing knowledge structures through the accommodation and association of new knowledge.
4. Quantitative and qualitative research methods (mixed-methods research), namely a Sequential-Explanatory Design (Creswell & Plano Clark, 2007:142; McMillan & Schumacher, 2010:405) were used to investigate the effectiveness of the intervention done to facilitate the Grade 11 learners' understanding of Newton's second law of motion. For the quantitative part of the study, an experimental design, more specifically

a one group pre-test-post-test design (Creswell, 2009:158) was used to determine the effectiveness of the intervention. Qualitative data collected by means of video-recordings during the intervention was used to illuminate the quantitative findings.

1.6.2 Literature study

The researcher obtained relevant literature sources by making use of academic books and articles related to the research topic. Books related to the empirical research and mixed-method research were utilised (Creswell & Plano Clark, 2007; Creswell, 2009; McMillan & Shumacher, 2010). Peer reviewed journals and articles were found with the aid of search engines such as ECSCO Host, Microsoft Encarta and Google Scholar. Dictionaries were used to clarify concepts.

Keywords relevant to this study are: Newton's second law of motion, teaching strategy, conceptual development, conceptual understanding, learning, cognitive learning theory, information processing model, cognitive resources, Newton's laws of motion, Sequential Explanatory design, Force Concept Inventory (FCI).

1.6.3 Paradigmatic perspective of researcher

The word "paradigm" is derived from the Greek and refers to "*a pattern stereotypical example, model, theory, perception, assumption or frame of reference in theories that are constructed within a particular research area*" (Meyer, 2011:11). Paradigms have a direct bearing on research and consist of the following (Meyer, 2011:11):

- theories and laws to which a researcher commits himself/herself;
- preconceptions and metaphysical assumptions;
- methodologies and research techniques
- assumptions of the researcher as scientist.

The theoretical basis for conducting mixed-method research is based on the pragmatic paradigm. This paradigm is based on the belief that the scientific method is insignificant by itself, but in combination with common sense and practical thinking, the correct approach (quantitative or/and qualitative) will be undertaken (McMillan & Schumacher, 2010:6). This leaves the researcher with a certain freedom to choose the methods, techniques and procedures that suit him and the research topic the best (Creswell, 2009:11).

During this study data was collected, analysed and constructed within the researcher's conceptual framework. Therefore, the researcher has to provide information on his personal frame of reference, experience and orientation as it relates to the study.

The researcher is an experienced Physical Sciences educator for the past 22 years. Currently the researcher is a senior teacher and the head of the Science and Mathematics department at a South African public school. The researcher is a national marker of Grade 12 Physical Sciences examination papers. The researcher is also involved in the training of other Physical Sciences teachers in South Africa.

From the researcher's experience as Physical Sciences educator, it became evident that learners experience difficulty in understanding Physical Sciences concepts, in particular Newton's laws of motion. As a result, the researcher experimented with teaching strategies to facilitate understanding of concepts amongst learners. During the experimentation with different strategies to facilitate learning, the researcher found that conceptual development strategies tend to be the most effective in facilitating learning among learners.

The above-mentioned experiences enable the researcher to understand the learning process of learners, learning strategies and teaching strategies that were investigated in this study.

1.7 THE COURSE OF THE STUDY

In Chapter 2 the cognitive learning theory is reviewed, in particular the information-processing model of learning. The concept of cognitive resources and the implication thereof on learning are described.

In Chapter 3 conceptual change and teaching strategies that foster conceptual development are investigated. The initial concepts and mental frameworks which serve as baseline for conceptual change are considered and goals are investigated for conceptual development teaching strategies.

In Chapter 4 the research design and methodology, including the quantitative and qualitative research methods, are discussed. The procedures, design, population, sample and instrumentation that were used to measure the effectiveness of the conceptual development teaching strategies, are discussed.

In Chapter 5 the analysis, interpretation and synthesis of quantitative and qualitative data take place. Based on the learning gain, the effectiveness of the conceptual development teaching strategies are evaluated.

In Chapter 6 a summary is provided and conclusions drawn regarding the effectiveness of the applied conceptual development teaching strategies on Newton's second law of motion.

CHAPTER 2

LEARNING AND TEACHING: A COGNITIVE APPROACH

“There are perhaps about one hundred billion neurons, or nerve cells, in the brain, and in a single human brain the number of possible interconnections between these cells is greater than the number of atoms in the universe” (Ornstein & Thompson, cited by Caine & Caine, 1994:7).

“We are given as our birth right a Stradivarius and we come to play it like a plastic fiddle” (Houston, cited by Caine & Caine, 1994:7).

2.1 INTRODUCTION

The cognitive and social learning theories are central to what educators do in the class. Both theories are important in the classroom, but the cognitive learning theory provides some indication of what happens in the brain of the learner. It also provides insight into how memory is formed and how the learner conceptualises the concepts and places them into context with the environment. Conceptual development teaching strategies are developed to facilitate learning in such a way that the learner's conceptual framework changes gradually, making use of the learners own initial concepts as a starting point. In order to understand the process of conceptual development, one also needs to know how the mind of a learner works. Chapter 2 is aimed at providing a clear understanding of the functioning of the brain and its processes during learning. The role of the resources that the learners bring into the classroom that are used to form the necessary mental structures, is discussed. The learning principles that are essential for learning according to the cognitive learning theory are also described.

2.2 LEARNING

Learning is an act or process of acquiring knowledge or skills (Colman, 2009:417), and the largest portion of a learner's behaviour is the result of learning (Louw & Edwards, 1998:211). Jarvis (2006:7) asserted the following: “Finally, we exist in the world, a world which is impregnated with human purposes and concerns, and in some other ways we mirror our world, so that facts can only have value when they have meaning and objects only have meaning when we are conscious of them”. According to Jarvis (2006:7), learning must not only be meaningful to learners but is based on different theories. The most important learning theories, according to Louw and Edwards (1998:211), are classical conditioning, operant conditioning, social learning and cognitive learning. These four learning theories will be discussed briefly.

Classical conditioning is described by Baron (2001:170) as “a basic form of learning in which one stimulus comes to serve as a signal for the occurrence of a second stimulus. Learners

acquire information about the relations between various stimuli”. Classical conditioning plays a role in the learner’s emotion and attitude when facts and ideas are learned. Emotional learning can interfere with academic learning if the learner has a negative connotation to a teacher, school or even peers at the school. However, the opposite is also true where a favourable environment enhances a learner’s academic performance (Woolfolk, 2010:201). Classical conditioning can be used in the classroom to strengthen favourable behaviour by rewarding it (Champion, 2013:7).

A learner’s disruptive behaviour can be explained by and rectified through the **operant conditioning** theory of Thorndike and the American psychologist, B.F. Skinner (Berliner & Calfee, 2009; Champion, 2013:7). Operant conditioning is based on rewards that shape and maintain the behaviour of learners. “Operant conditioning is a form of learning in which behaviour is maintained, or changed, through consequences” (Baron, 2001:182).

Albert Bandura, a Canadian psychologist, developed the **social-learning theory** that can, amongst other, be used to understand learner violence and vandalism (Berliner & Calfee, 2009). The learners learn violence and vandalism from their role models. Therefore the learners think it is acceptable social behaviour for the peer group that goes unpunished. The opposite is also true regarding social acceptable behaviour. It is important to note that it is the peer group that forms the social pressure. According to Woolfolk (2010:221) and Champion (2013:2), educators can use incentives to direct the learner’s behaviour. Certain a-social behaviour is penalised, but good social behaviour is rewarded. This theory underlines the conditions under which learners learn to imitate role models in the society (Baron, 2001:323).

The fourth theory, and also the focus theory for this study, is the **cognitive learning theory**, more specifically the information-processing theory. It is used to understand how learners retain information learned and solve problems using the stored information (Berliner & Calfee, 2009; Champion, 2013:7; Slavin, 2009:158).

Cognitive science is an umbrella term for an interdisciplinary enterprise concerned with information acquisition and processing. Cognitive science includes research into language, **learning**, perception, thinking and problem solving, and knowledge representation (Colman, 2009:146) and was popularised by Piaget. The cognitive view of learning deals with the way in which knowledge is gained through information acquisition and how useful information is stored in the brain (Baron, 2001:299; Champion, 2013:7).

From neuroscience and cognitive psychology certain deductions can be made regarding the way in which learners learn physics and make sense of the world they live in (Caine & Caine, 1994:4; Redish, 2002:1). There has been a growing understanding among researchers why learners respond so poorly to traditional instruction. Researchers started to explain how the

learners can utilise the vast innate and genetic capabilities to their disposal (Caine & Caine, 1994:4). The only way to raise the standard of education is when researchers and curriculum developers integrate educational research and technology into efficient learning environments (Redish, 2002:1).

There are frequent new advances that have far-reaching effects on teaching and learning and can to some extent even transform teaching in ways that are overlooked. As educators we are failing our learners and society and are inept in our classrooms if we do not recognise these new advances and apply it in our teaching (Redish, 2002:1). Physics, that is supposed to be inspirational to educators teaching a subject that the learners love and enjoy, becomes frustrating to the educators, and the learners lose interest. One rarely finds learners with the interest and ability and who learn the work the way the educators teach it. On the contrary, learners often find the work difficult, the explanations illogical and the subject boring, leading to frustration and aggression in the learners. Consequently the teacher tries to compensate by either entertaining the learners, over-simplifying the work or toning down on assessments in an attempt to improve the results of learners, resulting in a downward cycle (Redish, 2002:1).

Redish (1999:1) claims that there has been much research done on the teaching of topics that have presented learning difficulties to learners. Educators also need to study their learners and their responses to instruction in order to understand what is happening in the classroom (cf. par. 1.1).

2.3. THE COGNITIVE VIEW OF MEMORY

2.3.1 Functioning of the brain

The function of the brain is to learn, and the brain has an almost unlimited capacity to learn (Caine & Caine, 1994:4). The brain can perceive patterns and make approximations, has the unique capacity for various types of memory, has the ability to learn from experience and self-correct and has an unlimited capacity to create (Woolfolk, 2010:28). With all this potential, the question still remains, “Why are there learners who still fail Physical Sciences or who cannot understand certain concepts?” According to Caine and Caine (1994:4), educators must keep the functioning of the brain in mind during teaching. They must also keep in mind that different disciplines relate to each other and share common information and that the brain has the ability to organise and reorganise information (Caine & Caine, 1994:4). Thus, teaching and learning is more than an accumulation of facts; it is rather a process whereby facts are connected and organised into a **conceptual framework** (in the brain of the learner).

Cognitive science as well as educational science confirms that learning is a process of acquiring knowledge and/or skills. The formation of memory in the learner’s brain is central to the

learning process. To understand learning we must understand how information is stored and retrieved in the brain (Baron, 2001; Champion, 2013:7). Modern cognitive science has detailed structural information about how the memory of learners functions. To elaborate learning it is important to understand the structure of the human brain.

The human brain is the control centre for various functions of the body (Sukel, 2013). The brain controls actions, feelings, words and thoughts. Various parts of the brain have specific functions to perform (Champion, 2013:15). The largest part of the brain is known as the cerebrum, and sensation, conscious thought and movement can always be associated with this part of the brain. The cerebrum consists of four lobes, namely the temporal lobe, occipital lobe, parietal lobe and frontal lobe (see Figure 2.1). These lobes perform different duties. The cerebrum is divided into two halves which are connected by a thick band of nerve fibres known as the corpus callosum. The parietal lobe consists of two parts which they include the sensory cortex (part 9, Figure 2.1) and the motor cortex (part 3, Figure 2.1). Wernicke's area (part 11, Figure 2.1) is an integral part of the temporal lobe and Broca's area (part 4, Figure 2.1) is situated on the occipital lobe. The cerebellum (part 14, Figure 2.1) is the second largest structure in the brain, situated at the lower back of the brain. The cerebellum consists of two hemispheres and is engaged in controlling complex motor functions. The hypothalamus works closely with the pituitary gland to control the production of various hormones in the human body, and influences hunger, mood, thirst and temperature as well. Importantly it also stimulates the formation of neurons and connections between axons and dendrites.

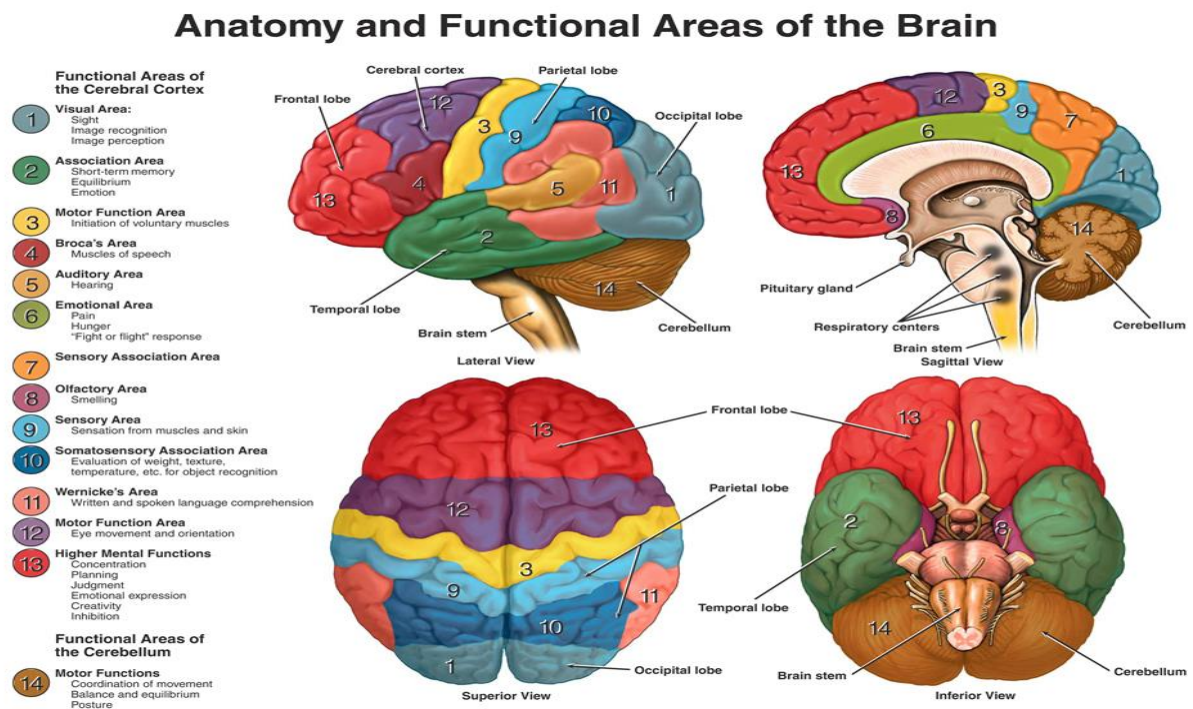


Figure 2.1: Brain areas and their functions (Sukel, 2013)

Within the cerebrum are small structures called neurons (Sukel, 2013). The neurons (Figure 2.2) are small structures that store and transmit information in the brain and form the basis of the long-term memory (Baron, 2001:47; Sukel, 2013; Woolfolk, 2010:29).

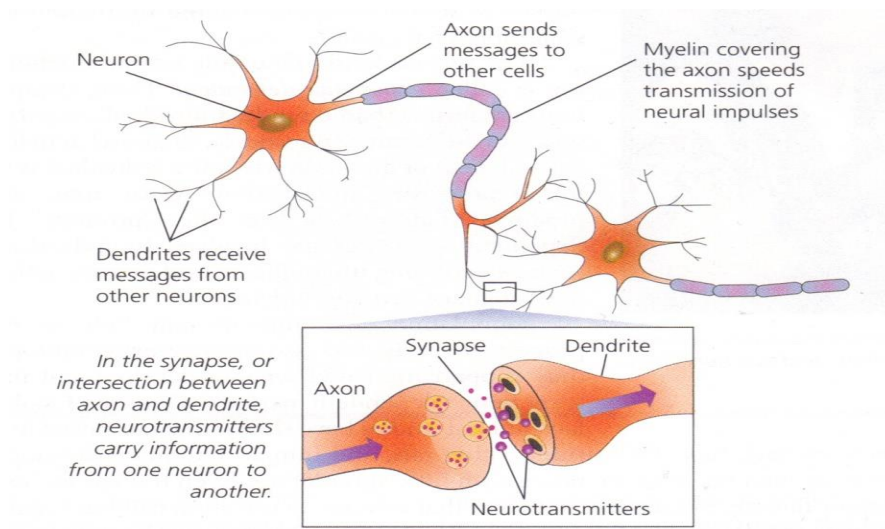


Figure 2.2: A single neuron (Woolfolk, 2010:29)

Neurons contain long arm-like structures called axons (for sending messages) and dendrites (for receiving messages). In the synapses neurotransmitters such as dopamine, carry information from the axon to the dendrites (Baron, 2001:47; Woolfolk, 2010:31). Myelin covers the axon and speeds up the transmission of messages. Neuroplasticity changes the neural network by adding and pruning synapses and dendrites and producing myelin layers around the axons. These neurons form a network with interconnecting axons and dendrites. During the learning process these axons and dendrites are pruned and/or new connections are made forming a neural network. These networks form the basis of the memory of the learner. The information-processing model for learning describes the passage information follows through the brain until it becomes part of the mental network. Before the information-processing model for learning is discussed in detail, it is necessary to take note of the properties of the sensory, short-term and the long-term memories. Table 2.1 shows the properties of memories. Table 2.1 furthermore summarises the differences between the short-term and long-term memories.

Table 2.1: Table of properties of memory (adapted from Gazzaniga, Ivry, Mangun & Steven, 2009:322; Woolfolk, 2010:237).

Sensory memory	Short-term memory (Central Executive)	Long-term memory
Time the memory is stored		
Between 1 and 3 seconds	15 or 20 seconds (one day according to Sousa, 2010:17)	Permanent
Capacity of the memory		
Very large	5 to 9 bits/chunks of information	Limitless
Parts of the memory		
Senses – Smell, Touch, sight, Taste, Hearing All the senses play a role during learning. Focus of attention on relevant senses is central.	Central executive Monitors and directs attention and other resources. Initiate control and decision processes. Reasoning, language and comprehension. Transfers information to long-term memory via rehearsal and decoding.	Declarative memory (Explicit memory) (conscious) • Episodic – One's own experiences. Deliberate and conscious recall. Specific personal experiences from a particular time and place (part 2, Figure 2.1) • Semantic - Facts and general knowledge. World knowledge, object knowledge, language knowledge and conceptual priming (part 2, Figure 2.1)
	Phonological loop (Short-term buffer) Repeats words or sound for retention Visio-spatial sketchpad Keeps visual and spatial information in the short-term memory.	Non-declarative memory (Implicit memory) (unconscious) Influences behaviour or thought without awareness. • Classical conditioning effects - Conditions responses between two stimuli (Skeletal muscle) • Procedural memory Motor skills, habits and implicit rules (part 3 & 14, Figure 2.1) • Perceptual Priming - Inherent activation of concepts in the long-term memory (part 7 & 10, Figure 2.1) Non-associative learning – Habituation and sensitisation (Reflex pathways).

2.3.2 Information-processing model

Learning and memory are tied to information processing and the retention of information over a long period of time (Champion, 2013:7; Gazzaniga, Ivry, Mangun & Steven, 2009:360, Gregory & Parry, 2006:12). The information-processing model for learning is divided into three main sections, consisting of the sensory memory, the working or short-term memory and the long-term memory (Gregory & Parry, 2006:12). Information firstly enters the brain through the senses and is gathered in the sensory memory before the most important information is filtered, coded and sent to the short-term or working memory. In the working memory; the information from the sensory memory is merged into the long-term memory. The long-term memory stores the information permanently.

Memory is the outcome of an information-acquiring process called learning (Gazzaniga *et al.*, 2009:313). Memory can be broken up into three hypothetical stages, namely encoding, storage and retrieval (Gregory & Parry, 2006:19). New information is received and processed to be stored in a process called encoding. Storage is a permanent record of the information and retrieval is a process where the stored information is used to originate an intentional action or behaviour (Champion, 2013:7; Gazzaniga *et al.*, 2009:313).

According to Gazzaniga *et al.* (2009:360), the structures that support diverse memory processes differ, depending on the type of information and how the information is coded and retrieved. The medial temporal lobe (part 2, Figure 2.1) forms and consolidates new episodic and semantic memory and is involved in connecting together different information regarding an episode. The prefrontal cortex (part 13, Figure 2.1) encodes and retrieves information based on the nature of the material being processed, and the temporal cortex (part 2, Figure 2.1) stores episodic and semantic knowledge. The association sensory cortices (part 7, Figure 2.1) are used for the effects of perceptual priming and other cortical and sub-cortical structures (part 13, Figure 2.1) play a role in learning new skills and habits.

The above-mentioned discussion served as a general background to understand the more detailed discussion of the information-processing model for learning, as illustrated in Figure 2.3 and discussed thereafter.

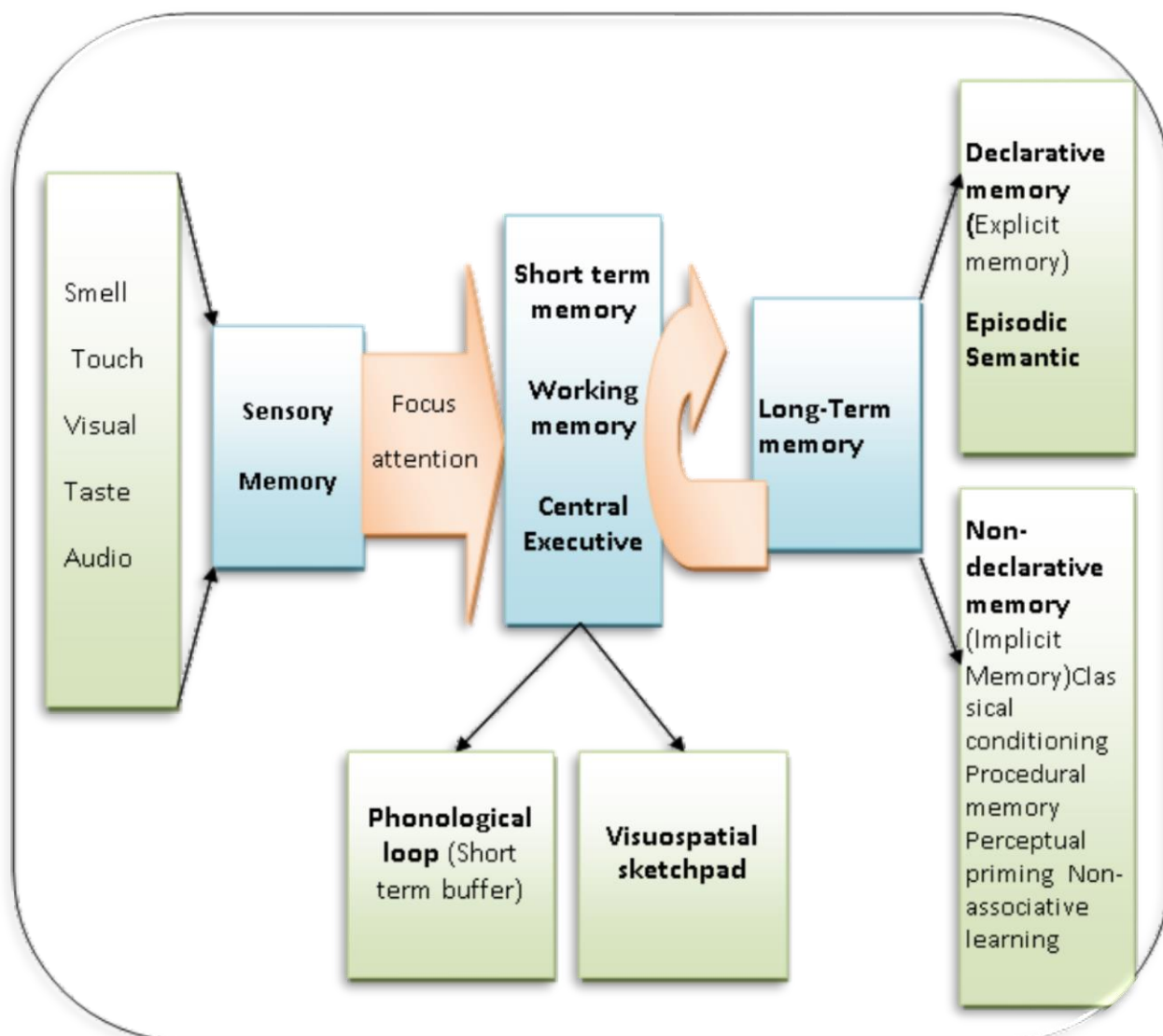


Figure 2.3: Information-processing model (Gazzaniga *et al.*, 2009:322; Woolfolk, 2010:237)

Following is a discussion based on the information-processing model of memory (Figure 2.3).

- **The sensory memory**

The sensory memory is very large in capacity and all five senses are active during a lesson or learning, but it only lasts between one and three seconds. Stimuli from the environment are transformed into information which is kept in the sensory register (Slavin, 2009:159; Ormrod, 2011:185; Woolfolk, 2010:237). All these stimuli have the potential to trigger previous experiences in the brain of the learners. It is therefore essential to focus the learners' attention. In the sensory register the relevant information is selected and coded for further use and perception; attention is vital at this stage of the learning process (Slavin, 2009:160; Woolfolk, 2010:238). Mayer (2011:30) refers to a "*dual channel processing*" in humans. Mayer explains that information from the sensory memory is separated into two channels, namely the verbal channel and the visual channel. This links with the cognitive theory, stating that the information from the sensory memory is processed by the phonological loop dealing with words and sounds

and visio-spatial sketchpad dealing with visual and spatial information (Table 2.1). The learner must be prepared for the forthcoming learning experience by, for example, an experiment to trigger their attention and the relevant concept in the long-term memory.

- **The short-term and working memory** (part 2, Figure 2.1)

The short-term memory is limited in capacity (Champion, 2013:7). However, when the short-term memory works with chunks of information and perceives it as a whole group of sensory information or one chunk of information, its capacity is enlarged to a great extent (Gregory & Parry, 2006:16; Woolfolk, 2010:242). The short-term memory consists of two distinct parts. The first part (immediate memory) codes incoming information coming from the sensory register and lasts from 15 to 20 seconds, whilst the second part (working memory) lasts up to 48 hours (Sousa, 2010:7). The working memory does not function in isolation, since the interpretation and understanding of the information in the working memory is dependent on the presence and association of the information in the long-term memory (Redish, 2002:19). The working memory also consists of two distinct parts, namely the verbal part (phonological loop) and visual part (visio-spatial sketch pad) (Gazzaniga *et al.*, 2009:318).

Another feature of the working memory is the filtering of information. All information reaching the long-term memory has to pass through two filters in the brain (Sousa, 2010: 53). Before entering the short-term memory the information from the sensory memory will pass through the first of the two filters, the reticular activating system (RAS), that consists of a basic network of cells in the lower brainstem through which all information must pass (Sousa, 2010:49). The selection process trimming the sensory information from a few million to a few thousand bits of sensory information per second happens automatically and involuntarily.

The RAS is a *survival-directed* filter according to Sousa (2010:50) that will, when a threat is detected, send the information to the lower brain where the response will be fight, flight or freeze. When a learner, for example, perceives the class situation as stressful, neural-activity will manifest in the lower brain and the reflective, cognitive part of the brain (the prefrontal cortex) is unable to receive information. This means that learning is almost impossible under these circumstances.

On the other hand, the RAS is also very receptive to creativity and to change when associated with pleasure and curiosity (Sousa, 2010:50). Knowing this can greatly influence the learner's classroom experience and the educator's presenting of new work. It is essential for educators to know how RAS functions if they plan to reach the learners and when linking new information with concepts in the long-term memory.

In contrast to long-term memory, the working or short-term memory is restricted to what a learner is currently thinking about. The information is processed in the short-term memory and

the problem a learner is currently dealing with is processed (Champion, 2013:7). According to Woolfolk (2010:252) and Redish (2003:9), information is retrieved in a process called spreading activation. When a learner thinks of a concept, this and other closely associated constructs are activated and spread through a network of neurons. Information is available even though it is not activated in a process called reconstruction (Ormrod, 2011:191; Woolfolk, 2010:252). Working memory or short-term memory consists of visual and verbal memory that can function together without interference (Redish, 2003:10). The visual and verbal memory that can function together without interference is a cognitive tool during the problem-solving process where answers are constructed by completing an incomplete scenario through logic, cues and knowledge (Woolfolk, 2010:252).

- **The long -term memory**

The long-term memory plays an essential role in the storage and maintenance of knowledge (Champion, 2013:7-8). The way in which information is processed by learners also determines whether learners will remember it or not (Ormrod, 2011:193; Woolfolk, 2010:251). Three factors are involved in the process where new information is linked to existing information, namely elaboration, organisation and context.

The long-term memory is active during the learning process, as stimuli activate information in the long-term memory that is sent to the working memory. In the working memory the concepts can be added to existing concepts or changed according to the new information received to form new concepts in the brain (Slavin, 2009:160; Woolfolk, 2010:251). This means that the long-term memory plays an active part during the formation of memory (Champion, 2013:7; Woolfolk, 2010:244). Information is brought out of the long-term memory into the working memory and is then processed. Most of the time new information is not simply added to the existing concepts, but existing information is used in new and productive ways to develop concepts. Other cognitive processes, such as recalling and identifying objects also play a role in the activation and formation of concepts (Gregory & Parry, 2006:17). These are all automatic and unconscious processes taking place in the brain of the learners. The processes all form part of the propositional networks in the brain, linking concepts and ideas.

A propositional network is a set of concepts and relationships that are connected in relation to one another. This is one of the most important factors regarding learning. Often we find that knowledge combines concepts, images and propositions into complex structures called schemas (Gregory & Parry, 2006:23). These schemas are abstract knowledge structures that organise vast amounts of information. The process is known as neuroplasticity, which is a process where neural networks in the brain are extended, pruned, reorganised, corrected or strengthened on receiving new information (Sousa, 2010:55). The learners develop a mental

framework that assists them to conceptualise an event, putting the event into perspective and assist them to make predictions (Slavin, 2009: 160; Woolfolk, 2010:245).

The knowledge stored in the long-term memory is structured and associative (Redish, 2003). When a stimulus is presented, a variety of interrelated information is transferred to the working memory. The stimulus may take the form of a key concept, smell, picture, touch or an experience and it can lead to a chain reaction of links being activated (Redish, 2003:23). The brain is constantly busy with the construction of stronger and more efficient networks or frameworks in the long-term memory. The more a concept framework is stimulated, the more prominent the framework gets, with faster retrievals and greater transfer, and the more permanent the framework becomes (Gregory & Parry, 2006:23; Sousa, 2010:58).

Extending the idea of the stimulus, one finds that the information or concept in the long-term memory that will be activated is context-dependent. This means that the context in which the stimulus is presented and the state of the learners' mind play an essential role in determining the concept that will be activated. Linked closely to this is the way in which the concept was learned before (Redish, 2002:22). If the stimulus is presented in a similar context in which it was presented before it is easy for the brain to activate the correct concept. It emphasises again that the long-term memory is both structured and associative. This is fundamental in learning where the brain builds schemas or knowledge structures, also called conceptual structures, linking concepts, ideas, pictures or experiences in the brain with each other according to common properties (Redish, 2002:24).

New information is added to the conceptual framework every time the framework is accessed, leading to more accurate predictions and problem solving. The brain perceives and generates patterns, according to Willis (Sousa, 2010:57), and this new information adds to existing structures, and when a stimulus is received a correct response can be activated (Gregory & Parry, 2006:23). The information reaching the brain and passing through the filters is evaluated and then linked with stored patterns, extending the existing patterns (Sousa, 2010:59)

Elaboration is the process where the learner makes meaning of the new information by linking it to existing constructs (Ormrod, 2011:193). During elaboration conceptual change can take place through **assimilation** where new knowledge is used to adjust existing knowledge constructs, and **accommodation** whereby existing constructs are replaced or reorganised completely (Dekkers & Thijs, 1998:33). Woolfolk (2010:251) asserts that the concept that is first elaborated on will be remembered best. **Organisation** is the process whereby concepts are placed in a structure to facilitate learning which improves the learner's ability to remember definitions and specific examples. The **context** in which the concepts are presented plays a key role in the activation process of concepts into the working memory. According to Redish

(2003:10), by using the correct context, association is increased and the correct resources activated. Woolfolk (2010:251) summarises that a concept will be remembered for longer when such a concept is extensively and elaborately analysed and connected to an already existing construct during the learning process (Ormrod, 2011:193; Woolfolk, 2010:251).

Looking closer at the development of the conceptual structures in the brain, it is important to understand how long-term memory is formed. The information coming from the working memory passes through the amygdala above the brain stem, where the amygdala acts like a second filter of information in the brain (Sousa, 2010:53). The amygdala acts a lot like Krashen's affective (emotion-responsive) filter that reduces learning ability when stressed. Information passes through Krashen's affective filter, and if the information is comprehensible in low-anxiety situations with a message that the learners want to hear, effective learning occurs (Sousa, 2010:48). Recent research found through functional magnetic resonance imaging (fMRI) that, as negative or stress situations increase activity in the lower brain (part number 6 in Figure 2.1) during the learning process, positive or joyful situations result in an increase in brain activity in the prefrontal cortex (PFC) (number 13 Figure 2.1) during the learning process (Sousa, 2010:53). Sousa (2010:53) mentions that, in order for learning to take place, the information needs to pass through the RAS and must be processed by the PFC. The PFC is associated with mental functions such as judgement, organisation, prioritisation, critical analysis, concept development and creative problem solving. When learners are confronted with pleasurable situations the metabolic activity in the PFC increases during learning, whilst the activities in the amygdala increase when they are confronted with stressful situations, blocking the information out that needs to go to the PFC.

A pleasurable learning situation is also associated with an increase in dopamine levels in the brain, whilst negative emotions cause a drop in dopamine levels in the brain. This is very significant because dopamine is one of the neurotransmitters that carries information across the synapses between neurons (see Figure 2.1).

In order for learners to learn effectively and keep the mind actively involved during learning, the pathway through the amygdala to the PFC needs to be open; and this can be accomplished by a low-fear environment (Sousa, 2010:50). When looking at the structure and functioning of the brain, it is possible that educators can reach every learner. There are a few guidelines that educators can adhere to in order to enhance learning and the learning experience in learners.

2.3.3 Memory-related guidelines for teaching and learning

Although the brain and the functioning of the brain is very complex, there are a few guidelines that are important for teaching.

Consider the information processing that gives occasion to meaningful cognitive processes during learning, according to Mayer (2011:37) and Ormrod (2011:186): firstly, during teaching learners' attention needs to be focused on the most important aspects of the concept that is being explained. The educator should know the learners well enough to use the correct stimulus in the correct context to trigger the appropriate knowledge framework in the long-term memory. The educator can effectively focus the learners' attention on important detail through cues and questions and at the same time take their attention away from extraneous information (Gunter, Estes & Mintz, 2007:19).

Secondly, the new information needs to be pruned to the essential information communicated to the learners in order to keep their attention focused on the most important aspects of the concept taught. In the process the working memory of the learners should be supported to organise the new concepts into coherent mental representations (Ormrod, 2011:191).

The theoretical content knowledge of the educator is used to formulate and represent science and the concepts taught into a comprehensible unit for the learner (Bybee, Powell & Trowbridge, 2008:25). The educator needs to know what makes the concept easy or difficult for the learners, what misconceptions they might have and what the learners' preconceptions are. According to Gunter *et al.* (2007:31), the educator must keep in mind that the learners' understanding is built on previous, more general understanding and that every concept includes other more complex concepts and also more general concepts at the same time.

Thirdly, the newly acquired information has to be linked by the learner to existing knowledge structures in the brain of the learner, and these structures are not just knowledge-dependent but also context-dependent. Prior learning and general knowledge form the foundation for more sophisticated learning (Gunter *et al.*, 2007:19). The information is now placed in the long-term memory ready to be activated when the brain is stimulated again. This can be achieved by using comparative organisers that link the new concept to familiar situations or events. The learners now have a framework and a context within which to place the new concepts (Gunter *et al.*, 2007:39).

An important point that Redish (2002:31) made is that educators should not only look at whether learners provide the correct answers or not during assessment, but also needs to consider the learners' thinking processes. Educators should also provide the learners with more realistic problems so as to determine whether learners access the appropriate information correctly.

From the discussions above it becomes evident that learners do not enter the classroom as empty vessels but they have existing knowledge structures, skills and experiences known as cognitive resources that play a role in building new knowledge frameworks. These cognitive resources are of utmost importance to the educator if he or she plans on reaching his learners, and are discussed in the following section.

2.4 COGNITIVE RESOURCES

Cognitive resources are the tools or skills that learners possess with which new knowledge is made sense of or interpreted in order to enable learners to link the new knowledge to the existing knowledge structures (Redish, 2002:25).

The mind of the learner consists of schemata or knowledge frameworks that are patterns of association which is context-dependent. This means that learners reason about the problems based on existing information in their memories (Redish, 2002:25). These schemata or knowledge frameworks form the bases of the cognitive resources and can have a cardinal effect on the learning process of learners.

Educators should have a thorough understanding of these existing knowledge structures and the way in which the learners experience and think about their physical world. Firstly, this knowledge will assist educators to know what possible common mistakes the learners may make when they are confronted with a specific problem (Gregory & Parry, 2006:35). Secondly, the learners can use their cognitive resources to build future knowledge on. The learners also use these resources to merge new information with existing schemata or knowledge frameworks. According to Hammer (2000:52), learners update their existing knowledge framework so that they can explain the world they live in. Following are three types of cognitive resources the educator needs to be aware of.

2.4.1 General novice conceptions

Not all preconceptions in learners are misconceptions or alternative conceptions. Some ideas of the physical world are not well defined but can be used to explain the new concepts. Hammer (2000:53) uses the example where the learners' knowledge of a spring can be used as an anchoring conception to explain passive forces. It was found that the alternative conceptions held by learners are not completely wrong, and then the educator must use the part of these conceptions that is correct and develop the concept so that the learners reconstruct the concept correctly in their minds (Donovan & Bransford, 2005:399; Hammer, 2000:52).

What is important is that educators need to address these preconceptions of the learners during the learning process if they want the learners to understand Physical Sciences (Donovan &

Brandsford, 2005:399). Donovan and Brandsford (2005:400) opine that conceptual change is not possible if these preconceptions of the learners are not addressed and refined or replaced by scientifically more correct concepts.

2.4.2 Modular reasoning structures

Redish (2002:28) refers to Di Sessa's (2000) work where he mentions that learners have "*primitives and facets*", which are simple statements to explain more complex scientific phenomena. This means that the learners either make the correct observation of scientific phenomena but draw inappropriate generalisations or map the concept to the wrong variables. Redish (2002:29) mentions that the correct elements in these primitives and facets can be used to build on in order to help learners alter their existing knowledge.

Scientific investigation is a process that involves observation, imagination and reasoning (Donovan & Brandsford, 2005:405). This leads to opportunities in the learner to merge the class experience to their world experience and give them the opportunity to organise the data into new conceptual frameworks.

2.4.3 Everyday experiences

Very little instruction incorporates everyday experiences in teaching, and in so doing, new concepts are formed in the brain of the learners with no link to existing concepts. Therefore when everyday experience is not incorporated into the learning process, it does not make the learning experience relevant for the learners (Redish, 2002:29) and opens the learners for misinterpretation of questions. Many of the thinking skills educators are trying to infuse upon learners can be linked to skills that the learners already possess and apply every day. The learners should learn the content of the work through active engagement in a relevant process of scientific inquiry (Donovan & Brandsford, 2005:405).

These cognitive resources are aspects of cognitive principles that inform teaching and learning. There are also other aspects such as social and environmental factors, which influence the learning experience. However, for the focus of the study these aspects are not discussed.

2.5 IMPLICATION OF COGNITIVE SCIENCE ON TEACHING AND LEARNING

When considering the memory-related guidelines and the principles for teaching one notice that the constructivist principal and the change principal are linked to the point where newly acquired information is linked to existing knowledge structured. The context principle, individual principle and social learning principle is associated closely to the focusing of attention and the pruning of the essential information. The lesson must be customised to the needs of the learners.

According to Redish (2002:30), the five principles for teaching physics that forms an integral part of the cognitive learning theory (cf. par. 2.3.3) are:

- 2.5.1 the constructivist principle
- 2.5.2 the context principle
- 2.5.3 the change principle
- 2.5.4 the individual principle
- 2.5.5 The social learning principle.

2.5.1 The constructivist principle

Constructivism views the learner as playing an active role in building understanding and making sense of the given information (Ormrod, 2011:182; Woolfolk, 2010:310). Redish (2002:30) defined constructivism as follows: *“Individuals build their knowledge by making connections to existing knowledge; they use this knowledge by productively creating a response to the information they receive”*.

The constructivist principle has a wide range of intellectual roots:, Piaget, Vygotsky, Gestalt, Bartlett and John Dewey, to mention but a few (Colman, 2009:166). There is not a single view of knowledge construction by the scientists, however, they agree on two central ideas (De Mynck & Van der Walt, 2006:32; Woolfolk, 2010:311):

1. The learners are actively constructing their own knowledge (individual constructivism).
2. Social interaction plays a central role during knowledge construction (social constructivism).

There are, according to Woolfolk (2010:313), three groups of thought that play a role regarding the construction of knowledge. Firstly, the information-processing theories claim that knowledge construction is a representation of the outside world. Learning is affected by direct teaching, feedback and explanation. Knowledge accurately reflects the outside world. Secondly, the Piaget chain of thought views the construction of knowledge as transforming, organising and reorganising prior knowledge. Piaget claimed that experience is the key, as it influences thinking and thinking influences knowledge. Therefore, teaching should consist of exploration, discovery and investigations. Thirdly, Vygotsky claimed that knowledge is constructed by social interactions and experiences. The outside world will be reflected by the knowledge through a filter of culture, beliefs, language, interactions with others and direct

teaching. The afore-mentioned ideas should form part of the teaching-learning strategy in the classroom.

2.5.2 The context principle

The process of learning is important, as is the internal and the external conditions surrounding the learning process that facilitates the recalling of the memorised work.

Redish (2002:31) states the context principle as follows: “What people construct depends on the context – including their mental states”. According to Redish (2002:31), educators should guide learners to construct new information into a rational framework that is correctly linked so that, when it comes to recalling, a wide variety of contexts can trigger the information again. Hence, recalling of the information is done more effectively in different scenarios. Woolfolk (2010:250) mentions that the way the learners in which learned the work will definitely affect the way in which the learners will remember it later on.

According to Redish (2003:22), this implies that when an external stimulus is received the information is presented to the working memory and this information is situation-dependent. The implication of this is that the learners can have a concept for everyday experience of force and a classroom experience of force. Each forms its own construct in the brain, and the one that is stimulated will be presented to the working memory.

Secondly the state of the mind of the learner at the time a stimulus is received will also play a role in memory. If we look at a situation where a football is kicked by a learner, the situation can lead to answering a question in terms of force or energy. If the leading question is on force, the response from the learner will be in terms of force (Redish, 2004:22).

Physical and emotional aspects of context are stored into the brain, together with the information that is learned (Woolfolk, 2010:251). This implies that the conditions (place, room, mood or company) under which a learner learns enhance the recall of the work in the same environment. For example, when learners learn material under exam conditions, they may remember it better during an examination.

The internal state of the learner can also serve as cues during the recall of memory. If the learner is in a positive mood when new information is learned, the information can be recalled much easier when the learner is in a positive mood again, and vice versa (Woolfolk, 2010:251).

“Even the intuitive act of knowing does not occur in a vacuum but can only occur within the context of the subject’s existent network of discriminating correlations in which specific materials and their components, procedures, relationships and classes of sensations are distinguished

and correlated” (De Muynck & Van der Walt, 2006:36). They furthermore state that “even the simplest statement depends on an already existing conceptual network that gives factual meaning to the components of the sentence ...” Knowing is furthermore described by De Muynck and Van der Walt (2006:36) as “a constructive response to the objects to be known”.

Context cannot be ignored during teaching. The educator needs to know his/her learners very well and be in touch with their environment in order to reach every learner. The context is important for learners to elaborate or change their knowledge frameworks.

2.5.3 The change principle

With regard to the change principle, Redish (2002:32) illuminates: “It is reasonably easy to learn something that matches or extends an existing schema, but changing a well-established schema substantially is difficult”. Elaboration or change is a way in which learners make sense of new information by linking it with existing knowledge structures in the long-term memory (construction). This process is done through assimilation or accommodation (cf. par. 1.3.3).

Assimilation occurs when new information is combined in the long-term memory into a more detailed conceptual framework (which is the preferable one of the two). Accommodation, on the other hand, occurs when the new information replaces the existing concept within the conceptual framework (Woolfolk, 2010:251). Accommodation is very difficult to accomplish in learners, especially when the knowledge structure exist for a long period of time. Hence, assimilation is preferable over accommodation.

The faster learners elaborate the new information, the easier they tend to recall the information at a later stage. Elaboration does not only change schemas, but also forms new links between other knowledge structures. The more elaborate these structure are, the deeper the understanding of the work and the better the recall of the knowledge (Woolfolk, 2010:251).

The brain has the ability to deal with and remember everyday events and experiences immediately. The brain also attempts to make sense of concepts and experiences, in other words, the brain searches for common patterns and relationships. In addition, the brain constantly tries to improve or update knowledge frameworks (Caine & Caine, 1994:8).

The term neuroplasticity was introduced in paragraph 2.2 and refers to physical changes that occur in the brain of learners as a result of experience and interaction with new concepts and the environment. The new knowledge that is generated is structured in the brain as concept frameworks (Caine & Caine, 2007:6), and new connections form between different neuron axons and dendrites.

Educators may find it challenging to change learners' existing schemas or knowledge frameworks. According to Redish (2002:32), the learners' existing knowledge frameworks will not change when telling them to do so or when providing them with knowledge or even more exercises. This is where the concept development teaching strategy fits in that will be discussed in Chapter 3.

Since each and every learner is unique, they will not always respond to the same stimuli activating the same construct or knowledge framework. Educators need to be aware of this.

2.5.4 The individual principle

Redish (2002:37) illuminates the individual principle as follows: "Since each individual constructs his or her own mental structures, different students have different mental responses and different approaches to learning. Any population of students will show a significant variation in a large number of cognitive variables".

When teaching, the first thing an educator should do is to discover the extent of the knowledge framework that is contained within the learners' long-term memory by asking questions or doing an experiment and listening carefully to their answers or discussions before attempting to teach the learners.

In an experiment to compare learners' observation and explanations in successive demonstrations, Hakkarainen and Ahtee (2010:176) found that information not processed in the working memory is forgotten. They also found that the information in the long-term memory is scanned when new information is received from the sensory memory so that three scenarios develop when a learner makes an observation.

- Firstly, if earlier experiences are activated in the long-term memory the important information is extracted from the long-term memory. In the working memory the information is merged. This may lead to a meaningful scientific explanation when the information is linked to a scientific law or it may lead to an alternative concept if linked to an everyday experience (Hakkarainen & Ahtee, 2010:176).
- Secondly, if inappropriate information is activated in the long-term memory, the sensory information will be disregarded as gratuitous information (Hakkarainen & Ahtee 2010:176).
- Thirdly, no observation is made when no sensors are triggered in the long-term memory by the observation (Hakkarainen & Ahtee, 2010:176).

Hakkarainen and Ahtee (2010:176) mention that, when the learners do not manage to activate any information in the long-term memory they either try to spontaneously explain the situation or they do not give any explanation.

Educators should therefore not use what “works” for the educator when explaining new work to the learners. Although it may sound logical to him/her, the educator should be sensitive to the learners and also understand that not all learners learn the same way or have the same pre-knowledge. Educators should rather find common ground in relation to the learners’ pre-knowledge and apply different teaching strategies to teach the same topic.

Dekkers and Thijs (1997:32) found it important to ensure that the learners are on the same knowledge level before continuing with new work. In addition, learners differ each year. Some strategies that might apply for a group during one year, might be ineffective for another group in the next year (Redish, 2002:38).

2.5.5 The social learning principle

Redish (2002:39) states the following regarding the social learning principle: *“For most individuals, learning is most effectively carried out via social interaction”*. Learning and development in learners are shaped through social interaction, cultural tools and activities (Woolfolk, 2010:312). This is accomplished when learners interact with one another around an activity. Many scientists are of the view that higher mental processes develop through negotiation and interaction (Woolfolk, 2010:315).

Caine and Caine (1994:29) mention that learners’ brains are shaped by their environments. When a child is born it grows up in a family, shaping its brain through experiences and modelling of family members. As the child grows up its social circle expands to more than the immediate family and this leads to more experience and modelling (Rogers & Horrocks, 2010:114). The child’s initial learning experience forms the basis of future learning.

The individual interacts with the material surroundings all the time and these interactions are transmitted socially. Subsequently, the mental ability of the learners is socially dominant (Illeris, 2007:99). Experience changes learners’ physiological structure and the operation of their brains. Learners from more enriched environments will have more developed brains. Early development in learners asks for safe, consistent environments that provide variety with rich emotional, social and cognitive interaction (Caine & Caine, 1994:29).

Previous studies revealed that learning is influenced by the role model and the attitude of the role model towards the subject (Rogers & Horrocks, 2010:114). The learners experiment with ideas, running them with their peers and also learn to communicate concepts in a process of

making meaning of their experiences. Learning also influences the community and the personality of the learners (Illeris, 2007:112).

Social learning plays a major role in setting the context within which concept development takes place. Educators need to be aware of social influences on the learners and manage the classroom climate to ensure maximum safety and participation.

2.6 CONCLUSION

The information-processing theory that forms part of the cognitive learning theory provides an understanding of how learners think and form memories. This theory is becoming more predominant and important as new discoveries in the field of neuroscience actually confirm the information-processing theory and the cognitive learning theory. One example is the research done about the neuroplasticity (cf. par. 2.2) which is the physical changes that is taking place in the brain when concept frameworks are formed during learning.

Neuroscience also informs the cognitive learning theory and teaching and learning in such a way that it motivates the reasons for sound teaching practices. The principles on which the cognitive learning theory is based, are strengthened by neuroscience; in fact neuroscience confirms these principles. Considering Figure 1.1 the concept-development teaching strategy is based on information-processing in the cognitive theory and will be discussed in the following chapter.

CHAPTER 3

TEACHING AND LEARNING OF PHYSICAL SCIENCES CONCEPTS

“If I had to reduce all of Educational Psychology to just one principle, I would say this: The most important single factor influencing learning is what the student already knows. Ascertain this and teach him accordingly” (Ausubel, cited in Redish, 2002:69).

“...what good is it to have students know the quantitative relation or equation for gravitational force if they lack a qualitative understanding of force and concepts related to the nature of gravity and its effects” (Donovan & Bransford, 2005:401).

3.1 INTRODUCTION

Concepts are mental categories for objects or events, and are stored in the brain in a network reflecting the relationship with other concepts, known as a propositional network, or also called a conceptual framework (Baron, 2001:222; Woolfolk, 2010:246). In this network of concepts links are formed with other concepts through some commonalities between them (Limón & Mason, 2010:6). A concept is represented by an exemplar, which is an example of a situation that comes to mind when the learner thinks of the concept (Baron, 2001:222).

As the learners learn, new connections are built in the brain between concepts, forming a conceptual framework that is coherent (cf. par 2.3.4). Coherent conceptual frameworks, which can either be correct or wrong, enable a learner to make predictions, to explain and answer questions (Limón & Mason, 2010:7). Coherent wrong conceptual frameworks can lead to an explanation by the learner that is scientifically wrong, but in the perception of the learner correct and are known as a misconception or an alternative conception. These coherent but wrong frameworks are particularly stubborn and difficult to rectify. In Physical Sciences, conceptual change teaching strategies are often used to deal with stubborn conceptual frameworks that are difficult to change (Treagust & Duit, 2009:91).

Scientific knowledge is taught to learners by analysing and dissecting the scientific concepts that the learner has to learn, into constituent sections based on the competence of the learners (Woolfolk, 2010:256). However this can only be done after the teacher has determined the learners' novice conceptual understanding of the concept or prior content knowledge in question (Moseley, Braumfield, Elliot, Gregson, Higgins, Miller & Newton, 2005:235). During the lesson this novice conceptual framework of the learner should be changed into a scientific correct or acceptable conceptual framework through a process of conceptual change. Donovan and Bransford (2005:400) mention that if educators fail to address the learners' novice concepts they forsake their task to assist learners to replace or correct their conceptual framework to a scientific more acceptable framework. An important consideration for the educator is that the learners' novice conceptions have been part of their existing knowledge framework and form

part of their world and how they perceive it. In order to change these concepts the teaching-learning strategy must be purposeful, especially with regard to difficult concepts like Newton's laws of motion.

What is important for this study is that the psychologists focused their studies on how information is stored in the long term memory and more specific the semantic and episodic memory, and not on how the information got there (Baron, 2001:221). In order to understand the conceptual development teaching strategy, one should also understand how concepts are stored in the brain of the learner and how the learner interrelates with these concepts during teaching (intervention). Neuroscience explains the path that the information travels in addition to the filters that information passes through during learning (cf par.2.3.3). Neuroscience furthermore indicates that it is essential that relevant existing information is directed to the prefrontal cortex where the new information and the information from the long term memory can be merged into a coherent conceptual framework (Sousa, 2010:53). Without this merging process learning is not possible (Gregory & Parry, 2006:27).

In chapter 2 the focus was on cognitive psychology and neuroscience, in particular the information processing view of learning and the role that concepts play during this process. Concepts and its connections within the conceptual framework are central in the knowledge structure or framework of the learners and form the foundation for future learning (cf. par 2.3.4). In this chapter, the focus will be on the instructional or educational psychological view of learning with Newton's laws of motion as fundamental concept.

Instructional psychology is the science where learning and teaching meets and focuses on how teaching and the teaching environment facilitate learning (Vosniadou *et al.*, 2001:382). The principles for teaching and learning (cf par. 2.5), must be considered when the educator decides on a teaching strategy or learning experience. In this study the focus is on Newton's laws and it is important to note that this topic has its own unique challenges during the teaching-learning process, as indicated in the previous paragraphs (cf. par.1.2 & par. 1.3.4.4.). As indicated in Figure 1.1, the goal is to reach conceptual development teaching strategies. During the following paragraphs the conceptual development, conceptual change and then teaching strategies strategy will be discussed.

3.2 CONCEPTUAL DEVELOPMENT IN TEACHING AND LEARNING PHYSICAL SCIENCES

During the learning process, concepts play a central role, especially with regard to Physical Sciences. Educators should aim to get their learners to understand the physics concepts and its roots in the physical world they live in (Novak, 2002:551). The learners should be able to construct the physics concepts into coherent physics frameworks in order to use these concepts

in a wide variety of scenarios and contexts. The learners should also have a clear understanding of the scientific concepts so that they are able to analyse problems by using the correct conceptual framework at the correct time (Donovan & Brandsford, 2005:576). Hence, activating the correct knowledge framework will result in the brain sending the correct information to the working memory to be merged with the information from the sensory memory (cf. par 2.2).

During the process of learning, concept elaboration can take place, an alternative concept can form or the information coming from the sensory memory can be rejected altogether (cf. par. 2.5.3). Elaboration occurs when a scientifically more acceptable concept and subsequently a more coherent conceptual framework can be formed (Jensen, 2008:173). When both sets of information, the information from the sensory memory and the information from the long-term memory, is merged into a more scientifically acceptable concept, the process is known as assimilation. When the concept in the long-term memory is replaced in total by the information from the sensory memory, the process is called accommodation (Woolfolk, 2010:251; Dekkers & Thijs 1998:30; cf. par. 2.5.3).

Alternative conceptions or misconceptions often form when the learner is unable to merge the information from the sensory memory with a concept in the long-term memory or replace the concept in the long-term memory. This can happen even when the new concept is called the same as a concept already in the long-term memory. Concepts such as force, power and work, to name a few, are some examples of concepts that pose problems with the formation of alternative conceptions in that the learner can develop two conceptual frameworks of the same concept. The learner develops a novice interpretation and a scientific interpretation of these concepts. The common, every-day, general or novice uses of these terms are completely different to the scientific application of these terms. When the context within which the new information is set and the context in which the concept in the long-term memory is set, is completely different, the learner will not be able to make associations between them. When the information from the sensory memory clashes directly with the properties of the concept in the long-term memory, the information from the sensory memory will either be rejected completely by the learner or the learner will form a new concept (Woolfolk, 2010:251; Dekkers & Thijs 1998:30).

During the learning process the brain uses the productive cognitive resources associated with a physics framework available to the learners to form a new more advanced conceptual framework of a concept (cf. par. 2.4). For example, the concept of force will be linked to other concepts such as velocity, acceleration and work, to mention just a few connections. This enables the learner not just to know the concept, but also its context and relations to other concepts. This framework is context-dependent. However, it is expected from learners to

answer questions on the same concept in different contexts (Taber, 2001:732). To be able to transfer knowledge to other contexts, the learners need to have a sound understanding of the concepts. The educator will eventually assess the ability of a learner to recognise concepts during a situation analysis. The educator will assess whether the learners can use their conceptual framework to solve problems that are set in a variety of contexts.

3.3 INITIAL CONCEPTS AND MENTAL FRAMEWORKS

A lesson learned from the past is that the way in which learners approach a problem is almost always different to the way experts face the problem (Guzzetti & Hynd, 2008:57). Vosniadou *et al.* (2001:384) provide the example of an inclined plane where learners' concepts will most probably be represented by external situational properties, whilst experts' concepts will most probably be represented by Newton's laws and the conservation of energy. A learner views a surface condition as reason for an object not sliding down the surface while an expert takes into consideration the gravitation force and its components on the object, normal force and the static frictional force.

Learners should be encouraged to change their initial novice conceptual framework into an expert conceptual framework. The alternative is to try to persuade the learners to replace their existing conceptual framework with the new conceptual framework, which is very difficult to achieve.

The learners' initial novice conceptual framework restricts their problem-solving ability and needs to develop into an expert view of the concept over time with the persuasion and effort from the educator. This is a process which starts at a very young age (Guzzetti & Hynd, 2008:57; Vosniadou *et al.*, 2001:384). As children experience their world and interact with it, they experience concepts such as gravity and motion and form initial knowledge frameworks that form the basis for future learning. From this experience they for example see force as an internal property of an object and not as a cause of action that changes the kinetic or physical state of matter.

The novice conceptions of force and kinematics in learners are almost identical to the historical view of motion, as seen in the previous paragraph. This underlying knowledge of forces and motion that forms the naïve or novice conceptions that generates an intuitive or novice knowledge framework of motion was investigated by physics educational researchers. The intuitive knowledge of motion and force is based on the learners' experience of the world and the pre-newtonian view of forces (Vosniadou & Ioannides, 1998:1213).

Vosniadou and Ioannides (1998:1213) mentioned the alternative framework is formed due to well-defined internally consistent interpretation of force that is not combined with or merged into

an intuitive or existing concept of force. The development of the novice framework starts at a young age when learners experience force as an internal property of an object and then develops into a view of force being an acquired property of an object. At a later stage the learner will combine different views of force and integrate it with the existing framework of force. It can lead to confusion if the learner has a fragmented view of force which they obtain when they develop alternative frameworks of force and motion. More attention must be given to the learners' conceptual framework and not so much to the stage-dependent view of cognitive development (Vosnaidou & Ioanides 1998:1213).

Woolfolk (2010:476) mention six stages through which learners progress during conceptual change to reach conceptual understanding. The learners move from:

- a point where they are comfortable with their own concept to
- an initial discomfort, then
- the learners try to rationalise inconsistencies,
- moving to a direct attempt to adjust measurements or observations to fit into their own conceptual framework.
- This is followed by doubt and vacillation and then
- finally conceptual change and understanding of the concept.

It is important to design and test teaching strategies to foster conceptual change so that the learner can form a realistic conceptual framework of the science concept (Wiser & Amin, 2001:332).

During the process of forming an expert concept of force, a misconception is most of the time the prior knowledge that is used to construct new knowledge. The educator needs to use appropriate methods to facilitate learning so that the learners develop correct and consistent scientific concepts (cf. par. 2.3.2). In order to achieve a consistent scientific concept during the learning process, the educator has to give thorough attention to goal-setting in order to direct his/her strategy of instruction (Staver & Shroyer, 2011:1).

3.4 CONCEPTUAL DEVELOPMENT THROUGH CONCEPTUAL CHANGE

The development of the novice conceptual framework of learners is not an easy or a quick process. It is a gradual building process, starting with the learners' experience of their world and building it up through the years as they progress through their school career (Limón & Mason, 2010:34). Keeping the cognitive principles in mind, the educator needs to know the learners' prior knowledge and the tools they bring into the classroom in order to develop a suitable teaching sequence and strategies for the learners.

The learners may see force as either an internal or an acquired property of the object that makes the object move. Such novice ideas cause many misconceptions and misunderstandings of force and energy (Vosniadou *et al.*, 2001:387). First of all, educators need to address the problem of the deeply entrenched presuppositions and beliefs of force, as mentioned in the previous paragraph, where the learners see force as a property of the object. This presupposition needs to be reinterpreted through the correct teaching strategies to form a more scientifically acceptable construct, namely force as the action of one object on another (Guzzetti & Hynd, 2008:57; Vosniadou *et al.*, 2001:388). In the case of force, the misconceptions are deeply entrenched in the conceptual frameworks of the learners, and time is needed to change the learners' concept of force. Making the learners aware of the misconceptions is only the start of the conceptual change teaching strategy.

Awareness of misconceptions is not enough; educators also need to create a meta-conceptual awareness of the learners (Vosniadou *et al.*, 2001:388). Meta-conceptual awareness is a point the learners reach where they recognise the misconception in their own conceptual framework and rectify the concept by reallocating the concept to the correct framework or rearranging the framework correctly (Limón & Mason, 2010:19). During the teaching of the concept the learner may develop an alternative concept of force additional to the existing misconception of force, due to the fact that these misconceptions are so deeply engraved in the long-term memory of the learners. The educator must be aware of this fact, and that the misconception needs to be changed into a more scientific concept. If the educator does not achieve this goal the learners may then use these misconceptions to solve problems. The learners will retain an alternative conceptual framework for force without being conscious of it. In some situations the learners may use one concept of force, and in others, especially in new situations or contexts, fall back to the initial novice conception of force (Taber, 2004:96). Conceptual change involves meta-conceptual awareness by the learners and the formation of more organised frameworks with greater consistency to explain situations more adequately.

During the learning process the pictures and diagrams that learners see are saved in the long-term memory with links to concepts that are used to provide an explanation to the picture or situation (Sousa, 2010:59). Mental misrepresentations, also a form of misconception, need to be adjusted or replaced with the correct representations. Sometimes it is the context that needs adjustment and sometimes it is only a focus change. It is important that the educator develops scientifically correct mental representations of force in the learners' minds, because of the interrelatedness of concepts in science. Misrepresentation can lead to other misconceptions (Vosniadou *et al.*, 2001:390). These delicate mental representations are placing even more emphasis upon the development of a teaching strategy to rectify these misconceptions by the educator.

Vosniadou *et al.* (2001:390) mention that the order of acquisition and the teaching strategies are influenced by the concepts that comprise of interrelated subject matter. An appropriate teaching sequence, and more directly the teaching strategy of force needs to be implemented if conceptual change is to be achieved. Sometimes a misconception may impede the understanding of a concept, hence affecting the development of a scientifically correct conceptual framework and ultimately affecting the problem solving process negatively (Limón & Mason, 2010:34).

3.5 TEACHING STRATEGIES TO FOSTER CONCEPTUAL CHANGE

Scott, Asoko and Driver (1991:1) mention that there are two groups of basic strategies that promote conceptual change learning, namely the *cognitive conflict* and *development of ideas* strategies. Both strategies use the learners' existing novice concept and develop it into an expert concept. The two groups of strategies achieve conceptual change, but are different in focus. The *cognitive conflict* strategy is a very direct strategy and focuses more on conflict that is created between the learner's concept and the scientific concept. Once the learners accept the scientific concept, they have ability to change their conceptual framework during learning. *Development of ideas* strategy is a strategy that focuses more on the educator's ability to provide scaffolds and gradually pilots the learners through predetermined steps to develop their conceptual frameworks. These two strategies empower the learners to achieve conceptual change through a conceptual development process. These groups of teaching strategies are based on Piaget's theory of elaboration that consists of assimilation and accommodation (cf. par. 2.4.3).

3.5.1 Cognitive conflict teaching strategy

There are two main schools of thought when it comes to cognitive conflict teaching strategies (Scott *et al.*, 1991:1). The first and more direct method is the so-called "*discrepant events*" and the second, which has three underlying strategies, is the "*conflict of ideas*". Both strategies are based on the principle of accommodation. When the learners develop a conflict between their existing concept and the new concept, the old concept is supposed to be replaced by the new, more acceptable concept (Duit & Treagust, 2003:4).

During the "*discrepant events*" strategy the learners are first of all exposed to an event and their preconception is activated through their response to the situation. The learners' existing knowledge frameworks are sharpened with predictions or discussions by the learners trying to make sense of the situation. Cognitive conflict is established when the learners start to interpret the results or attempt to explain the events. The educator should encourage and guide learners to cognitive accommodation and the formation of a more scientific concept or knowledge framework (Limón & Mason, 2010:102; Scott *et al.*, 1991:2).

An example is when the pendulum experiment is done to determine the gravitational acceleration of an object. The educator asks the learners whether mass has an influence on the gravitational acceleration. The learners make a prediction and discuss why they think mass has an influence on the gravitational acceleration or not. The experiment is done and the results are discussed. If the experimental results do not concur with the learners' predicted results conflict is established. The learners will initially reject the experimental results or attempt to adjust the results. If this attempt fails the learners will doubt their own existing concept. Once they accept the results, the conceptual framework of the learner is adjusted to accommodate the new information and conceptual change occurs.

The “*Conflict between ideas*” or cognitive conflict group of strategies involve three strategies:

- Firstly, the “*Generative learning model of teaching*”, is organised into four phases (Scott *et al.*, 1991:2). The first phase is the preliminary phase during the educator's preparation where the educator orientates himself /herself according to the learners' pre-concept, the scientific concept and his/her own concept. The educator can use standardised tests like the FCI, to establish the learner's concept of force. The focus phase aims to provide learners the opportunity to explore the context of the concept in a real everyday situation and to clarify their views. During this phase the educator can supply the learners with a piece of paper and a metal ball and ask them which one will land first if you let them fall from the same height at the same time. This phase is followed by a challenge phase where the learners get the opportunity to debate and challenge each other's concept and also give the educator the opportunity to introduce the scientific view of the concept. For example, the educator firstly demonstrates with a open, flat paper (with air resistance) and secondly with a paper folded into a small ball (without air resistance). Educator explains: if $g = \text{constant}$ then $F \propto m$. Finally, the learners get the opportunity to apply their view to a wide range of different contexts.
- Secondly, the “*ideational confrontation*” strategy is based on a situation where the learners make predictions or explanations about a physical situation challenging their concept. For example, the educator supplies the learners with a piece of paper and a metal ball and asks them which one will land first if you let them fall from the same height at the same time. The learners will then develop an analysis of the situation and present it to the class, followed by a class discussion where they attempt to convince each other, which leads to every learner's concept being challenged within the context. The educator will then demonstrate the situation, followed by the scientific explanation of the scientific concept. First, the educator demonstrates the experiment with the paper open (with air resistance) and secondly with the paper folded into a small ball (without air

resistance). Educator explains: if $g = \text{constant}$ then $F \propto m$. Finally, the learners get an opportunity to challenge the scientific concept in a class discussion (Scott *et al.*, 1991:2).

- The third “*Conflict between ideas*” strategy follows a different approach to the previous strategies in that the learners are first confronted with the new scientific concept and then confronted with their initial concept. The educator explains the experiment to the learners. They are asked to write their predictions on a piece of paper. The educator first demonstrates the experiment with the paper open (with air resistance) and secondly with the paper folded into a small ball (without air resistance). This is followed by a class discussion where the educator clearly proves to the learners that all objects accelerate with the same acceleration to the ground. This is because, if $g = \text{constant}$ then $F \propto m$.

The principle this strategy is based upon is that a concept is only replaced by a better and more acceptable concept. The confrontation is not necessary for the construction of new knowledge, and although conceptual change involves strategic and meta-strategic knowledge they need not be constructed simultaneously (Scott *et al.*, 1991:3). The educator establishes the learners’ ideas regarding a situation and the learners make notes of their views. The learners are enlightened with the new scientific concept, followed by the explanation linking the new knowledge to existing knowledge. The new knowledge is applied to problems and then followed by a discussion on the comparison between the learners’ initial concept and the explained scientific concepts (Duit & Treagust, 2003:4).

One of the dangers of using the cognitive conflict strategy is that it can lead to an alternative concept formation or reinforcement of an alternative concept during the teaching and learning process. This will happen when the new knowledge does not sufficiently persuade the learners that they see the necessity to change their existing concept (Scott *et al.*, 1991:3).

3.5.2 Development of ideas

The *development of ideas* teaching strategy takes the learners’ ideas and develops them into a scientific construct. This is in contrast with the cognitive conflict strategy, which is based on conflict and relies on the learners to change their existing concept into the correct scientific concept (Limón & Mason, 2010:74; Scott *et al.*, 1991:3).

In 1989, Brown and Clement developed a “*bridging strategy*” in mechanics which presupposes that concepts can be achieved by giving learners the opportunity to develop a “*qualitative-intuitive*” understanding of a concept before mastering “*quantitative principles*” (Scott *et al.*, 1991:3). Scott *et al.* (1991:4) mention that the “*bridging strategy*” has been valuable when an analogy is drawn between a misunderstood situation and an “*anchoring example*” which draws

on the intuitive knowledge of the learner. Two examples are selected from the learner's background knowledge: one the misconception and two the "*anchor example*" that is close to the reality. The educator attempts to form an analogy between the ideas. If the learners reject the analogy, "*bridging*" ideas are introduced to link the misconception to the "*anchor*".

Another approach that differs from the previous one, is that the educator does not attempt to replace the learners' novice concept but develops a conscious knowledge of both, the everyday concept and the scientific concept (Scott *et al.*, 1991:3; Wiser & Amin, 2001:333). Wiser and Amin (2001:351) explain that the novice concept and the scientific concept are both elaborated upon to such an extent that the scientific conceptualisation can explain the novice concept, thus merging the two concepts into one theoretical framework. The learners are encouraged to differentiate between the novice concept and the scientific concept and then integrate them into one coherent framework.

The two groups of strategies, namely the cognitive conflict and the development of ideas, have elements of importance within the concept development strategy for teaching Physical Sciences, and more specifically Newton's laws of motion. So when developing a teaching strategy for Newton's laws of motion, all the pre-mentioned strategies need to be considered. There are some theoretical issues flowing from these strategies and the cognitive learning theory that are central when teaching for conceptual change.

3.6 IMPLEMENTATION OF CONCEPTUAL CHANGE TEACHING STRATEGIES

The knowledge that the learner brings into the classroom is a key factor in the cognitive learning theory. The challenge for the Physical Sciences teacher is to use these pre-existing concepts of the physical world as a starting point for teaching (Duit & Treagust, 2003:2). It is testing for educators to guide learners to a point where they have a scientific view of the concepts that are most of the time abstract concepts.

There are a few theoretical issues that need consideration when teaching learners Physical Sciences according to the conceptual development teaching strategy that is based on the cognitive learning theory (Scott *et al.*, 1991:5), which is discussed in the following sub-paragraphs.

3.6.1 The role of novice conceptions of learners

Fundamental to the cognitive learning theory and the associated teaching and learning strategies is the acknowledgement of the existence and a deep understanding of the learners' novice conceptions. The novice conceptions of the learners are their prior knowledge and fundamental ideas they maintained (cf. par. 2.6.1).

There are three aspects to consider when the educator is teaching for conceptual change. Firstly, the educator needs to have a thorough idea of the learners' existing prior knowledge, cognitive tools, concepts and ideas (cf. par. 2.5). The next consideration is the commencement of the planned teaching experience and finally the curriculum design.

Conceptual development teaching strategies provide the learners the opportunity to express and clarify their own view of a concept. The educator uses this opportunity to identify the difference between the scientific knowledge and the learners' knowledge, and uses this information to design future learning (Scott *et al.*, 1991:4). This will also serve as the initiation or the foundation of further knowledge construction (Duit & Treagust, 2003:8). This can be established by pre-tests and class discussions on everyday experiences of the learners.

The information gained from the learners during pre-teaching discussions will to a large extent inform the activation for the educator. Whether he/she follows the cognitive conflict route or the idea development route, designing a target question is eminent. The way forward towards a scientific view will be initiated by the target question (Scott *et al.*, 1991:4). The initial teaching activation for the educator does not necessary correspond to learners' ideas that materialised in class, but rather towards the deeper-lying misconceptions that brought about the learners' views, such as a common misconception about force is the belief that a force is an inherent property of an object. An example of this is the belief that when a learner kicks a ball, the ball will accelerate after been kicked for a while before slowing down.

No matter how educators start a lesson, they must realise that there is a difference between the learners' view, the scientific view and the educator's view. The educator wants to develop learners' view into a scientific view of a concept, and this may lead to conflict in the learners' knowledge framework.

3.6.2 The role of conflict

Scott *et al.* (1991:4) declare that all the conceptual development teaching strategies have an element of conflict in them, whether it is the conflict between the learner's views of the knowledge or the learners' new construct of the presented concept, and the scientific view of the concept. There is always an element of conflict present, often without the learner being aware of it (Duit & Treagust, 2003:27).

For any conflict-based strategy to be successful, the learners must be mentally involved and have the resources to recognise and resolve the conflict. The reason for this is that, at some stage the conflict between the ideas is likely to become unambiguous. However, it is also important to note that the conflict will not always lead to the construction of new knowledge, but

can lead to a deepening in the conflict and an outright rejection of the conflicting idea (Limón & Mason, 2010:107; Scott *et al.*, 1991:4).

Educators can apply conflict in different ways in the classroom (Scott *et al.*, 1991:5), e.g.

- The strategy popularised by Nussbaum and Novic in 1982 (cited in Scott *et al.*, 1991:5) is where learners are made aware of the conflict at the onset of a teaching sequence.
- According to Scott *et al.* (1991:5), Rowell and Dawson found in 1983 that it more effective when the learner clarifies his or her own ideas before confronted with the scientific concept.
- In 1987 Clement suggested that both ideas need to be looked at and compared. He made use of analogy to develop the concept and use the classroom discussions to foster dissonance, internal motivation and conceptual restructuring (Scott *et al.*, 1991:5).
- In 1991 Stavy suggested a strategy to avoid conflict all together so that learning took place without the learners' knowledge of it. She relies largely on analogy in her teaching by matching the learners' knowledge with the scientific knowledge focusing on similarities and not the contrasts (Scott *et al.*, 1991:5).

In Physical Sciences it is always an option to make use of a demonstration or experiments to establish conflict. It is important that the learners need to express their views and communicate their observations. Class discussions can also be used to further develop the learners' concepts. Through the verbalisation of their conceptual framework and ideas the learners are able to get a clear view of their beliefs and to identify the flaws in their conceptual framework.

3.6.3 The role of conceptual framework construction

What makes Newton's laws and other physics concepts so difficult is that they are constructed upon other important concepts, such as velocity and acceleration the learners need to have conceptualised before attempting to conceptualise the main concept. Even the sub-concepts have other concepts they build upon and these concepts are to a large extent abstract. Then we are not even mentioning the cognitive tools needed by the learners during the learning process, such as mathematical tools. During this process the educator should use different strategies to facilitate the learning process, such as making use of "scaffolds" and well-planned assessment to guide the learning process (Scott *et al.*, 1991:5).

When learners verbalise their conceptual frameworks and communicate their ideas with other learners, they manage to identify shortcomings in their own conceptual frameworks. This metacognition creates conflict and persuades the learners to change their conceptual frameworks. Once learners become aware of their own conceptual framework and they start

thinking of the concepts that is the time when they are starting to learn effectively. The learners take control of their own learning and monitor their understanding of the concepts (Donovan & Bransford, 2005:10).

The construction principle, as underlined by the cognitive learning process, emphasises that the educator must know his/her learners and their pre-knowledge (Duit & Treagust, 2003:96). This allows the educator to know where to start with the construction process. Once the starting point has been established the construction process can commence by presenting the complex concept in bits by choosing the appropriate scaffolds so that the whole can make sense.

As an example, the force concept starts with a definition of force, followed by establishing force as a vector. The following scaffolds involve balanced and unbalanced contact and non-contact forces. Vertical motion and horizontal forces are placed in context and the concept of friction is brought into the contexts. Newton's first law and the term inertia are brought into the knowledge framework of the force concept at this stage of the construction process. The roll of inertia on friction is explained and the differentiation between static and dynamic friction is made clear. Then Newton's second law is discussed and placed into context with the motion of objects. Newton's laws of motion are now also linked to mathematical concepts making use of the mathematical tools of the learner.

The learners must be mentally involved during the learning process and it is important that the educator assesses the learners continuously to secure that the learners' mental framework develops during the learning process.

3.6.4 The role of assessment

Assessment is an important link in the learning process. In the first place, assessment is the process through which the educator monitors the progress of learning within the context of the presented content. The educator confirms that the content is made intelligible by the learners.

Assessment as mentioned in the previous paragraph is only the beginning of the assessment process and should not stop at this point. The educator needs to establish that the newly learned concept is forming part of the learners' knowledge framework. The educator also needs to ascertain that the newly learned framework is the preferable framework that the learners use to solve problems. This is especially relevant when it comes to new contexts and also the integration or linking of the concept with other concepts (Scott *et al.*, 1991:6).

Formative assessment is a very powerful tool in the arsenal of the educator with which he/she monitors the learners' progress and keeps the learners mentally involved. Summative

assessment indicates to the educator to what extent conceptual change has occurred during the learning process and it also informs the following lessons.

The most important aspect of assessment mentioned by Scott *et al.* (1991:6), is the internal process taking place in the learners. Learners compare two or more existing concepts with each other and test the internal consistency of the concept. Through this process learners obtain scientific consistency by applying the concept in a variety of contexts.

3.6.5 The role of the learner

The role of the learners can be summarised in one sentence: learners have the responsibility to make sense of the concepts taught and ultimately take responsibility for their learning process (Scott *et al.*, 1991:6). It is a serious call for responsible learners in the classroom to revolutionise the classrooms to places of effective learning and teaching.

The learners need to be engaged in focused small groups and whole-class discussions which are features of effective teaching practices and form part of social learning (cf. par. 2.4.5). These discussions form a forum through which the learners can test their own knowledge structures and also become aware of fellow learners' viewpoints (Duit & Treagust, 2003:2). During this process learners also develop much needed tools such as listening, forming opinions, analysing and evaluating other paradigms (Scott *et al.*, 1991:6).

These discussions place the learner in an intellectual challenging position; they learn to form opinions of other learners' ideas and to communicate their knowledge structures. This is an excellent forum for some learners, but can be detrimental to other learners, according to Scott *et al.* (1991:6). What builds self-esteem in the one learner breaks down self-esteem in another, and the educator needs to be sensitive to these learners and manage the learning and teaching environments.

3.6.6 The role of the educator

The educator should create an environment in which the learners feel safe. In addition, the educator should create a classroom environment conducive to teaching and learning. The learners need to feel free to be themselves and express themselves in a relaxed, though academic focused environment (cf. par. 2.5.2). According to the information processing model for learning it is important for the information to pass through the correct channels for the merging between new information and existing information in the long-term memory. The merging takes place in the working memory. Neuroscience is clear in that, if the learner lacks the necessary security the information from the sensory memory is channelled to the lower brain and learning is impossible (cf. par. 2.3.2).

In order to achieve a favourable classroom atmosphere the educator should be comfortable with himself/herself and his/her knowledge of the subject matter. The educator should be mature enough to manage the classroom environment in such a manner that there are always discipline and mutual respect, not only respecting the person, but also the opinion of individuals (Scott et al., 1991:6).

The educator should know the learners well enough as to confront each learner with a new concept. Therefore, the educator needs to know and understand the learners' knowledge framework of the concept to be explained. He/she also needs to know how the learners learn and how to reach each one of them with the new concept (Scott *et al.*, 1991:6). In order to do this, the educator needs to listen intensely to the learners, ask the right questions and be aware of the misconceptions the learners might have of-n the concepts (Duit & Treagust, 2003:3).

It is the responsibility of the educator to develop the necessary scaffolds for the learners, after determining the learners' knowledge on the concept. The educator should also develop the most effective teaching strategy. Thereafter he/she should develop learning tasks most suitable for the learning progress of the learners. To achieve this, the educator should be a subject matter expert. It will also give the educator the necessary confidence to go into discussion with the learners (Scott *et al.*, 1991:6). In the following section the intervention that was followed by the researcher is discussed.

3.7 CONCLUSION

The focus of this chapter was on learning and it started by looking at how learners learn and how the concepts develop during the process. Conceptual change and the role of initial concepts and mental frameworks play during the learning process were also discussed. Thereafter the goals to promote conceptual development teaching and the different teaching strategies were discussed and the theoretical guidelines given. This was followed by a discussion of how these teaching strategies were implemented in the intervention.

In Chapter 4 the research design and methodology related to this study are discussed and in Chapter 5 the results from the data analysis are discussed. In Chapter 6 findings and conclusions are discussed and recommendations are provided for further research.

CHAPTER 4

RESEARCH DESIGN AND RESEARCH METHODOLOGY

4.1 INTRODUCTION

In this chapter all the information with regard to the research design and quantitative and qualitative methods that were used to evaluate the effectiveness of the proposed conceptual development teaching strategies on Newton's second law of motion are discussed. First the mixed-methods research that was used will be looked at, thereafter the quantitative research method and finally the qualitative research method will be discussed. The ethical aspect that received attention will also be discussed.

4.2 RESEARCH DESIGN

A mixed-methods research design was used in this study (Creswell, 2009:211; cf. Figure 4.1). Creswell and Plano Clark, in Creswell (2009:4), define mixed-methods research as "an approach to inquiry that combines or associates both qualitative and quantitative forms. It involves philosophical assumptions, the use of qualitative and quantitative approaches, and the mixing of both approaches in a study. Thus it is more than simply collecting and analysing both kinds of data; it also involves the use of both approaches in chorus so that the overall strength of a study is greater than either qualitative or quantitative research". According to Creswell (2009:4), mixed-methods research developed as a result of the pragmatic worldview which is not committed to any one system of philosophy. Pragmatism focuses on research problems in social sciences and uses pluralistic approaches to obtain knowledge about problems. So, mixed-methods researchers are allowed different worldviews and assumptions, they may use multiple methods as well as diverse forms of data collection and analysis (Creswell, 2009:10, 11).

There are four aspects that researchers need to consider to determine the kind of mixed-methods design to use. These four aspects are timing, weighting, mixing and theorising (Creswell, 2009:206-207). Theorising refers to the theoretical perspectives that may guide the design (cf. par. 1.6.3). Timing, weighting and mixing and how these relate to this study will be discussed next:

- **Timing**

Timing refers to whether data are collected in phases (sequential) or concurrent (simultaneously). In this study a sequential mixed-methods design was used, as data were collected and analysed in phases or *sequentially* (Creswell, 2009:206) and *not* concurrently (as in a concurrent design).

- **Weighting**

Weighting refers to the priority given in a study to either quantitative or qualitative research. In this study, the primary orientation was *quantitative research* (QUAN) (pre-test and post-test) and qualitative data (qual) were only collected during the intervention.

- **Mixing**

Mixing refers to *when* the quantitative and qualitative data are integrated. In this study the data were integrated during the final interpretation of the entire analysis.

A sequential explanatory design was used in this study, as described by Creswell (2009:209) and McMillan and Schumacher (2010:405). The rationale for this mixed-methods design was to use the qualitative data to elucidate the quantitative findings and also to follow up on pre-eminent and substandard cases (McMillan & Schumacher, 2010:401). The sequential explanatory design as adapted for this study is illustrated in Figure 4.1.

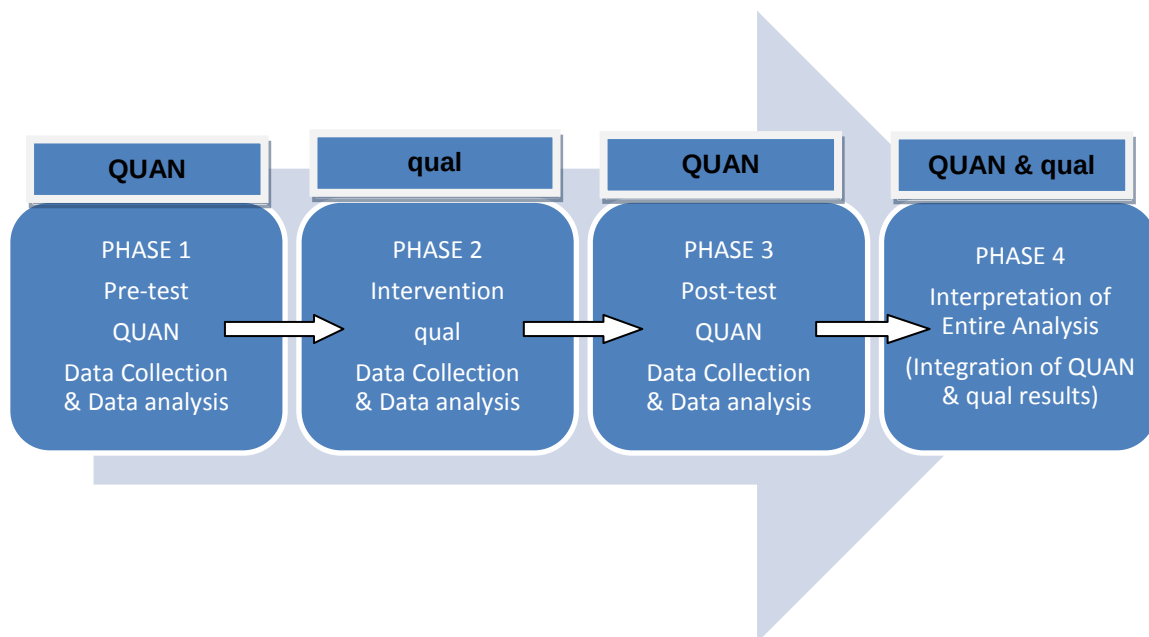


Figure 4.2: Sequential explanatory design (adapted from Creswell and Plano Clark (2007:87))

Figure 4.1 shows that the focus of the data collection in this study was more quantitative (QUAN) than qualitative (qual) and that the study was conducted in four phases. The arrows in the illustration indicate the sequence in which data were collected, namely quantitative (QUAN), qualitative (qual) and again quantitative (QUAN).

The first phase (pre-test) and third phase (post-test) involved quantitative methods to determine learning gain during the intervention. Qualitative data were only collected during the intervention (phase 2). Although the quantitative and qualitative data were collected in different

phases and analysed separately, the quantitative and qualitative data were integrated during the interpretation of the final analysis (phase 4).

During the *first* phase (QUAN) or pre-test, a deductive approach, from the general concept to the specific use or application, was followed and quantitative data were collected by means of the Force Concept Inventory (FCI) (cf. 4.4.1). An inductive approach goes from the specific to the general and may be based on a specific experiment or situation. During the *second* (qual) phase, qualitative data were collected from the same respondents during the intervention by means of a video-recording and analysed (inductive by generating themes). After the intervention, quantitative data (QUAN) were again collected through the FCI (post-test) and analysed in phase *three*. During the final interpretation (*phase four*) the findings of both datasets were integrated and interpreted (Creswell & Plano Clark, 2007:87; McMillan & Schumacher, 2010:401).

The *main strengths* of the Sequential Explanatory Strategy lie in its straightforward nature, easy implementation and steps that fall into clear separate stages. It is straightforward to describe and report. The design appeals to quantitative researchers due to its initial strong quantitative orientation (Creswell & Plano Clark, 2007:74; McMillan & Schumacher, 2010:405).

The need for extensive data collection, the requirement that the researcher has to be familiar with both quantitative and qualitative forms of research, and the length of time involved in the two methods of data collection, especially if the methods are given equal priority, can be considered the Sequential Explanatory Strategy's main *weaknesses* (Creswell, 2009:205, 211). McMillan and Schumacher (2010:405) also mention the additional time that is required to do the research as another disadvantage.

The quantitative method is discussed first in Section 4.3, whilst in the following Section 4.4 the qualitative method is discussed.

4.3 QUANTITATIVE METHOD

The major focus of this study was on quantitative research. Quantitative research is defined by Creswell (2009:4) as "a means for testing objective theories by examining the relationship among variables. These variables, in turn, can be measured, typically on instruments, so that numbered data can be analysed using statistical procedures".

According to Creswell (2009:6), quantitative research was emphasised in the post-positivist worldview which is sometimes called "scientific method or doing scientific research". Post-positivism is based on the thinking after positivism that challenged the notion of absolute truth of knowledge when studying the behaviour or actions of human beings (Creswell, 2009:7). Table

4.1 summarises the characteristics of quantitative research according to McMillan and Schumacher (2010:12).

Table 4.1: Characteristics of quantitative research (McMillan & Schumacher, 2010:12)

Orientation	Quantitative research
Assumptions of the world	The world is a single reality, i.e. measurements can be made by instruments. Positivism.
Research purpose	Establish relationship between measured variables.
Research method and process	Procedures are established before study begins.
Prototypical study	Experimental design reduces error and bias.
Researcher's role	Detached with the use of instruments
Importance of context	Goal of universal context-free generalisations.

Quantitative research can furthermore be divided into two main groups, namely experimental designs and non-experimental designs (McMillan & Schumacher, 2010:20). According to McMillan and Schumacher (2010:20), an experimental design implies that the researcher intervenes with an intervention and has some control over the experience of the subjects. Experimental designs can be subdivided into three designs, namely the true experimental, the quasi-experimental and the single-subject designs, as shown in Table 4.2.

Table 4.2: Quantitative research methods (McMillan & Schumacher, 2010)

Quantitative research methods	
Experimental designs	Non-experimental designs
True experimental	Descriptive
Quasi-experimental	Comparative
Single-subject	Correlational
	Survey
	Ex post facto
	Secondary data analysis

The non-experimental (McMillan & Schumacher, 2010:21) or survey (Creswell, 2009:12) designs refer to research where there is no manipulation of the conditions. It consists of six designs, namely descriptive, comparative, correlational, survey, ex post facto and secondary data analysis. In this study a *quasi-experimental design* was used, specifically a *single-group pre-test-post-test design* which is discussed in more detail in the following section.

4.3.1 Experimental design

The quantitative research in this study was conducted by means of an *experimental design* (Creswell, 2009:155). According to Creswell (2009:229), an experimental design is used in quantitative research to test the impact of a treatment or an intervention on the outcome whilst the researcher controls all other factors that might influence the outcome. In this study the implementation of conceptual development teaching strategies served as the intervention (cf. par. 4.7), and the effectiveness thereof was established on the outcome of learning as determined by the learning gain (*g*) of the learners (Savinainen & Scott, 2002:49).

The kind of experimental design employed in this study is a *quasi-experimental design*, given that a convenience sample and not a random sample was drawn (cf. par. 4.4.1). In particular a *one or single-group pre-test-post-test design* as described by Creswell (2009:160) was used in this study.

The one or single group pre-test-post-test design is illustrated in Figure 4.2 (McMillan & Schumacher, 2010:268; Creswell, 2009:160):

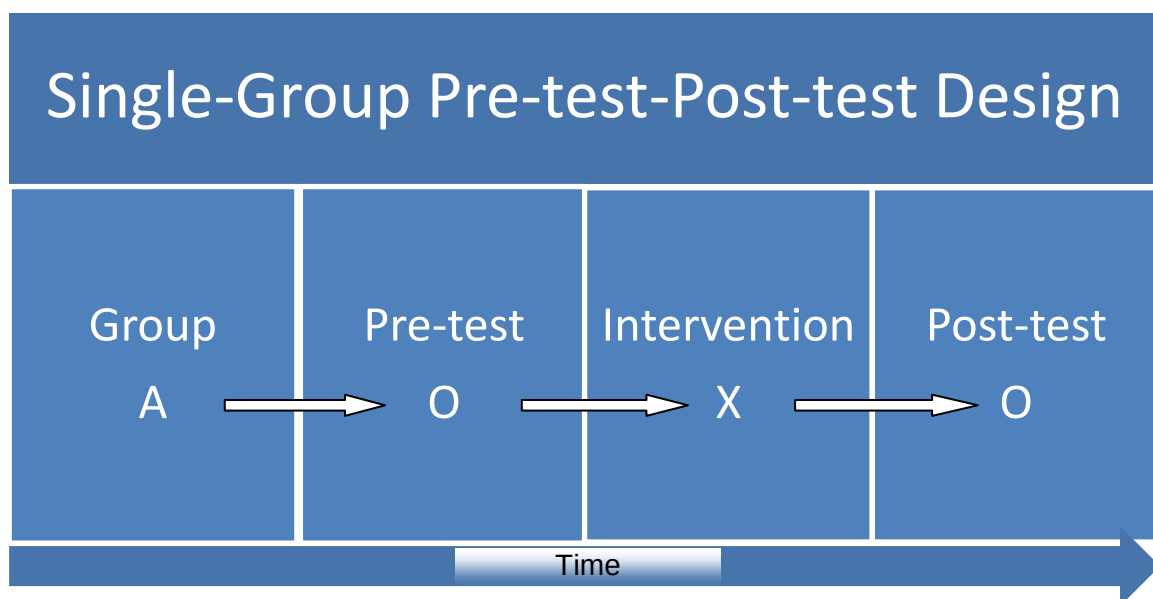


Figure 4.2: Single-Group Pre-test-Post-test Design (McMillan & Schumacher, 2010:278)

The group of learners (respondents) was given a pre-test (O), that was followed up with an intervention (X), and thereafter the respondents did the post-test (O). The results of the pre- and post-tests were used to calculate the learning gain. The result gave an indication on how effective (or not) the teaching strategies (intervention) were.

The rationale for utilising a single group pre-test-post-test design is so that the researcher can establish how much conceptual learning was gained by the respondents during the intervention

or implementation of the teaching strategies. The intervention is explained in Section 4.7. The independent variable in this study is the intervention, namely the concept development teaching strategies on Newton's second law of motion. The dependent variables are learners' conceptual knowledge of Newton's second law of motion and related concepts. The outcome is the effectiveness of the intervention.

4.3.2 Study population and sampling

The study population consisted of Grade 11 English-speaking high school learners who have Physical Sciences as subject. The respondents were selected from a school in town (Potchefstroom) in the Kenneth Kaunda district, North-West Province.

The researcher used naturally formed groups, in particular Grade 11 learners who took Physical Sciences as a subject and who were grouped in three classes. Since the respondents were not randomly assigned, the sample is classified as a convenience sample. The researcher was an educator at the school and all the respondents were taught by him and he also did not made use of other schools learners in the region.

The final sample consisted of 46 learners, specifically 41 African, 2 Indian, 2 white and 1 Asian Grade 11 Physical Sciences learners. Thus all the South African racial groups were present in the sample. All the respondents in the sample were male, because the school consist of boys only. The mother tongue of majority of the learners is Setswana, but they are fully conversant in English, given that they attend an English high school where tuition (instruction) is in English. The researcher employed the teaching strategies whilst teaching the learners in the sample.

4.4 QUANTITATIVE DATA COLLECTION

Quantitative data was collected during the pre and post-tests through questionnaires that were distributed to all the respondents in the sample. The revised Force Concept Inventory (FCI) (Halloun *et al.*, 1995) was adapted for purposes of this study and used as questionnaire to collect the quantitative data (cf. Annexure D). The questions pertaining to Newton's third law and Newton's law of gravitation were excluded due to the focus of the study on Newton's second law of motion. The pre-tests were done by the respondents two weeks before the intervention commenced to give researcher time to analyse the data. The post-tests were done two weeks after the intervention finished.

4.4.1 The Force Concept Inventory (FCI)

Stewart, Griffen and Stewart (2007:1) mention that the Force Concept Inventory (FCI) was developed by Hestenes, Swackhammer and Wells in 1992 based on research done by Ibrahim

Halloun. The FCI was developed from the Mechanics Diagnostic Test (MDT), about 60% MDT, and the results from both tests are reliable and substantiate each other, according to Hestenes and Halloun (1995:502). The FCI provides a systematic analysis of the basic concepts in Newtonian mechanics (Hestenes & Halloun, 1995:1).

The FCI is an applicable and existing standardised internationally accepted measuring instrument (Halloun *et al.*, 1995). This inventory was utilised before in South Africa in a study with Physical Sciences student educators at the University of Limpopo and the University of Pretoria (Potgieter, Malatje, Gaigher & Venter, 2009:1413). According to Potgieter *et al.* (2009:1415), they found a “fairly weak relation between performance and the Certainty of Response Index (CRI) of the students” and concluded that “only 31 % of the variance in the students’ confidence level is accounted for by the test performance”.

A shortened version of the revised FCI was used in this study to determine the effectiveness of the teaching strategies (Appendix D). Only twenty questions of the original thirty questions were used. The ten questions dealing with Newton’s third law and Newton’s law of gravitation were excluded, because these topics were not part of the intervention on Newton’s second law of motion. The questions that were selected were left unchanged. The questionnaire was distributed during the pre- and post-tests to all the respondents in the sample simultaneously.

The selected FCI questions were divided into five groups, namely kinematics, contact forces, Newton 1 diagrams, Newton 1 explanatory and Newton 2 (Savinainen & Viiri, 2007:726). The reason for dividing the questions into groups is that the groups of underlying concepts form part of the teaching sequence. Kinematics is the pre-knowledge for forces, whilst contact forces deal with the identification of the forces acting on an object. Kinematics and contact force serve also as scaffolds for Newton’s 1st and 2nd law of motion. The questions dealing with Newton’s first law of motion can be divided into two groups due to the way the questions are asked. Diagrams refer to the visual representation of the scenarios and explanatory refers to the verbal representation of the scenarios.

4.4.2 Reliability and validity in quantitative research

Mouton (2008:8) suggests that quantitative researchers should record the research process to serve as a form of quality assurance. The researcher therefore kept field notes such as dates on which the data were collected, the number of instruments distributed and response rates as well as statistics on the study population and sample.

Reliability refers to the internal consistency of the items on a quantitative instrument, the stability of the test over time (test-retest correlations) and whether consistency was applied in the administration and scoring of the test (Creswell, 2009:233). For each question in the FCI

there is only one Newtonian response. Many scientists have made suggestions to improve the wording and diagrams to rectify any misunderstandings (Hestenes & Halloun, 1995:2). Potgieter *et al.* (2009:1413), who utilised the FCI in the South African context, found the FCI to be reliable with an alpha reliability coefficient of 0.80 for the specific population in which it was used. The Cronbach's alpha for this research was also determined for the pre-test and the post-test and reported (cf. par.5.3.1).

Quantitative validity refers to whether meaningful and useful conclusions can be drawn from scores on instruments (Creswell, 2009:235). Since the force concept is fundamental to the Newton's laws of motion, each of the six conceptual dimensions, kinematics, contact forces, Newton 1, Newton 2, Newton 3 and Newton's law of gravity, with its additional structures is complete (Hestenes & Halloun, 1995:2). The FCI measures what it is designed to measure, namely the learners' understanding of the Newtonian force concept (Hestenes & Halloun, 1995:3).

When utilising experimental procedures as in the case of this study, internal validity threats may arise that need to be identified and addressed (Creswell, 2010:162). The internal validity threats that could arise during the research process are described, followed by the researcher's responses to minimise possible threats in this study:

- **Threats to internal validity**

According to McMillan and Schumacher (2010:269), history is the most serious threat to internal validity. The reason for this is the non-existence of a control or comparison group, where an event could happen between the pre-test and the post-test over which the researcher had no control. In this research all the Grade 11 learners who have Physical Sciences as a subject took part in the research and were exposed to the same teaching strategies or intervention, so that statistical regression did not play a roll, as indicated by McMillan and Schumacher (2010:269).

If an incident happened during the progress of the research, the whole group was affected, but it would not necessarily have an influence on the results. This is not the case when two comparative groups are used, since an incident may only influence one of the two groups. Since conceptual knowledge was tested, the pre-testing did not have an effect on the outcome of the results as in the case when attitudes or emotions are tested.

Attrition refers to aspects that can have an effect on the result of research due to external factors such as the day to day running of a school (McMillan & Schumacher, 2010:269) and could pose a threat for this research, because the respondents were school children who took part in sport and other activities that could cause them to miss the intervention or even some of the intervention activities, especially because the effectiveness of the intervention was

researched. As the research was done over a relatively short time, namely four weeks, the effect of attrition and maturation, the time span of the research too long, was reduced to some extent. Another aspect that could have had an effect was that the respondents did the post-test during the exams and their attention could have been divided. Due to the pre-test and the post-test taken at different times, instrumentation could also pose a threat because the focus of the respondents were divided at the time of the post-test. McMillan and Schumacher (2010:269) also mention that instrumentation may be a threat if the pre-test and post-test are not taken on the same day and at the same time.

McMillan and Schumacher (2010:269) claim that the experimenter, subject effects, and statistical conclusion threats are present in any research and these were also monitored by the researcher.

- **Threats to external validity**

External validity threats may arise when researchers draw incorrect conclusions from data obtained from the sample and generalise it to other settings or past and future situations (Creswell, 2009:162). It also needs to be mentioned that, since a quasi- experiment was utilised and the respondents were not randomly selected, generalisations of sample results to the population will not be possible as in the case of a true experiment where random sampling ensures that the sample is representative of the population (Creswell, 2009:233).

The first type of threats to external validity, according to Creswell (2009:165), is the interaction of selection and treatment. This is due to choosing one group of learners with the same characteristics, all male respondents coming from financially stable homes. The result cannot be generalised and made applicable to learners with different characteristics.

Creswell (2009:165) also indicates settings and treatment as possible threats to external validity. This is because respondents are restricted to one type of setting, and results cannot be generalised to individuals in other settings.

Another threat to external validity, according to Creswell (2009:165), includes historical factors. These factors will always be a threat to studies running over a period of time. The researcher has no control over this threat, unless the respondents are removed completely from their environment, which was not possible. Attempts were made to shorten the study, but the study expanded across four weeks.

Attempts were made to minimise the influence of the external factors like the sport programme of the school, but some factors may still have played a role and will be discussed as limitations to the study in Chapter 6 (cf. par. 6.4).

4.4.3 Quantitative data analysis (also cf. par. 5.3)

The research instruments were marked by the researcher and controlled by statistical service and the results were handed to the Statistical Consultation Services of the North-West University (Potchefstroom Campus) for further processing. They scored the research instruments by assigning numeric values to responses, cleaning of data errors from the database and created special variables needed. Recording and computing were conducted by means of the statistical computer programme: SPSS Inc (2013), IBM SPSS Statistics Version 21, Release 21.0.0. Data obtained from the FCI were statistically analysed in conjunction with statistical services North-West University Potchefstroom campus.

The FCI questions were grouped in kinematics, contact forces, Newton's 1st law diagram, Newton 1st law explanatory, and Newton 2nd law of motion, as indicated by Savinainen and Viiri (2007:726). This allowed the researcher to identify trends in learners' conceptions and with which science concepts the respondents had problems.

The respondents' conceptual knowledge gained on Newton's second law of motion and related concepts were determined. A comparison was drawn by using the results obtained from the pre-test before the intervention and thereafter (post-test) and analysed it to determine how much learning gain per concept had taken place. The normalised learning gain was determined by the following formula:

$$g = \frac{\text{Average (\%) of the posttest} - \text{Average (\%) pretest}}{100 - \text{Average of pretest (\%)}}$$

According to Hake (cited by Savinainen & Scott (2002:49), a high g score is $(g) > 0.7$, a medium g score is $0.7 > (g) > 0.3$ and a low g score is $(g) < 0.3$. According to Savinainen and Scott (2002:49), traditional learning yields a low learning gain of below 0.25.

The same group of learners were tested twice, during a pre-test and a post-test and the dependent groups t-test were done to compare the mean scores. The formula used (Ellis & Steyn, 2003:52) was:

$$t = \frac{\bar{D}}{\sqrt{\frac{\sum D^2 - \frac{(\sum D)^2}{N}}{N(N-1)}}}$$

$\bar{D}$ is the mean difference for all pairs of scores. $\sum D^2$ is the sum of the squares of the differences.

$(\sum D)^2$ is the square of the sum of the differences.

N is the number of paired scores

$N - 1$ is the degrees of freedom (one less than the number of pairs of scores).

Effect sizes that were based upon the above mentioned t-test were determined to provide an indication of what difference the intervention made (Leedy & Ormrod, 2005:274). An effect size of about 0.2 indicates a small or practically insignificant difference, and effect size of about 0.5 indicates a medium or practically visible difference and an effect size of 0.8 indicates a large or practically significant difference (Ellis & Steyn, 2003:51). The effect size was determined by the following formula:

$$d = \frac{\overline{X_{pre}} - \overline{X_{post}}}{SD_{pre}}$$

d = Cohen's ratio for effect size; $\overline{X_{pre/post}}$ = mean; SD_{pre} = Standard deviation for the population.

The learning gain and the effect size gave the researcher a good idea of to what extent the respondents' knowledge of the concepts had changed (Ellis & Steyn, 2003:52).

4.5 QUALITATIVE METHOD

Qualitative research focuses on how individuals and groups view and understand the world and how participants generate meaning from their own experiences (Maree, 2007:5). According to Locke *et al.* (cited in Creswell, 2009:194), the purpose of qualitative research is to understand a specific social situation, role, group, event or interaction. Qualitative research is based on the constructivist worldview (Creswell, 2009:8). Accordingly, qualitative researchers visit the context of the participants and gather information personally to understand the setting or context of the participants studied (Creswell, 2009:8).

4.5.1 Phenomenological study

In this study, a phenomenological research approach was utilised to gain a better understanding of participants' learning experiences during the intervention (teaching strategies). According to McMillan and Schumacher (2010:489), phenomenological research is "*research that describes the meanings or essence of a lived experience*". In this research the teaching of the concepts (intervention) was the phenomenon and the learners' responses were interpreted to get the learners' perception of the phenomenon. The learners' responses were interpreted by the researcher without considering his own pre-conceived idea of the intervention.

4.5.2 Qualitative data collection

In this study, the qualitative data were collected during the intervention by means of video-recordings and were used to better understand, explain (illuminate) and support the findings of the quantitative data (cf. par. 4.2). The same respondents who were involved in the quantitative

phase of the study were used for the qualitative phase of the study, namely the teaching intervention.

The qualitative data were collected to serve a supportive role in the interpretation of the quantitative data, as already mentioned. The qualitative data were also used to identify possible classroom behaviours (if any) that may have had an influence on the teaching situation and hence the learning gain.

Qualitative researchers do not use a single source of data, but multiple data sources (Creswell, 2009:175). For the purpose of this study, data was collected by the researcher and therefore the researcher's role during the research including data collection, needs to be discussed, as suggested by Creswell (2009:177). The qualitative data collection strategies thus commences with the role of the researcher.

4.5.2.1 Researcher's role

As mentioned, the researcher collected the data and conducted the intervention. According to Creswell (2009:177), it is essential that the qualitative researcher identifies his personal values, biases and assumptions at the onset of the study. This was partly done in Chapter 1 (cf. par. 1.6). In addition, the researcher was of the view that the teaching strategy would be effective and that a medium learning gain would be achieved. From experience, the researcher believed that Physical Sciences learners were struggling with conceptualising certain concepts in Physical Sciences, specifically Newton's laws. The researcher was of the view that a conceptual development teaching strategy could be used effectively to curb the mentioned problems.

The qualitative researcher is also considered as an instrument, as the researcher personally conducted the intervention with participants and collected qualitative data. Leedy and Omrod (2005:133) state in this regard that a researcher's ability to interpret and make sense of what is seen is critical for understanding social phenomena (Leedy & Omrod, 2005:133).

4.5.2.2 Literature study

The quantitative and qualitative study was preceded by a comprehensive literature study (cf. Chapter 1 to 3) which contributed to the formulation of a theoretical framework and served the purpose of an extra point of reference for triangulation.

4.5.2.3 Field notes and observations

Field notes during the intervention were kept by the researcher to capture the context of observations, as suggested by Mouton (2007:108) and Creswell (2009:191). Announcements

during lesson or other external activities can play a role during the intervention which is not captured on the video recordings.

4.5.3 Qualitative data analysis

The qualitative data consisted of video-recordings that were taken during the intervention. These recordings were viewed to ascertain what it contained as a whole, and the sections related to the research questions were transcribed. General themes or main themes and subcategories were identified and verbatim quotations cited to provide evidence of categories, as suggested by Creswell (2009:184). Identified themes or categories were expected to provide answers to the research question (Creswell & Plano Clark, 2007:132). Lastly, the researcher interpreted the data, based on his own understanding of Newton's law of motion. The researcher's interpretation of the data was influenced, according to Creswell (2009:188), by what the researcher brings to the research from his/her own experiences, culture and history. This implies that the researcher's cognitive resources will guide his interpretation.

4.5.3.1 Trustworthiness

Inter-coder agreement was used to increase trustworthiness during the qualitative study. Another person (co-coder) was asked to review themes (categories) and codes for the purpose of inter-coder agreement (Maree, 2007:114; Creswell, 2009:191).

4.5.3.2 Credibility

Credibility implies that the findings from the study are authentic. Peers familiar with qualitative data and the content should review the data to validate it, a process known as peer examination (Creswell & Plano Clark, 2007:135). The researcher's study leaders reviewed the data. Knowledgeable persons were asked to provide evidence for themes and 'rich' and 'thick' descriptions were used to convey findings. Multiple sources of information were used for the purpose of triangulation, namely a comprehensive literature study, observations and field notes (cf. par. 4.5.2.2). The researcher's role was described and the researcher also reported disconfirming evidence in Chapter 5 (as suggested by Creswell & Plano Clark, 2007:135) to ensure credibility/validity during qualitative research.

4.6 ETHICAL ASPECTS OF RESEARCH

The research was part of a National Research Foundation (NRF) project for which written permission from the Department of Education and the NWU ethical committee was obtained. The headmaster of the school as well as the learners gave their consent for the research. The following strategies were employed to protect the rights of respondents:

Respondents were informed that they partook voluntarily in the research by means of informed consent and that they could withdraw at any time during the research process and that it would not be held against them. In a further step to protect the identity of the learners, they were each allocated a number. A written informed consent form was drafted (Annexure B) for respondents to sign before engaging in the research (Creswell, 2009:89). The research objectives were attached to the letter of consent, (Annexure B), with a brief background on the study to facilitate respondents' understanding of the research. Respondents were also informed about all data collection methods and activities and how the data would be utilised. The confidentiality finally rested with respondents (Creswell, 2009:198). The researcher did not disclose the names of the learners to anyone and only worked with respondent numbers, hence further protecting the identity of the learners. The research was not harmful to the respondents, since it involved teaching strategies and the respondents were expected to gain by the teaching strategies.

4.7 INTERVENTION BASED ON TEACHING STRATEGIES

4.7.1 General application of conceptual development

The learning of Physical Sciences, and also the concept of force and other related concepts, can be viewed as upside down triangles, as illustrated in Figure 4.3. When a new concept is introduced to a learners their only experience is their environment, and the way they see and experience their world. As conceptual development occurs, the concept becomes more abstract with more applications (Vosniadou *et al.*, 2001:383).

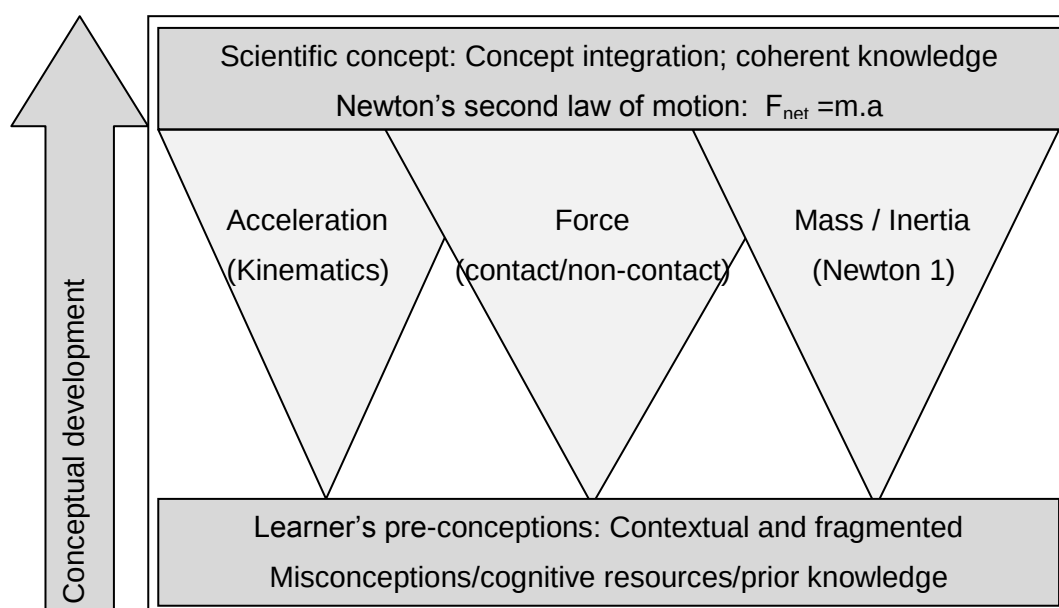


Figure 4.3: Conceptual development model developed by researcher

Figure 4.3 shows that concepts in Physical Sciences start as simple unrelated concepts or ideas, with an undeveloped framework. The bottom part of the upside down triangle represents

the novice concept of the learner and is rooted in and influenced by the experience world of the learner. As the learners learn the concepts, their concepts develop into large or complicated knowledge structures with numerous applications (the broad side of the triangles that are touching or overlapping). Later, these structures become integrated with other concepts, enabling the learner to form links between the different concepts. In the conceptual framework, the concept of force links with other concepts such as mass, acceleration and with other concepts and even other subjects such as mathematics and technology, to mention a few integration applications. The journey of the learners' conceptual development reaches a point where the educator can pass learners on to the next level of development, as in this study to Grade 12 and then later to tertiary education. At tertiary education level a sound coherent conceptual framework is crucial for further development of the learners into scientists.

4.7.2 The conceptual development teaching strategies on Newton's laws of motion

The teaching sequence is important, for the Newton 2 concept needs to be built into a conceptual framework coherent with the scientific framework of force. The scaffolds are developed in such a way that the new concepts form the pre-knowledge for the next concepts.

Table 4.3: Approach and teaching strategies

Approach	Teaching strategies	Concepts
4.4.3 Conceptual development	4.4.3.1 Cognitive conflict teaching strategy	Kinematics
		Contact forces
	4.4.3.2 Development of ideas teaching strategy	Newton 1 diagrams
		Newton 1 explanatory
		Newton 2

For the first part of the intervention (cf. fig 4.1) the aim was to establish a scientific sound conceptual definition of force by making use of a cognitive conflict teaching strategy to be used as an anchoring concept. Kinematics concepts and contact forces were focussed on in the first part. Newton's laws of motion were explained during the second part of the intervention by making use of the development of ideas teaching strategy.

4.7.2.1 Cognitive conflict teaching strategy

The intention of the initial part of the intervention was to establish a scientifically suitable definition of force acceptable for all concerned. The objective was to use the cognitive conflict teaching strategy to establish the said definition of force from the kinematics concept, the pre-knowledge, and then use the new concept of contact forces and the representation of these forces and develop a scientifically sound definition of force.

The first aspect of the definition is that objects in contact can exert forces on each other such as normal force and frictional force. These forces may or may not have an effect on each other. The second aspect is that, when objects exert force on each other they may experience an effect when the forces are unbalanced, and experience no effect when the forces are balanced. The type of motion (e.g. constant velocity or accelerated) of the object when a force is exerted on the object will determine whether the object experiences a balanced or unbalanced resultant force.

Forces acting on each other can be classified as contact or non-contact forces, and the effect of these forces upon each other can be represented in the form of vector diagrams. The resultant force or unbalanced force acting on an object will induce a change in the state of motion of the object. If the resultant force acting on an object is zero or the forces are balanced, no change in the state of motion is experienced (cf. par.4.7.3 and Figure 4.4).

4.7.2.2 The development of ideas teaching strategy

The development of ideas teaching strategy was used to explain Newton's first two laws of motion. An anchoring concept, the conceptual definition of force (Figure 4.5), was established during the first part of the intervention. The anchoring concept, which is acceptable for the learners, educator and scientifically agreeable, was used during the second part of the intervention.

Newton's first law of motion states that an object continues in a state of rest or moving with constant velocity unless it is acted on by an unbalanced (nett) force. The concepts *normal force* and *static* and *dynamic friction* were also introduced. The more familiar context of motion along a horizontal straight line was used to introduce the new concepts before the more difficult context of objects moving along an inclined were used.

Newton's second law of motion deals with the effect on an object when an unbalanced force is acting on it. In formula form Newton's second law of motion can be expressed as

$$F = m.a \text{ (F – force (N), m – mass (kg) and a- acceleration (m.s}^{-2}\text{)}$$

Newton's second law of motion deals with the relationship between mass and acceleration when a constant unbalanced force acting on an object was also considered.

4.7.3 The planned teaching sequence of the intervention

The researcher used interventions based on the conceptual development teaching strategies. The first step was to identify the core knowledge (see Table 4.4) to be taught, the researchers' impression of what needs to be taught and also alternative concept (see Table 4.4) that the

learners might have during the intervention flowing from the pre-test done by the learners (cf. par. 2.4.1. & 3.6). Additionally the researcher probe the learner's understanding of forces within different contexts to familiarise himself with the learners' knowledge framework.

Table: 4.4 Core knowledge and misconceptions to take into consideration.

Core knowledge	Possible misconceptions of force by learners
Objects in contact exert forces on each other (e.g. normal force, frictional force): ➤ Define force: Push/pull that can cause an effect on an object's velocity. ➤ Effects of forces on object. ➤ Types of forces: Contact or non-contact. ➤ State Newton's First Law: An object continues in a state of rest or moving with constant velocity unless it is acted on by an unbalanced (net) force ➤ Know that a surface in contact with the object exerts two types of contact forces, a normal force and a friction force perpendicular and parallel to the surface, respectively. ➤ Distinguish between static and dynamic friction forces and explain why there is difference. ➤ Calculate the value of the static friction force for an object at rest and of the dynamic friction force for a moving object. ➤ Solve problems for objects on a horizontal surface and on an incline. A nett force causes an object to accelerate (Newton's Second Law): ➤ State Newton's Second Law in the special case of constant mass: the nett force exerted on an object equals its mass times its acceleration. ➤ Draw force diagrams for objects at rest, moving with constant velocity and accelerating. ➤ Draw free body diagrams for objects at rest, moving with constant velocity and accelerating. ➤ Calculate the acceleration of a single object on which several forces act simultaneously. ➤ Calculate the acceleration of two objects that are joined together, e.g. two masses joined by a string	1. An object will slow down if there is no nett force acting on it. 2. A force is needed to keep a body moving, even on a frictionless surface. 3. The motion will follow the path of the stronger force on the object. 4. Passive forces don't exist (tables don't exert a normal force). 5. Normal forces won't exceed the weight (active force) on an object. 6. An object with a constant (non-zero) nett force will have a constant speed. 7. Faster moving objects have larger force acting on them. 8. A constant force accelerates a body, until the body uses up all the power of the force. 9. The nett force must be in the direction of motion, so objects will travel along a line in that direction. 10. Objects can be trained by forces to follow a certain path, and will continue along that path, even after the forces are removed. 11. Heavier objects fall faster than light objects. 12. Forces will point in the direction of their velocity. 13. Force must be positive, plotted above the time axis. 14. Strings transmit (unchanged) an external force acting on one object to another object.

The second step was to decide on a teaching sequence or scaffolds the researcher could use during the intervention (cf. Annex. D). During the design of the scaffolds the researcher needed to pay close attention to the cognitive tools such as the learners' everyday experiences and also general novice conceptions such as forces and the learners' mathematical concepts.

The following is an outline of the developed scaffolds by the researcher based upon the prescribed syllabi, but not in the same sequence as prescribed by the syllabi.

- a conceptual definition of force is established
- push or pull resulting from the interaction between two objects
- contact and non-contact forces
- has no effect (balanced forces) or has an effect (unbalanced forces) on an object
- force is a vector
- vertical motion and horizontal forces are placed in context
- draw force diagrams and free body diagrams of the forces acting on the object
- predict the motion of an object by considering the force diagram and free body diagram
- friction is brought into the contexts; only the effect of friction and no calculations.
- Newton's first law and the term inertia are introduced.
- the roll of inertia on friction is explained and the differentiation between static and dynamic friction is make clear and the mathematical calculations are done.
- Newton's second law is discussed and placed into context with the motion of objects (unbalanced forces). Newton's laws of motion are now also linked to mathematical concepts making use of the mathematical tools of the learners (Only forces two dimensions are used)
- momentum and Newton's second law are related to one another

$$F_{net} = m \cdot a \left(a = \frac{v_f - v_i}{\Delta t} \right) \text{ where } mv = \text{momentum}$$

$$F_{net} = \frac{mv_f - mv_i}{\Delta t}$$

F_{net} = force; m = mass; a = acceleration; v_f = final velocity; v_i = initial velocity and Δt = change in time

The next step to consider was to decide on the teaching strategies to be used during the intervention. The researcher had a choice between two conceptual development strategies, namely the cognitive conflict teaching strategy, which is a direct method, and the development of ideas, which is a more indirect teaching strategy (cf. par 3.6).

The decision was made to use a combination of the two conceptual development teaching strategies. The first objective was to establish an "anchor" concept which was drawn from the learners' existing pre-knowledge. This "anchor" or "bridging concept" that must be scientifically correct and acceptable to all learners, can be used in explaining more difficult scaffolds or

aspects of force. The “anchor” chosen was the definition of force. To establish common ground among the learners, the researcher had to extensively probe the learners’ pre-knowledge of force. This was done through questioning and also giving the learners everyday examples and listening to their explanations. During the establishment of the definition of force as the “anchor” the researcher ensured that all the learners were cognitively on the same level regarding force. In doing so, the “anchor” was established. During learning the learners will only develop their existing concepts if the new information fits into their existing knowledge framework (cf. par.3.6.1). The educator uses the anchor to persuade the learners that the new information, Newton’s laws of motion, fits into their existing conceptual framework of force.

The anchor is also referred to as the bridging concept, as it will form a bridge between the new aspect of the concept, Newton’s laws of motion, and the prior knowledge, in order to convince the learners to make the necessary changes to their existing knowledge frameworks (see Figure 4.4). It also establishes a common context which is acceptable for all the learners (cf. par 2.4).

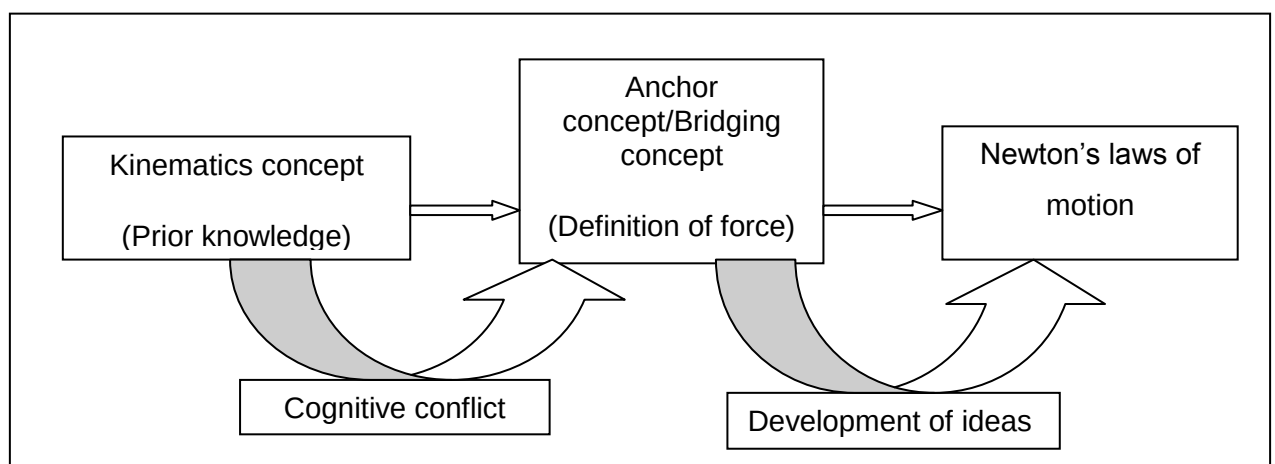


Figure 4.4: Anchor or bridging concept by author

During the process to establish the anchor, the cognitive conflict teaching strategy was used extensively. What the researcher accomplished by using the cognitive conflict strategy was to challenge the learners’ concept of force and to make use of assimilation and accommodation in order to establish a conceptual definition of force (cf. par.2.3.2). The researcher also attempted to understand what the learners intuitive/novice knowledge framework of force was and to ascertain what cognitive resources the learners had (cf. par. 2.3). The learners had a wide variety of experiences with force and the researcher had to clarify the various underlying concepts so that they form part of the learners’ scientific knowledge framework of force (cf. Figure 4.4).

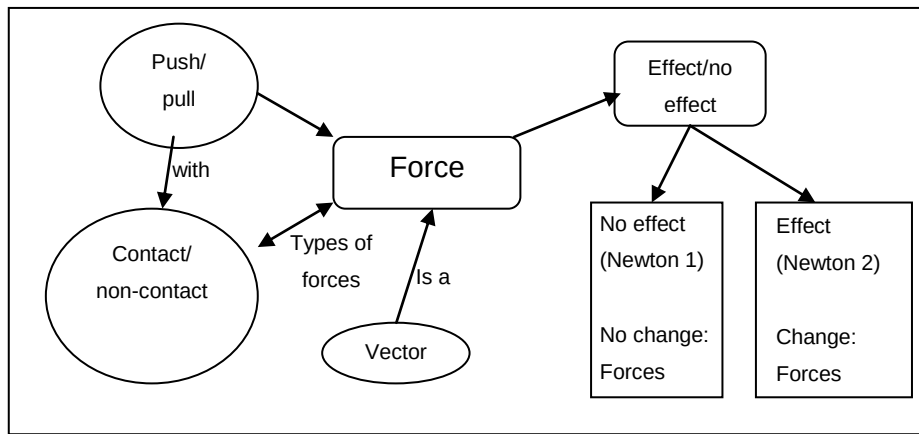


Figure 4.5: Schematic representation of the “anchor” (definition of force) by author

The learners need to clearly understand that the interaction between two objects results in a push or a pull and that it can be established with or without contact. There must be physical contact between surfaces for a force to be exerted onto each other with contact. Non-contact forces are electrostatic forces, magnetic forces and gravitational forces. These are concepts that were introduced to the participating learners in earlier grades. Forces are also vector quantities, so they have magnitude and direction. When a force is applied onto an object the force will either have an effect or no effect on the objects. When an object experiences an unbalanced force it will rotate, change shape, change direction, change its state of motion, accelerate or decelerate. When an object is stationary or moving at a constant velocity there can be forces acting on it, depending on the scenario. In the majority of the scenarios the forces acting on the object are balanced.

When it gets to using the “anchor” concept which became the “bridging concept” it was applied to other situations for example a stationary object on an inclined plane. The first question was to identify the forces, if any, acting on the object (cf. Figure 4.6).

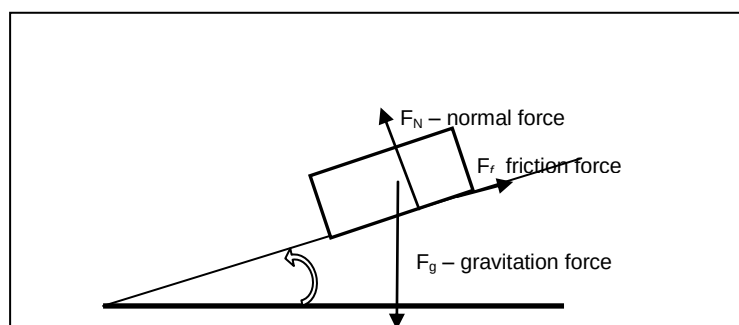


Figure 4.6: Application of an anchor/bridging concept: Object lying on an inclined plane

The learners had to identify the gravitational force, which is a non-contact force, then the normal force, present when objects are in physical contact and lastly the friction force. Then the researcher asked the learners what the effect of the forces was on the object. The obvious answer is that the forces have no effect on the object because it is stationary. The researcher

then asked the learners to divide into groups, using the definition of force (“anchor”) and then calculated the mass of the object. Hence, the learners needed to use their cognitive resources in combination with their knowledge of force to calculate the mass of the object.

During the design of the intervention in this study special attention was given to specific activities to develop the concepts related to and including Newton’s laws of motion. Scenarios were given and questions such as “explain ...”, “what would happen if ...” or “how will you ...” were asked. Alternative conceptions of the learners were confronted with experiments or situations given and the learners had to give explanations or they had to verbalise their reasons for their answers. The learners’ existing cognitive resources were used to develop their conceptual framework of Newton’s laws of motion. During learners’ activities, important concepts were singled out to focus their attention on the correct and relevant content, as suggested by Woolfolk (2010:238).

Conceptual change strategies were utilised. The anchoring concept used during this intervention was the definition of force. Attention was also given to create an initial unease among learners related to their existing knowledge framework. For instance, during group discussions the initial feeling of doubt in the learners’ own construct of force and related concepts was strengthened, as suggested by Dekkers and Thijs (1998:33). The former was followed up with activities and experiments to establish the correct force concepts amongst learners. Learners’ attention was focused on the new concept, and through repetition of the concept learners were expected to keep the information in the working memory according to the cognitive learning theory (Redish, 2003; Woolfolk, 2010; cf. par. 2.3.2).

Once the learners had all the information on the concept, they were able to draw new conclusions and change the relevant concepts in their long-term memory (Woolfolk, 2010:238). The memory of the concept can be improved at this point by placing the concept in a structure or framework and connecting the concept to other concepts and also to other contexts by choosing appropriate exercises. These exercises are also important to firmly fix the concept in the current context and then extend it to other contexts (Bell & Cowie, 2000:539).

4.8 SUMMARY

The mixed-methods research design, particularly the sequential explanatory design that was used to investigate if a group of Grade 11 learners’ understanding of Newton’s second law concepts improved through an intervention that focuses on conceptual development, was explained and visually presented. The quantitative and qualitative data collection and analysis were described. Reliability, validity, trustworthiness, credibility and ethical considerations related to this study were attended to as well as the intervention. The research findings, interpretation thereof and synthesis of data will be presented in Chapter 5.

CHAPTER 5

ANALYSIS, INTERPRETATION AND SYNTHESIS OF DATA

5.1 INTRODUCTION

In order to investigate the effectiveness of the conceptual development teaching strategies on Newton's second law, the data analysis is presented. The data are also interpreted and synthesised to determine the learning that took place during the implementation of the conceptual development teaching strategies.

Firstly, the quantitative results obtained through the Force Concept Inventory (FCI) are presented to establish the learning impact of the intervention. Thereafter the qualitative data that was obtained during the intervention by means of video-recording are presented to enlighten the quantitative data, all in all to gain a complete understanding in terms of the effectiveness of the teaching strategies and to answer the research questions:

- To what extent has the Grade 11 learners' understanding of Newton's second law improve through teaching strategies that focuses on conceptual development?
- What is the effectiveness (the learning gain) of conceptual change teaching strategies on the conceptual development of grade 11 learners on Newton's second law of motion?

The quantitative database was analysed by the Statistical Consultation Services, Potchefstroom Campus of the North West University. Frequency tables, learning gains and dependent t-tests are presented and discussed in Sections 5.2 to 5.4. Section 5.5 reports on the interpretation of the transcribed qualitative data. The quantitative and qualitative results were then synthesised to give a complete picture of the investigated phenomenon (Section 5.6)

5.2 QUANTITATIVE DATA ANALYSIS

This section deals with the data collected with the aid of the Force Concept Inventory (FCI) (cf. Annexure D). The statistics obtained from the FCI (cf. 4.4.1) is presented by referring to descriptive statistics (cf. 4.4.3), the learning gained and the dependent t-test. Effect sizes were calculated to indicate the practical significance of the difference between the averages scored on the pre- and the post tests. The p-values are reported for completeness sake, but not interpreted, since a convenient sample and not a random sample was used (Ellis & Steyn, 2003).

In the following section the data obtained are tabled, discussed and compared, and conclusions are drawn. The correct answers are shaded in the tables.

5.3 Data analysis: Learning gains and effect sizes

The rationale for utilising a Single Group Pre-test-Post-test Design was that the researcher wanted to establish how much conceptual learning was gained by the respondents during the intervention. The normalised learning gained (Savinainen & Scott 2002:49) was determined between the pre-test and the post-test average scores.

Dependent t-test was conducted to determine the difference between the pre-test and post-test average scores. More specifically, effect sizes were calculated to determine whether or not the differences were practically significant. The effect size is the “*difference between two means in standard deviation units*” (McMillan & Schumacher, 2010:315), which is calculated between the pre-test and post-test average scores. Effect size indicated what difference the intervention made (Leedy & Ormrod, 2005:274; Ellis & Steyn, 2003).

The combination of the learning gain and the effect size are used to determine the extent to which the respondents improved their knowledge of the concepts.

5.3.1 Whole group analysis

The whole group analysis views all the questions scores simultaneously, indicating whether the respondents show an overall improvement in learning gained.

Table 5.1 also shows an effect size of 1.19, which was determined based on the pre-test and the post-test scores of the whole group. This large effect size indicates a practical significant difference, i.e. the difference in learners’ responses to the pre- and post-test is significant in practice. The improvement of the learners was significant when looking at the effect size. But this is not reflected by the learning gain. With regard to the learning gain, Savinainen and Scott (2002:50) argued that it is easier for a learner to increase test scores from a lower initial score (say from 20% to 35%) than to increase test scores from a higher value (e.g. 70% to 85%).

Table 5.1: Whole group effect size and learning gain

Paired Samples T-test Statistics						
Question		Mean	N	Std. deviation	p-value*	Effect size
1 - 20	Pre-total	20.72%	46	12.32%	<0.0001	1.19
	Post-total	35.42%	46	15.90%		

* p-values are reported, but not interpreted, for completeness sake, since a convenient sample and not a random sample was used.

Table 5.1 shows that the average obtained by the learners in the pre-test is only 20.72 %. The mean improved to 35.42 % in the post-test, which indicates progression towards a Newtonian view of motion. However, the average learning gain was lower than 0.3. A low learning gain of

only 0.19 was achieved, which is similar to conventional teaching strategies (cf. 4.4.3). In the context of the low pre-test average of 20.72%, the 70.95% increase in the result to 35.42% is not substantial. If the learners had a pre-test average of 65%, an increase of 14.7% would be substantial, but it is not substantial for a low score average of 20%.

The Cronbach's Alpha coefficient for the pre-test of 20 questions was a low 0.324 initially, but was 0.522 after questions 2, 6 and 14 were excluded due to reliability, and 0.642 for the post-tests. McMillan and Schumacher (2010:185) mention that, to achieve consistency the instrument must be appropriate in reading level and language and that the respondents must be motivated. The FCI was developed for first year university students, so one can say that the low alpha value can be due to the reading ability or even less developed conceptual framework of the Grade 11 respondents. Younger respondents' scores are usually less reliable than older respondents (McMillan and Schumacher, 2010:185). Due to the low reliability the questions will be discussed individually. Due to the Cronbach's Alpha coefficient without questions 2, 6 and 14 was more than 0.5 the tests will also be discussed as a whole.

In the following section the results for the groups of FCI questions on kinematics, contact forces, Newton 1 diagrams, Newton 1 explanatory and Newton 2 are discussed separately (cf. 4.4.1).

5.3.2 Kinematics per question analysis

In physics, kinematic concepts form the basis for the concepts of force and acceleration, and more specific Newton's second law of motion (cf. par. 4.7.2). Therefore the learners' prior concepts on which their knowledge of Newton's laws of motion are build is determined. Table 5.2 compares the pre-test and post-test responses to each question on kinematics. The correct options are shaded.

Table 5.2: Frequency table: Pre-test and post-test results of kinematics questions

Pre-test Post-test results of Kinematics questions per question																	
Question 1 Pre-test			Question 1 Post test			Question 2 Pre-test			Question 2 Post-test			Question 11 Pre-test			Question 11 Post-test		
	Frequency	Valid %		Frequency	Valid %		Frequency	Valid %		Frequency	Valid %		Frequency	Valid %		Frequency	Valid %
A	0	0	A	9	19.6	A	26	56.5	A	7	15.2	A	14	30.4	A	8	17.4
B	12	26.1	B	3	6.5	B	14	30.4	B	38	82.6	B	1	2.2	B	4	8.7
C	24	52.2	C	23	50.0	C	2	4.3	C	1	2.2	C	4	8.7	C	3	6.5
D	7	15.2	D	7	15.2	D	4	8.7	D	0	0.0	D	19	41.3	D	26	56.5
E	3	6.5	E	4	8.7	E	0	0.0	E	0	0.0	E	8	17.4	E	8	17.4
Total	46	100	Total	46	100	Total	46	100	Total	46	100	Total	46	100	Total	46	100

When we consider the results of the kinematics pre-test questions in Table 5.2, the majority of the learners chose option C for Question 1, which shows a misconception of force. Force is wrongly considered as a property of an object (cf. par 3.7.1). The largest percentage of learners maintained this misconception after the intervention. Only 26.5% chose the correct option B during the pre-test, but only 6.5% of the learners opted for option B during the post-test. The largest increase was option A from 0% during the pre-test to 19% for the post-test. This indicates that some learners associate gravity with a constant velocity.

Question 2 option A is the choice of the 56.5% learners during the pre-test who use a wrong frame of reference for the motion in question. Only 30.4% of the learners chose the correct option B during the pre-test. During the post-test a much larger percentage (82.6%) of the learners chose the correct answer (option B).

Question 11 and 12 are the same type of questions and most of the respondents selected the incorrect option D (41.3%) and C (41.3%) respectively during the pre-test. Only 17.4% (option E) and 6.5% (option D) of the respondents selected the correct answers for Questions 11 and 12 respectively, which are E and D respectively. During the post-test 17.4% of respondents for both questions chose the correct option E and D respectively.

During the following part the dependant t-test and learning gain for the questions on kinematics are discussed according to Table 5.3, Figure 5.1 and Figure 5.2.

Table 5.3: Kinematics: Effect size and learning gain

Paired Samples T-test Statistics Kinematics						
Question		Mean	Std. deviation	p-value*	Effect sizes	Gain
1	pre	26.09%	44.40%	.018	0.44	-0.26
	post	6.52%	24.96%			
2	pre	30.43%	46.52%	<0.001	1.12	0.75
	post	82.61%	38.32%			
11	pre	17.39%	38.32%	1.000	0.00	0.00
	post	17.39%	38.32%			
12	pre	6.52%	24.96%	.024	0.44	0.12
	post	17.39%	38.32%			

* p-values are reported for completeness sake, but not interpreted, since a convenient sample and not a random sample was used.

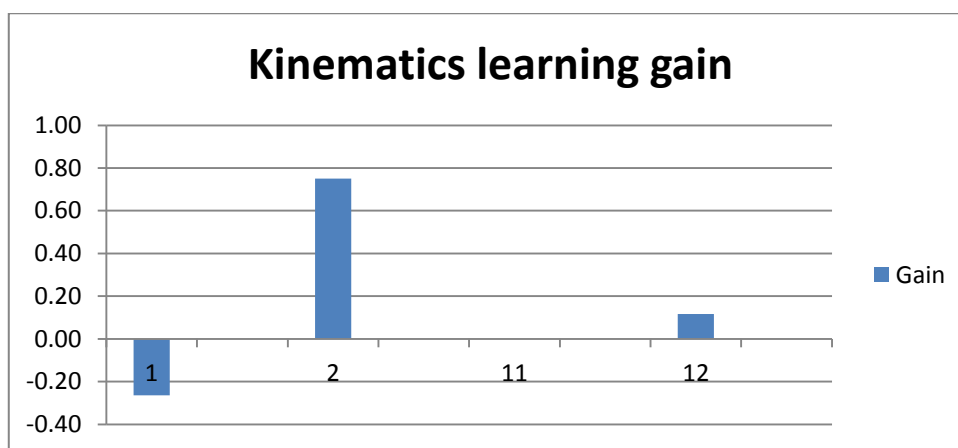


Figure 5.1: Kinematics learning gain versus question number graph

When looking at Table 5.3 and Figure 5.1, the learning gain obtained by the respondents for Question 1 is negative, Question 11 yielded no gain and Question 12 a very small gain. Questions 11 and 12 are diagram-type of questions and if the learners have a problem with the interpretation of diagrams, they will have a problem with these questions. Question 2 showed a high learning gain of 0.75, indicating that the learners' frame of reference with regard to the bowling ball that accidentally falls out of the cargo bay of an airliner as it flies, was adjusted correctly.

Considering Table 5.3, Question 1 shows that the difference between the pre-test average and the post-test average tends to a medium effect size, indicating that on average the misconception of force was strengthened. Looking at the difference between the pre-test average and the post-test average Question 12 had a small effect size of 0.44 which leans towards a medium effect size, but Question 2 had a large effect size while Question 11 remained unchanged in average.

Question 2 shows medium learning gain and a practical significant difference. The rest of the questions show insignificant knowledge development. Question 2 deals with the frame of reference of motion and one can argue that the respondents changed their frame of reference to the one where they are standing stationary on the ground and looking at the air plane dropping the bowling ball. Question 1 had a negative learning gain. In this question the majority of the respondents chose option C (pre-test 52% and the post-test 50%) indicating that they maintained the misconception that an object contains internal force. It is also evident that the learners were not able to link the force concept with their kinematics concept which was the pre-knowledge of the learners. Since Questions 11 and 12 are based on the interpretation of diagrams the learners showed an inability to interpret the diagrams correctly.

5.3.3 Analysis of responses on contact forces

The topic contact forces deals with the identification of the forces acting on an object. The following section looks at the learners' ability to identify these forces.

Table 5.4: Contact forces: Pre- and post-test results

Contact forces: Pre-test Post-test results per question																							
Question 3 Pre-test			Question 3 Post-test			Question 8 Pre-test			Question 8 Post-test			Question 19 Pre-test			Question 19 Post-test			Question 20 Pre-test			Question 20 Post-test		
	Frequency	Valid %		Frequency	Valid %		Frequency	Valid %		Frequency	Valid %		Frequency	Valid %		Frequency	Valid %		Frequency	Valid %		Frequency	Valid %
A	4	8.7	A	5	10.9	A	5	10.9	A	10	21.7	A	25	54.3	A	4	8.7	A	1	2.2	A	7	15.2
B	3	6.5	B	27	58.7	B	25	54.3	B	4	8.7	B	7	15.2	B	37	80.4	B	11	23.9	B	9	19.6
C	29	63.0	C	7	15.2	C	14	30.4	C	2	4.3	C	6	13.0	C	1	2.2	C	3	6.5	C	10	21.7
D	5	10.9	D	2	4.3	D	1	2.2	D	28	60.9	D	0	0.0	D	0	0.0	D	7	15.2	D	1	2.2
E	5	10.9	E	5	10.9	E	1	2.2	E	2	4.3	E	8	17.4	E	4	8.7	E	24	52.2	E	19	41.3
Total	46	100	Total	46	100	Total	46	100	Total	46	100	Total	46	100	Total	46	100	Total	46	100	Total	46	100

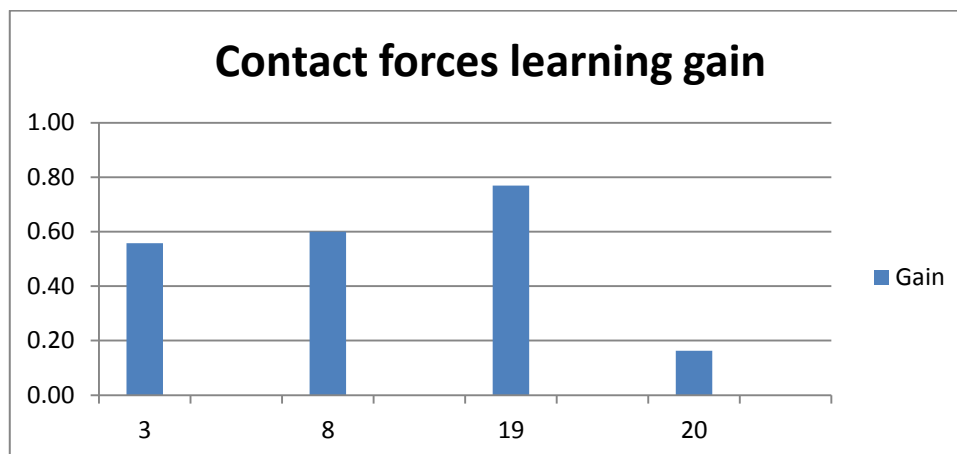
For the topic *Contact forces* (Table 5.4) the main misconception in the pre-test is that when there is motion the object will experience a force in the direction of motion. This misconception is maintained by the learners; hence the majority of learners marked the wrong options. For Questions 3, 8, 19 and 20 only 6.5%, 2.2%, 15.2% and 6.5% respectively selected the correct options B, D, B and C respectively. The majority of the learners opted for C (63%), B (54.3%), A (54.3%) and E (52.2%) respectively for Questions 3, 8, 19 and 20 during the pre-test. In all these questions the learners displayed the misconceptions that objects contain an internal force and that an object always has a force in the direction of motion.

During the post-test the majority of the respondents marked the correct options B (58.7%), D (60.9%) and B (80.4%) respectively for Questions 3, 8 and 19. The majority of the respondents marked the wrong option E (41.3%) for Question 20. They maintained the misconception that once an object, like a ball, is hit with a racquet the ball will experience a force even though the ball is not in contact with the racquet.

During the following part the dependent t-test and learning gain for the topic contact forces will be discussed in concurrence with Table 5.5, Figure 5.3 and Figure 5.4.

Table 5.5: Contact forces effect size and learning gain

Dependent t-test Statistics Contact forces						
Question		Mean	Std. deviation	p-value*	Effect sizes	Gain
3	pre	6.52%	24.96%	<0.001	2.09	0.56
	post	58.70%	49.78%			
8	pre	2.17%	14.74%	<0.001	3.98	0.60
	post	60.87%	49.34%			
19	pre	15.22%	36.32%	<0.001	1.80	0.77
	post	80.43%	40.11%			
20	pre	6.52%	24.96%	.018	0.61	0.16
	post	21.74%	41.70%			

**Figure 5.2: Contact forces learning gain versus question number**

When we now look at the learning gain in Table 5.5 and also Figure 5.2, we see that all the questions had a positive learning gain. Questions 3 and 8 had a medium learning gain ($0.7 > (g) > 0.3$ cf. Section 4.4.3) and Question 19 had a high learning gain (> 0.7). This is an indication that the initial misconceptions were addressed and rectified by the learners. Question 20 had a low learning gain of only 0.16.

Looking at Table 5.5, the difference between the averages, i.e. the pre-test average and the post-test average, the effect sizes for Questions 3, 8 and 19 were large. A large difference between the averages (above 0.8, cf. Section 4.4.3) is an indication that the intervention was effective for these questions. The effect size for Question 20 was medium at 0.61 i.e. the learners' conceptual development is practically visible based on the average scores of the pre- and post-test.

In Questions 3, 8, 19 and 20 we find that respondents showed positive learning gains. Question 19 had a high learning gain and Questions 3 and 8 had medium learning gains. Only Question 20 had an insignificant learning gain. The learners rectified the initial misconceptions that an object contains an internal force and that an object always has a force in the direction of motion. In Question 3, 8 and 19 the objects are also in physical contact with one another but in Question

20 the object is in free fall. Comparing this with kinematics Question 1 where the object is also in free fall, it become noticeable that the learners have a problem to identify the forces and the effect of these forces on free falling objects.

5.3.4 Newton 1 Diagram-type forces question analysis

The following section deals with Newton's first law of motion, i.e. the effect of balanced forces on an object's velocity. It also deals with the role that mass play within these situations. The following gives an indication of the learners' perception when viewing diagrams.

Table 5.6: Newton 1 diagram pre- and post-test results

Newton 1 Diagram Pre-test Post-test result per question																													
Question 4 Pre-test			Question 4 Post-test			Question 5 Pre-test			Question 5 Post-test			Question 6 Pre-test			Question 6 Post-test			Question 10 Pre-test			Question 10 Post-test			Question 14 Pre-test			Question 14 Post-test		
	Frequency	Valid %		Frequency	Valid %		Frequency	Valid %		Frequency	Valid %		Frequency	Valid %		Frequency	Valid %		Frequency	Valid %		Frequency	Valid %		Frequency	Valid %		Frequency	Valid %
A	10	21.7	A	12	26.1	A	7	15.2	A	15	32.6	A	10	21.7	A	15	32.6	A	3	6.5	A	7	15.2	A	11	23.9	A	7	15.2
B	34	73.9	B	10	21.7	B	23	50.0	B	5	10.9	B	12	26.1	B	6	13.0	B	2	4.3	B	3	6.5	B	3	6.5	B	6	13.0
C	0	0.0	C	4	8.7	C	8	17.4	C	5	10.9	C	5	10.9	C	15	32.6	C	21	45.7	C	11	23.9	C	16	34.8	C	18	39.1
D	1	2.2	D	2	4.3	D	2	4.3	D	17	37.0	D	6	13.0	D	9	19.6	D	14	30.4	D	13	28.3	D	10	21.7	D	10	21.7
E	1	2.2	E	18	39.1	E	6	13.0	E	4	8.7	E	13	28.3	E	1	2.2	E	6	13.0	E	12	26.1	E	6	13.0	E	5	10.9
Total	46	100	Total	46	100	Total	46	100	Total	46	100	Total	46	100	Total	46	100	Total	46	100	Total	46	100	Total	46	100	Total	46	100

Considering the pre-test Newton 1 diagram questions in Table 5.6 we see that for Question 4 73.9% of the respondents chose the correct option B, while 21.7% respondents chose the correct option B during the post-test. Only 15% chose the correct option A for Question 5 in the pre-test, while 32.6% respondents selected the correct option A during the post-test. For Question 6, 13% of the respondents chose the correct option D in the pre-test and during the post-test it moved slightly up to 19.6%. For Question 10 only 4.3% of the respondents selected the correct option B during the pre-test and 6.5% of the learners opted for this option in the post-test. Question 14 shows the highest percentage: 34.8%, of respondents chose the correct option C during the pre-test and 39.1% learners chose option C during the post-test.

For Question 4 (option E with 39.1%), 5 (option D with 37,0%) and 10 (option D with 28.3%) the learners showed the same misconceptions as in the previous concept of contact forces, namely that an object contains an internal force and that it always has a force in the direction of motion. One can argue that the fact that the learners did not do centrifugal forces in their curriculum that the unknown scenario of rotating objects in these questions confused them. However, it is obvious that the learners maintained the same misconceptions when dealing with the more familiar situations in Questions 6 (options A & C with 32.6%) and 14 (option D with 21.7%). The basic principle for Newton's first law remains that when no unbalanced forces act in on an

object, the object is either at rest or moves at a constant velocity. This is difficult for the learners to conceptualise, especially the constant velocity part. The learners tend to link all motion to unbalanced forces.

During the following part the dependent t-test and learning gain for the topic Newton's first law of motion will be discussed in concurrence with Table 5.7, Figure 5.5 and Figure 5.6.

Table 5.7: Newton 1 diagram dependent t-test and learning gain

Dependent T-test Statistics Newton 1 Diagrams						
Question		Mean	Std. deviation	p-value*	Effect sizes	Gain
4	pre	73.91%	44.40%	<0.001	1.18	-2.00
	post	21.74%	41.70%			
5	pre	15.22%	36.32%	.088	0.48	0.21
	post	32.61%	47.40%			
6	pre	13.04%	34.05%	.371	0.19	0.08
	post	19.57%	40.11%			
10	pre	4.35%	20.62%	.660	0.11	0.02
	post	6.52%	24.96%			
14	pre	34.78%	48.15%	.675	0.09	0.07
	post	39.13%	49.34%			

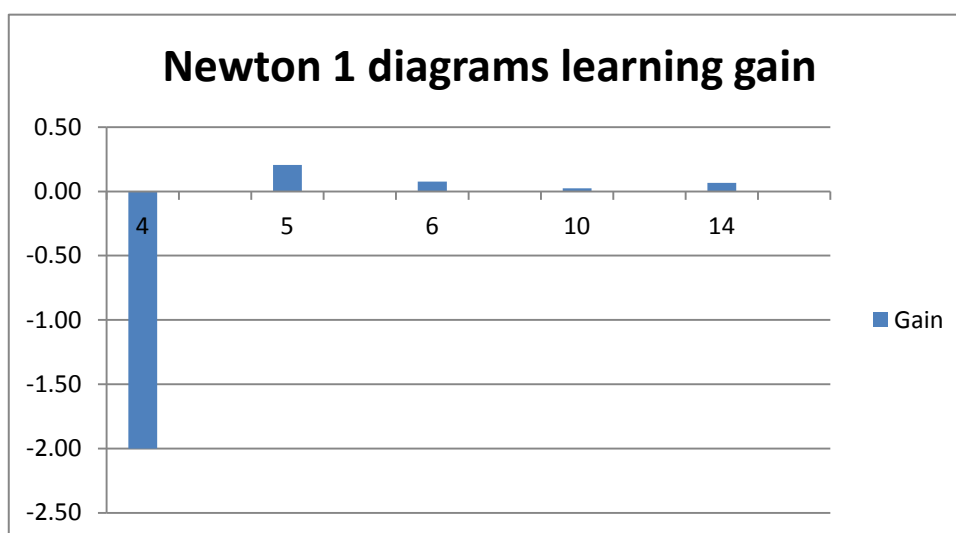


Figure 5.3: Newton 1 diagrams learning gain versus question number graph

Looking at the learning gain in Table 5.7 and Figure 5.3, Question 4 shows a negative learning gain of -2. For Question 5, 6, 10 and 14 the learning gain is 0.21, 0.08, 0.02 and 0.07 respectively, which is very low (below 0.3). What is interesting is the difference between Questions 4 and 5 which are similar type of questions. Question 4 is based on a context with which the learners are not familiar and produced a negative learning gain of -2.00. Question 5, a more familiar context, gave a higher learning gain of 0.21.

Table 5.7 show a decrease in the test averages of question 4. This result of a large effect size is indicating a practical significant difference. Question 5 shows that the test averages increases and shows a medium effect size. The differences between the pre-test averages and the post-test averages of Questions 6, 10 and 14, are small (giving very low effect sizes), which means that the differences between the pre- and post-test averages are practically not significant.

It is apparent that for Questions 5, 6, 10 and 14 the learning gains were insignificant. For Question 4 the learning gain had a high negative value. This indicates that the learners' first impression during the pre-test was correct, but they changed their views during the post-test. When considering the questions asked it become apparent that the respondents have a problem interpreting diagrams. In all the questions the same misconceptions that were initially held by the learners during the contact forces, were present. The difference is that the learners maintained these misconceptions with regard to Newton 1 diagrams and rectified them with regard to contact forces.

5.3.5 Newton 1 explanatory type question analysis

As in the previous section, the following section deals with the effect of forces on objects. The focus of these questions is on Newton 1 explanatory type of questions and not diagrams. The following gives an indication of the learners' perception and understanding when reading word questions.

Table 5.8: Newton 1 explanatory pre- and post-test results

Newton 1 Explanatory Pre-test Post-test results per question																							
Question 7 Pre-test			Question 7 Post-test			Question 9 Pre-test			Question 9 Post-test			Question 15 Pre-test			Question 15 Post-test			Question 16 Pre-test			Question 16 Post-test		
	Frequency	Valid %		Frequency	Valid %		Frequency	Valid %		Frequency	Valid %		Frequency	Valid %		Frequency	Valid %		Frequency	Valid %		Frequency	Valid %
A	5	10.9	A	0	0	A	18	39.1	A	20	43.5	A	20	43.5	A	23	50.0	A	10	21.7	A	9	19.6
B	3	6.5	B	29	63.0	B	5	10.9	B	17	37.0	B	6	13.0	B	4	8.7	B	6	13.0	B	7	15.2
C	7	15.2	C	14	30.4	C	3	6.5	C	2	4.3	C	13	28.3	C	14	30.4	C	11	23.9	C	18	39.1
D	25	54.3	D	0	0.0	D	10	21.7	D	3	6.5	D	2	4.3	D	3	6.5	D	9	19.6	D	6	13.0
E	6	13.0	E	3	6.5	E	10	21.7	E	4	8.7	E	5	10.9	E	2	4.3	E	10	21.7	E	6	13.0
Total	46	100	Total	46	100	Total	46	100	Total	46	100	Total	46	100	Total	46	100	Total	46	100	Total	46	100

When looking at the pre-test result for Newton 1 explanatory type questions in Table 5.8, the majority of the respondents chose option D in Question 7, which is a common misconception, namely a constant force accelerates a body until the body uses up all the power of the force. Only 6.5% of the respondents selected the correct option B. During the post-test 63.0% respondents chose the correct option B.

For Question 9 the majority of respondents (39.1%) chose option A during the pre-test, which is the misconception that an object with a constant (non-zero) net force will have a constant speed. Only 10.9% of the respondents chose the correct option B, while during the post-test 37.0% of learners opted for option B. Although the average percentage of correct answers increased, the majority of learners (43.5%) still supported the misconception.

Question 15 sees the majority, 43.5%, of the respondents during the pre-test chose the correct option A and a large number of learners, 28.3%, chose the wrong option C. During the post-test 50% of the learners opted for the correct option A, but there was still a large number of learners (30,4%) that chose option C. That means that a large number of learners maintained the misconceptions that an object will slow down without a net force or that a force is needed to keep a body moving even on a frictionless surface.

Most of the learners (23.9 %) chose the correct option C for Question 16 during the pre-test, but a high percentage of learners selected the wrong options A and E, 21.7% for both. During the post-test a larger percentage, 39.1%, of respondents chose the correct option C for Question 16. There was a fairly large number of respondents (19,6%) that still opted for option A, stating incorrectly that the applied force to move a box along a surface is equal to the weight of the box.

During the following part the effect size and learning gain for the topic Newton's first law of motion explanatory questions will be discussed in concurrence with Table 5.9, Figure 5.7 and Figure 5.8.

Table 5.9: Newton 1 explanatory dependent t-tests and learning gain

Dependent t-tests Statistics on Newton 1 Explanatory						
		Mean	Std. deviation	p-value*	Effect sizes	Gain
7	pre	6.52%	24.96%	.000	2.26	0.60
	post	63.04%	48.80%			
9	pre	10.87%	31.47%	.002	0.83	0.29
	post	36.96%	48.80%			
15	pre	43.48%	50.12%	.554	0.13	0.12
	post	50.00%	50.55%			
16	pre	23.91%	43.13%	.109	0.35	0.20
	post	39.13%	49.34%			

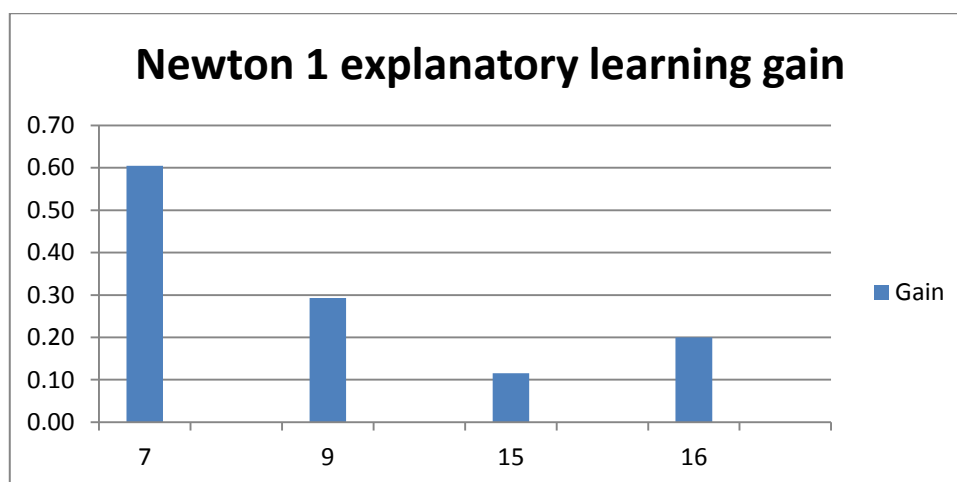


Figure 5.4: Newton 1 explanatory learning gain versus question number graph

Considering Table 5.9 and Figure 5.4 (the learning gain per question), we find that all the questions show a positive learning gain. Question 7 had the highest learning gain, with a medium value of 0.6, and Question 9 with a value of about 0.3. The other two Questions 15 and 16 show a low learning gain of 0.12 and 0.2 respectively.

Considering Table 5.9 (the dependent t-test per question), the effect size of the difference between the pre-test average and the post-test average for Question 7 is a large value of 2.26. The difference between the averages for Question 9 in the pre-test and the post-test was also large, giving an effect size of 0.83. For the other two questions (15 and 16) the difference between the pre-test average and the post-test average is small, with small effect sizes of 0.13 and 0.35 respectively.

We find that all questions show a positive learning gain for Newton 1 explanatory (Figure 5.7). Question 7 shows a high medium learning gain and Question 9 a low medium learning gain, whilst Questions 15 and 16 show an insignificant low learning gain.

When looking at the individual questions, for Question 7 dealing with an object on a frictionless surface, the learners were able to give the correct answer after the intervention during the post-test. Question 9 showed a low medium learning gain, but the majority of the learners maintained the misconception that if an object moves upwards at a constant velocity the upwards force is greater than the gravitational force vertically downwards.

What is interesting is that Question 15 is almost the same as Question 7; only the scenario differs with a rocket in outer space. Still, there is a large difference between the learning gains. It seems as if the learners can associate with Question 7, as they play the game fuzz ball; hence they are familiar with a frictionless surface, but not with a weightless atmosphere. The context of Question 15 is thus unfamiliar with the learners.

Also Question 16 is similar to Question 9; only the scenario differs, and again a large difference in learning gains was obtained. The observation can be made that the questions with high

learning gain were set in a more familiar context (e.g. the elevator that moves up a shaft) and the questions with low learning gain used in less familiar contexts (a woman pushing a box across a surface). The same concept yielded different results; only the context differs. This is an indication that learners need to be exposed to as many contexts as possible.

5.3.6 Newton 2 force question analysis

The following section deals with the effect of unbalanced forces on objects. The focus of these questions is on Newton's second law of motion. The following gives an indication of the learners' perception and understanding when confronted with accelerating objects.

Table 5.10: Newton 2 Pre- and post-test results

Newton 2 Pre-test Post-test results per question																	
Question 13 Pre-test			Question 13 Post-test			Question 17 Pre-test			Question 17 Post-test			Question 18 Pre-test			Question 18 Post-test		
	Frequency	Valid %		Frequency	Valid %		Frequency	Valid %		Frequency	Valid %		Frequency	Valid %		Frequency	Valid %
A	9	19.6	A	23	50.0	A	24	52.2	A	22	47.8	A	19	41.3	A	13	28.3
B	18	39.1	B	12	26.1	B	3	6.5	B	6	13.0	B	5	10.9	B	11	23.9
C	2	4.3	C	0	0.0	C	4	8.7	C	2	4.3	C	21	45.7	C	21	45.7
D	13	28.3	D	11	23.9	D	11	23.9	D	8	17.4	D	1	2.2	D	1	2.2
E	4	8.7	E	0	0.0	E	4	8.7	E	8	17.4	E	0	0.0	E	0	0.0
Total	46	100	Total	46	100	Total	46	100	Total	46	100	Total	46	100	Total	46	100

For Newton 2 pre-test Question 13 (Table 5.10), dealing with a rocket in space, the largest portion (39.1%) of the learners' first impressions were correct by choosing option B, but a large group of learners (28.3%) also chose the misconception option D, that states that a force is needed to keep a body moving even on a frictionless surface. Only 26.1% of respondents chose the correct option B during the post-test, whilst the majority of the learners (50%) chose the misconception option A that states that an object with a constant (non-zero) nett force will have a constant speed.

For Question 17 the overwhelming majority of the learners (52.2%) chose the wrong option A during the pre-test, which is a misconception, and only 8.7% of the respondents selected the correct option E. During the post-test 47.8% of the respondents selected the wrong option A and 17.4% of the respondents chose the correct option E. The misconception maintained by the learners by choosing option A, is that faster-moving objects have larger force acting on them.

For Question 18 during the pre-test the majority of respondents (45.7%) chose the correct option C, but a large portion, 41.3%, chose option A. During the post-test 45.7% of respondents

chose the correct option C and the majority of other respondents were divided between options A and B. The misconception associated with choosing option A is that a force is needed to keep a body moving even on a frictionless surface, and once a force is withdrawn from an object, the object will move at a constant velocity or even accelerate for a while until the object uses up all the power of the force.

During the following part the dependent t-test and learning gain for the topic Newton's second law of motion will be discussed in concurrence with Table 5.11, Figure 5.9 and Figure 5.10.

Table 5.11: Newton 2 effect size and learning gain

Dependent t-test Statistics on Newton 2							
Question		Mean	N	Std. deviation	p(Sign(2-tail))	Effect size	Gain
Pair 13	pre	39.13%	46	49.34%	.160	0.26	-0.21
	post	26.09%	46	44.40%			
Pair 17	pre	8.70%	46	28.49%	.253	0.31	0.10
	post	17.39%	46	38.32%			
Pair 18	pre	45.65%	46	50.36%	1.000	0.00	0.00
	post	45.65%	46	50.36%			

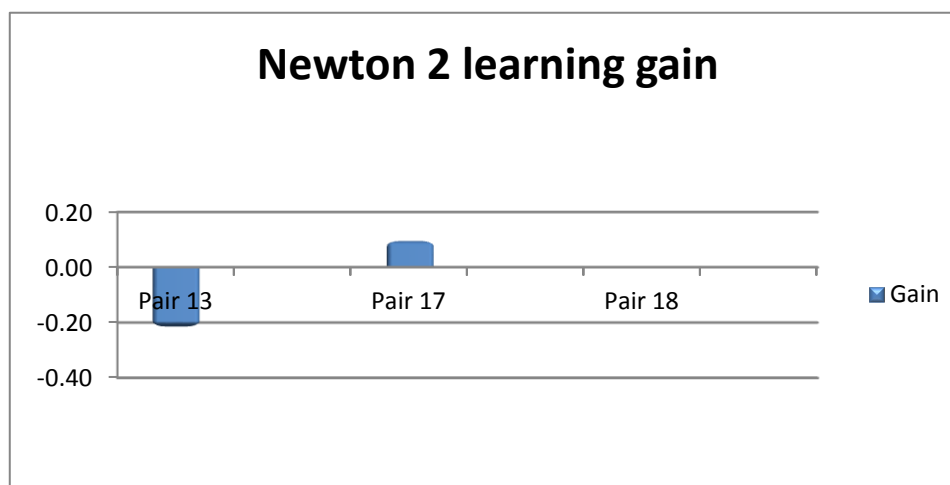


Figure 5.5: Figure 5.9: Newton 2 learning gain versus question number

When considering the learning gain in Table 5.11 and Figure 5.5, Questions 17 and 18 show a low learning gain of 0.1 and 0.00 respectively (below 0.3). Question 13 shows a low negative learning gain of -0.21.

When considering the effect size in Table 5.11, the effect size of the difference between the pre-test average and the post-test average for Question 13 was small at 0.26. The difference

between the averages for Questions 17 and 18, i.e. the pre-test average and the post-test average was also practically non-significant at 0.31 and 0.00 respectively.

The results for the Newton 2 questions were indifferent, because the average learning gain was -0.037, which can be neglected. In Questions 13, 17 and 18 we find that Question 13 had a low medium negative learning gain, Question 17 had a low positive learning gain and Question 18 had no learning gain. When looking at the individual questions, the learners were unable to identify the effect of an unbalanced force on the object. The misconceptions that the learners to some extent retained were:

- an object with a constant (non-zero) net force will have a constant speed;
- a force is needed to keep a body moving even on a frictionless surface
- once a force is withdrawn from an object, the object will move at a constant velocity or even accelerate for a while until the object uses up all the power of the force
- faster-moving objects have larger forces acting on them.

The association of force with speed instead of velocity and acceleration and the other misconceptions were also reported by Palmer (1997:692).

5.4 Summary of findings from quantitative data

Some misconceptions are more difficult to change than others, and the misconceptions dealing with Newton's laws of motion are particularly stubborn. The misconception that views an object containing an internal force was present in four of the five topics, namely kinematics, contact forces, Newton 1 diagrams and Newton 1 explanatory. This concept was particularly difficult to rectify regarding Newton 1, but with contact forces the learners managed to change their conceptual framework. Other prominent/common misconceptions were that the motion of an object is in the direction of the net force applied to the object; a large object exerts a greater force than small objects, and a force is needed to keep an object moving with a constant speed

One of the common problems the learners faced was their inability to recognise and interpret diagrams when answering questions. This was clear when we consider the learning gain between Newton 1 diagrams with an average learning gain of -0.32 and Newton 1 explanatory with an average learning gain of 0.3. It is clear that the learners did better with questions explaining the scenarios than making use of formal diagrams, making use of vectors and motion diagrams to illuminate the situations. One can conclude that the learners are able to verbalise the theory, but are unable to link the formal visual images with the knowledge framework.

When comparing Question 6 (Newton 1 diagram), with a learning gain of 0.08, to Question 7 (Newton 1 explanatory), with a learning gain of 0.6, the two questions test the same concept.

The difference is that in Question 6 the scenario is elaborated with a sketch and the options are also given in the form of a sketch, whilst the possible answers in Question 7 uses words to describe the velocity after contact. The learners were not able to link the Newtonian principle that when no external force acts in on an object the velocity remains constant, with the graphical representation of a constant velocity as a straight line.

Looking at the concepts leading up to Newton's second law of motion one finds the following:

- Viewing kinematics, which can be regarded as prior knowledge to a study of Newton's laws, we find that the learners yielded a very low average learning gain of 0.15. This means that the base of the learners' knowledge construction is not sufficient. The kinematics topic forms the theoretic framework on which Newton's first but more specifically the second law of motion is based. One can say that Newton's laws of motion attach kinematics to the force concept in a knowledge framework.
- The topic contact forces yielded an average learning gain of 0.52, which is acceptable and indicates a sound base for the construction of Newton's first law of motion. This is also an indication that the cognitive conflict teaching strategy was successful with regard to establishing a definition of forces. The aim is to try and connect Newton's laws of motion to the force concept through elaboration of the learners' definition of the force concept established during the first phase of the intervention.

Newton 1 explanatory yielded an average learning gain of 0.3, which indicates that the learners' knowledge structures improved. It is also an indication that the development of ideas teaching strategy was successful with regard to the Newton 1 explanatory topic. This is an indication that the learners' knowledge framework developed in such a way that a link was formed between the force concept and Newton's first law of motion when verbal explanations were used.

- Newton 1 diagrams yielded a low average learning gain of -0.32. This implies that the misconceptions were strengthened during the teaching strategy. It is also an indication that the development of ideas teaching strategy was not successful with regard to linking the Newton 1 diagram concepts to the greater force concept (Figure 4.5). Taking the Newton 1 explanatory questions in consideration it is clear that the explanations were understandable for the learners. However, when testing the same concept in the diagrams, the learners were not able to link the diagrams to their existing concepts of force. It is important that they are able to do that, since Newton 1 diagrams and explanatory form the theoretic framework base for Newton 2. This implies that it cannot be expected that the learners would be able to understand Newton 2 problems without the background knowledge of Newton 1.

- For Newton 2 the learning gain was -0.036, which indicates that the development of ideas teaching strategy was not successful to enhance the learners' knowledge of this topic. What is necessary for the learners is to make Newton 2 part of their knowledge framework. Knowledge of Newton 2 is should be connected to accelerated motion knowledge structures and also Newton 1 knowledge structures. Therefore it is imperative that the learners reveal a sound knowledge structure regarding kinematics, forces and Newton 1 concepts before the onset of the development of ideas teaching strategy.

Since the learning gain and the effect size showed similar results only the learning gain was discussed in the previous paragraphs.

The qualitative data, as well as the results that were obtained from the qualitative data, will now be discussed.

5.5. QUALITATIVE DATA ANALYSIS

This section deals with the qualitative data that was obtained during the analysis of the video recordings made during the intervention. It focuses on the answers of the learners to specific questions from the researcher. This was done to determine whether conceptual development was obtained during the intervention and to support or elucidate the quantitative data.

Two teaching strategies, namely cognitive conflict teaching strategy (cf. par. 4.7.1.1) and development of ideas teaching strategy (cf. par. 4.7.1.2) were implemented in the intervention to accomplish conceptual development (cf. par. 4.7.1). The qualitative data were obtained during the intervention. Examples of results obtained from the transcribed data are given and discussed in the following sections with reference to the two teaching strategies of the conceptual development approach. The "R" used in the direct verbatim quotations refers to the researcher's words, whilst the "L" refers to the learners' words/responses.

5.5.1 Conceptual development

Conceptual development refers to the change that occurs in the learners' conceptual framework from a novice framework to a scientific conceptual framework (cf. par.1.3.3). It transpired from the responses of the learners that conceptual development was obtained by the intervention process and will become clear over the next couple of paragraphs.

The *conceptual development* approach was formulated based on the teaching strategies contained in it.

5.5.1.1 Cognitive conflict teaching strategy

The cognitive conflict teaching strategy is based on a strategy where the learners' conceptual frameworks are directly challenged by the researcher. This causes conflict and uneasiness in the mind of the learner with regard to their existing conceptual framework. When that point is reached the researcher presents information to persuade the learners to change their existing concept with a scientific more correct concept (cf. par. 3.6.1).

The use of the **cognitive conflict** teaching strategy is illustrated by the following verbatim quotations:

- R *... So we sit with contact and non-contact forces. What else do you know about forces? Yes!*
- L *An object can't experience forces when it is on its own.*
- R *What do you mean about that.*
- L *When an object is lying on its own, it will not experience a force, you said that objects need contact to experience force.*
- R *So you tell me, when I place a book there on the table (indicating a book in the table), it is not experiencing a force?*
- L *It is experiencing a force.*
- R *Then, what do you mean when you say an object cannot experience a force on its own?*
- L *There must always be an object exerting a force on another object.*

During this interaction the **misconception** that is addressed is the conception that, if an object is **not moving, no force is acting** on it. What the researcher does is confront the learners' concept directly, creating conflict in the learner's conceptual framework. The method used in this case is done through a demonstration. The learner rectifies his misconception accepting the correction with a scientific more acceptable conceptual framework. The learners also show difficulty in linking the force concept with motion.

- R *How can we define a force? ... Yes.*
- L *A force is work done on an object.*
- R *Is force work done on an object? Is that what you are saying?*
- L *Yes.*
- R *When is work done on an object? All right, you are a prop, right? Go and scrum the wall. Go and scrum the wall!*

- L *(Learner stands up and walk to the wall.)*
- R *What are the conditions for work to be done? ... There are two. ...*
- L *Force and distance.*
- R *Force and movement in the direction of the force. Can you remember that? For work to be done we need a force and we need a motion in the direction of the force. Bull, scrum the wall ... Push the wall, my friend. That is leaning against the wall; push against the wall! Don't push it with your head, try your hands ... OK, are you exerting a force?*
- L *Yes sir.*
- R *I agree, you do exert a force. Are you doing work?*
- L *No*
- R *You are not doing work. You are going to push and you are going to sweat while you are pushing the wall, but you are not doing work. So we need to clarify the situation. So not always is work done when a force is applied. OK. So we need to clarify and define force more closely. So that we can get a better understanding of what a force is. Alright, let's try again, when you think of forces, what do you think of?*
- L *It is a push or a pull.*

The learner wrongly **define force as work done** and the researcher use the opportunity to create conflict in the mind of the learner to experience discontent or uneasiness with his current concepts and also attempts to rearrange the learners' conceptual framework (cf par. 3.3). Work done is related to resultant force, but work is not force. In this case the idea of the learner is not completely wrong, so the researcher is careful not to focus on just the fact that the answer is wrong. The researcher attempts to place work into context with the conceptual framework of force. The researcher challenges the learner's concept of force again and this time it is obvious the learner access the correct conceptual framework.

- R *..... When does the state of motion on an object not change?*
- L *When there are no forces.*
- R *(Push a trolley on a bench). When I push this trolley, what happens to that trolley?*
- L *It changes its motion.*
- R *Correct, it changes its motion, it started at the beginning with a certain speed and then as I let go, it slows down. So there is a force acting in on it. What force is acting on the trolley?*

- L *Gravity.*
- R *First the push changes the state of motion of the trolley accelerating it, but when my hand let go of the trolley. What happened to the trolley?*
- L *It slows down.*
- R *What forces are causing it to slow down?*
- L *Friction.*
- R *So friction force slows the trolley down. If there was no friction forces will the trolley slow down?*
- L *No.*
- R *No it will not. What will happen to it?*
- L *It will go at a constant velocity.*

In this example the researcher addresses the same **misconceptions** (passive forces do not exist and a **force is needed to keep a body moving** even on a frictionless surface) as in the first example, but in a different context. The researcher again creates cognitive conflict by creating doubt or an uneasiness in the mind of the learner with his concept of force. But through a demonstration and also by making use of his cognitive resources, he leads the learner to a more scientific conceptual framework of force. Again the learners show a difficulty in bringing forces in line with the kinematics concept.

- R *Let's look at a person that jumps out of an airplane to free fall to the ground (Show picture on the board). What will happen to him?*
- L *He will accelerate.*
- R *He will accelerate. Once he is out of the plane, what will happen to him?*
- L *The acceleration is constant.*
- R *When he jumps out. What comes into play then? What happens when you push your head out of the car?*
- L *Friction.*
- R *We find there is air friction. The same happens when you jump out of an airplane; the air friction comes into play.*
- R *What forces come into play when you jump out of the airplane?*
- L *Gravity and air pressure.*
- R *Gravity down and the force due to air pressure pushing up. What happens to his acceleration as he falls?*

- L *It decreases.*
- R *The acceleration becomes less until we get to terminal velocity. Terminal velocity is reached when the acceleration is?*
- L *Zero*
- R *Zero? What does the fact that the acceleration is zero imply?*
- L *His velocity is zero.*
- R *His velocity is zero? ... But what does it imply in terms of the forces acting on him? What is the nett force acting on him?*
- L *Increase (other learners shout no it decrease). Sorry, sir there is no difference to the forces.*
- R *Listen carefully to the question. What happens to the nett forces acting on the person?*
- L *It becomes zero.*

The initial example used by the researcher is an unfamiliar context for learners. The learners experienced uneasiness with this unfamiliar scenario. The researcher then uses a familiar context (“push your hand out of the driving car”) to guide the learners to understand the new context. The researcher was able to assist the learners in correcting their conceptual framework by linking the unfamiliar context with a familiar context. Once they rectify their concept the researcher leads the learners to the correct scientific relation between force and acceleration.

5.5.1.2 Development of ideas teaching strategy

The development of ideas teaching strategy is an indirect teaching strategy where the researcher first establishes an “anchor” or bridging concept that is scientifically acceptable. This is done by reaching an agreement between the learners, the researcher and the scientific theory. Once a bridging concept or “anchor” is established, it is integrated into everyday examples to develop the conceptual framework further. This is expected to persuade the learner to change his or her concept (cf. par. 3.6.2).

The ***development of ideas teaching strategy*** is formulated based on the following direct verbatim quotations:

- R *(Draws a block on an inclined plane on the white board and tells the learners that the block is not moving). What forces are acting on the block?*
- L *Force due to gravity and frictional force.*

- R *What do you know about the forces?*
- L *Frictional force is greater than the applied force.*
- R *Let's go back to the definition of force. We get balanced and unbalanced forces. When unbalanced forces act on an object change will occur and when balanced forces act on an object there will be no change. Can the friction forces in this case be larger than an applied force?*
- L *Yes, it can*
- R *So you tell me that the block will move in the direction of the friction.*
- L *No.*
- R *But that is just what you told me. What you say is that when the friction force is larger than an applied force, the resultant force will be in the direction of the frictional force, causing acceleration in the direction of the friction force. Can frictional force be larger than the applied force in this case?*
- L *No.*
- R *When are forces balanced?*
- L *No motion or constant velocity.*

In this situation the learners are taken back to the definition of force which is the **anchor or bridging concept** in this situation (cf. par. 4.7). Once they see that the answer does not agree with the anchor the concept is changed to concur with the anchor. The learners do not doubt their bridging concept, so they are more likely to change their concept to adapt to the new information.

- The researcher has two diagrams on the board, w (1) ith $F_a > F_f$ (applied force is larger than the friction force) and (2) $F_a = F_f$ (applied force is equal to the friction force).

R *Under which one does constant velocity fall? If a car is driving at a constant velocity of 20 km/h, where does it belong? (Indicating (1) and (2))*

L *Under (1)*

R *Indicate it on the board. Who agree? Put up your hands.*

Three learners agree with him.

R *Who does not agree with him?*

Three other learners put up their hands.

R *What do you say?*

- L *The second (2) one.*
- R *(Researcher writes the options on the board). One group says constant velocity belongs there (indicating (1)), and the other group says it belongs there (indicating (2)). Here we have an unbalanced force (indicating (1)), you agree?*
- L *Yes.*
- R *There we have a balanced force (indicating (2)). You agree?*
- L *Yes sir.*
- R *Let's look at the definition of force. (Goes back to the definition of force on the white board). We have an unbalanced force and we have a balanced force. Here we have a nett force and there no nett force. What did we find here (indicating unbalanced force)?*
- L *Change.*
- R *Yes, change of shape, state of motion also changes in velocity, meaning acceleration or deceleration. For balanced forces you said there is no change in the state of motion, in other words no motion or moving at a constant velocity. That is what you told me last week. Now we got to this situation here (indicating the original diagrams). Some of you tell me if an unbalanced force acts on an object it gives a constant velocity?*
- L *We apologise sir, it is wrong. A balanced force gives a constant velocity.*

The learners were confronted with two scenarios and were asked to fit a **certain motion into one of the two scenarios**. The majority of the class had it wrong. But when they were reminded about the anchor concept that they developed, they immediately recognised their mistake and rectified their concept. The learners were able to rearrange their concept and conceptual development took place effectively.

5.5.2 Field notes and observations

The researcher observed the following during the intervention:

At the onset of the intervention, most learners were motivated, cooperative and diligently completed the worksheets. As the learning intervention progressed and the concepts became more difficult and the mathematical component increased, the confidence levels of the learners dropped accordingly, as was observed in their behaviour and the non-completion of work sheets. For example, only one learner completed and handed in the worksheets pertaining to Newton's second law. The learners who usually underperform, also became more restless as the intervention progressed and the difficulty increased.

5.5.3 Summary of findings from qualitative data

The quotations revealed that conceptual development during the intervention was probably achieved. During the intervention the cognitive conflict teaching strategy was used to establish first of all the anchor concept; then it was also used to clarify some concepts in which the anchor concept was not viable. The development of ideas teaching strategy was used to explain Newton's laws of motion (cf. par.3.8).

The qualitative findings revealed that the cognitive conflict teaching strategy seemed to be successful to establish conceptual development, even though some misconceptions were particularly resilient and reoccurred when the context changed. The learners displayed an inability to bring the kinematics concept in connection with the force concept. The moment the learners were confronted with a new context they fell back to their novice concept of force to explain the situation. They rectified their conceptual framework quickly once they understood the context.

It was also found that the development of ideas teaching strategy seemed to be more effective than what the quantitative data revealed in establishing conceptual change. The learners were more susceptible for conceptual change when the anchor concept was used during the intervention. The learners were more reluctant to change their conceptual framework with new information that replaced parts of their existing conceptual framework. It was easier for learners to elaborate their conceptual framework by adding new information into their existing conceptual framework, than to change it.

It is important, though, to remember that it takes time for learners to change their conceptual framework (Von Aufschnaiter & Rogge, 2010:9; Woolfolk, 2010:244). Although they accept the change during teaching it is not necessary a permanent change. The learners still need to spend some time with the concept, working through scenarios, doing worksheets, or even applying the new theory to everyday situations and experiences. Time spent on a concept ensures that the changes made to the learners' conceptual framework is made permanently. The new knowledge framework becomes the preferred framework by the learners to answer questions and not their novice knowledge framework.

5.6 QUANTITATIVE AND QUALITATIVE RESULTS: SYNTHESIS & DISCUSSION OF THE TEACHING SEQUENCE OF NEWTON'S SECOND LAW OF MOTION

The results of both quantitative and qualitative datasets are integrated in this section. In addition, and as suggested by Creswell and Plano Clark (2007:106, 137), the extent to which the data converge or concur, how it converges and to what extent data confirm each other, would be discussed, as well as differences or disconfirming evidence in the data. The former is

essential to ensure validity of the integrated results (cf. par. 4.5.3 – credibility). The effect sizes are not discussed as such because the learning gain and the effect size results are comparable.

The following *similarities* were found between the two data sets (cf. par. 5.4 & par.5.5.2):

It emerged from the results of both quantitative and qualitative data sets that the participants' understanding of contact forces (cf. par. 5.3.3 & par.5.5.1.1) and Newton 1 explanatory (cf. par. 5.3.5 & par.5.5.1.2) improved through the teaching strategies that focused on conceptual development and that learning gain was accomplished with regard to:

- Cognitive conflict (cf. par. 5.4 & par.5.5.2)

From both data sets it became evident that contact forces (cf. par. 5.3.3 & par. 5.5.1.1) showed the highest learning gain. Kinematics (cf. par. 5.3.2 & par. 5.5.1.1) showed some learning gain, but not as prominent as contact forces. Contact forces and kinematics were the topics that were established at the beginning of the teaching strategy, during the establishment of the anchor concept. This is an indication that the cognitive conflict strategy was effective. It can also be argued that the cognitive conflict teaching strategy seemed to be effective when dealing with small undeveloped conceptual frameworks. The moment the conceptual framework becomes more advanced a development of idea strategy becomes more eminent.

- Development of ideas (cf. par. 5.4 & par. 5.5.2)

Newton 1 explanatory (cf. par. 5.3.5 & par. 5.5.1.2) group of questions also showed a positive medium learning gain. It seems evident from the qualitative results that the development of ideas teaching strategy was probably effective. The learners readily accepted the new content during the teaching process and it became evident that the learners understood the concept and were also eager to change their conceptual framework during the lesson. But time spent on the topic and repetition of knowledge in different contexts are important for the change that occurred to make it permanent. If that does not happen, interference may take place and the learner may fall back to their novice concept when dealing with new scenarios, as was found amongst the results.

Disconfirming evidence that emerged between the two data sets and possible reasons thereof:

- Development of ideas (cf. par. 5.4 & par. 5.5.2)

Although the post-test of the quantitative data revealed that no significant learning gain was obtained with regard to Newton 2 (cf. par. 5.3.6 & par. 5.5.1.2), the qualitative data revealed that

conceptual development occurred during the intervention but did not endure, as became evident through the responses of the learners. One can argue that the learners did not spend enough time with the concept to make the changes to their knowledge framework permanent.

Another difference was between the qualitative and the quantitative results sets of Newton 1 diagrams (cf. par. 5.3.4 & par. 5.5.1.2). According to the qualitative results, the development of ideas teaching strategy appears to be effective at the moment, but it was not mirrored by the quantitative results.

Short-term changes seemed to be made by the learners to conceptual framework, but due to insufficient reinforcement the changes made by the learners were not stored permanently in the long-term memory (cf. par. 2.3.2.).

Possible reasons that learning gain could not be established are:

A possible explanation of the results is that the learners commenced with examinations two days after finishing Newton's second law of motion. One can assume that the learners prepared for the examination instead of working on their worksheets. This became clear when the researcher checked the worksheets pertaining to Newton's second law of motion and found that only one learner made some effort to answer the questions. It was further observed that only 6 of the 46 learners managed to complete the worksheets pertaining to Newton's first law of motion. Almost all the learners completed the worksheets on contact forces. In order to secure the conceptual framework in the long-term memory, the learners need to repeat the work and also do enough exercises so that the learners can change their conceptual frameworks.

The learning process starts in the classroom, but there are additional aspects that may influence learning. For example, when learners are not motivated or some learners are disruptive in class it may influence the learning process, and the learners will not be able to permanently change their conceptual frameworks. The post-test was done during the examination, even if it was done on a day that the learners did not write any other subjects. The problem was that the learners did not give their exercises the necessary attention, which means construction of their mental frameworks was not complete. The learners would rather study for the exams than concentrate on Newton's law of forces (cf. par. 3.3). This is an example of attrition which is a threat to reliability and validity (cf. 4.4.2).

Another consideration can be the limitation placed on the researcher due to time constraints. This was due to the limited time available due to a very full timetable and the department forwarding the exam two weeks. Other contextual factor that could also play a role like the visiting overseas rugby team, the department moving the exam two weeks earlier and ill-

disciplined learners in the classes disrupting the lesson. All the pre-mentioned factors can all have an effect on the learning gain.

5.7 SUMMARY

Both sets of data showed conceptual development for kinematics, contact forces and Newton 1 explanatory. The teaching strategy that was used to explain kinematics and the contact forces was the cognitive conflict teaching strategy (cf. par. 5.5.1.1), whilst for Newton 1 explanatory the development of ideas teaching strategy was used (cf. par. 5.5.1.2).

The learners found Newton 1 diagrams more difficult to conceptualise than Newton 1 explanatory. Since Newton 2 can be linked to all the kinematics concepts, it can be expected that if the learners have a problem within their kinematics knowledge framework, they will have a problem conceptualising the Newton 2 concept. The under-developed kinematics conceptual framework is detrimental to the development of the Newton 2 conceptual framework as was substantiated by the results.

CHAPTER 6

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

In this concluding chapter, the results and findings from previous chapters are summarised. The limitations pertaining to this study are discussed, conclusions are drawn and recommendations for future research are provided.

The aim of this study was to determine the effectiveness of conceptual development teaching strategies applied to Newton's second law of motion to Grade 11 learners (cf. par. 1.4.1).

The specific research objectives of this study were to (cf. par. 1.4.2):

- ❖ compile a theoretical framework through a literature study on
 - how learners form concepts in their memories;
 - conceptual change strategies for facilitating the development of science concepts;
 - learners' alternative conceptions related to Newton's laws of motion.
- ❖ perform a pre-test to determine the Grade 11 learners' alternative conceptions and conceptual resources for the learning of Newton's second law of motion.
- ❖ design an intervention that utilises conceptual development teaching strategies to elaborate and transform learners' existing knowledge structures through accommodation and association of new knowledge.
- ❖ determine the effectiveness of the intervention to facilitate understanding of Newton's second law in the Grade 11 learners.

6.2 SUMMARY OF CONTENT OF CHAPTERS

Physical Sciences as a subject should not only prepare learners to study further at a higher level, but also to follow a career in a Physical Sciences-related field. In South Africa there is a demand for people following a career in science and also for scientific literate citizens (cf. par. 1.1). However, Physical Sciences has been a problem nationally and internationally with poor learner performance. Moreover, statistics related to the pass rates of Grade 12 South African learners with regard to Physical Sciences showed a decline in learner performance, as alluded to in Chapter 1. Therefore, it is imperative that research be conducted in Physical Sciences to address the afore-mentioned problems. One way to address these afore-mentioned problems is to improve the instruction and education of Physical Sciences educators. It was mentioned that the learners bring prior knowledge, experience, cognitive resources and interests into the

classroom. Educators should be aware of these tools the learners bring into the classroom. In order to develop scientific enlightened learners, these tools should be integrated with the scientific knowledge of learners (cf. par. 1.2).

A conceptual development teaching strategy is based on the information-processing model of learning. The roots of the information-processing model are found in the cognitive learning theory, research done in neuroscience, psychology and educational science (cf. par. 1.2). This model facilitates elaboration through assimilation and accommodation. It was also explained why assimilation is preferred and favoured above accommodation. Through this process the skills, the cognitive resources the learners bring into the classroom are used to develop the novice conceptual framework of the learners into a scientific sound conceptual framework (cf. par. 1.2). Attention must be paid to the teaching strategy to guard against the formation or strengthening of misconceptions during the learning process.

In Chapter 2 the theory and process of learning were investigated. It was argued that the only way to raise the level of education is to integrate educational research and technology inefficient learning environments (cf. par. 2.1). The four learning theories, namely classical conditioning, operant conditioning, social learning and cognitive learning theory were discussed (cf. par. 2.1). The focus of this study, however, was on the cognitive learning theory that deals with the functioning of the brain that comprehends patterns, makes approximations and uses various types of memory. It also became evident that the brain has the ability to learn from previous experience, can self-correct and create (cf. par. 2.2).

The brain of the learner connects, organises and reorganises the new information into a conceptual framework to be stored in the long-term memory (cf. par. 2.2.1). This conceptual framework connects with other conceptual frameworks to form a proportional network of interrelated concepts. Propositions, images, smell and experiences form schemas that are abstract knowledge structures that form in the brain and are organised into vast amounts of interrelated knowledge structures (cf. par. 2.2.2). During learning neuroplasticity occurs when these neural networks are extended, pruned, reorganised, corrected or strengthened on receiving of new information. The learners develop a mental framework that assists them to conceptualise an event, put the event into perspective and assists them to make predictions (cf. par. 2.2.3).

According to the information-processing model new information starts its journey to the long-term memory through the five senses of the learner entering the sensory memory where the important information is filtered and pass through to the working memory (cf. par. 2.2.2). As the information pass through the sensory memory, conceptual frameworks in the long-term memory are stimulated and moves into the working memory where the new information is merged with

the existing frameworks and placed back into the long-term memory (cf. par. 2.2.2). The educator should prune the information to be communicated to the learners to the most essential, and then draw the learners' attention to these most important aspects of information. If the message containing the information is convincing, the learner will link the new information to their existing knowledge structures in the pre-frontal cortex of the brain (cf. par. 2.2.3). These knowledge structures are not just knowledge-dependent, but also context-dependent (cf. par. 2.3). According to Redish (2003), learning is based on five principles namely the constructivist, the context, the change, the individual and the social learning principles (cf. par. 2.4).

In Chapter 3 the learning theory that was discussed in Chapter 2 informed the teaching and learning strategies to be reviewed. Accordingly, learners are required to construct the physics concepts into coherent physics frameworks thereby enabling the learners to use these concepts in a wide variety of scenarios and contexts (cf. par. 3.1). These scientific conceptual frameworks are used to analyse problems and place it in the correct context to solve problems (cf. par. 3.2). It is imperative that educators understand how concepts are stored in the brains of the learners in order to use the conceptual development teaching strategy. Educators should also know how the learners interrelate with these concepts during teaching (cf. par. 3.2). It was also explained that alternative conceptions (or misconceptions) often form when learners are unable to merge the new information from the sensory memory with a conception in the long-term memory. When the information from the sensory memory clashes directly with the properties of the concept in the long-term memory, the information from the sensory memory will either be rejected completely by the learner or the learner will form an alternative concept (cf. par. 3.2). It was furthermore explained that learners use algorithms when they are not able to understand a problem fully due to an underdeveloped conceptual framework or alternative conceptual frameworks.

During the process of forming a scientific concept of force, conceptual resources act as the prior knowledge that is used to construct the new knowledge, as described (cf. par. 3.3). It was suggested that educators need to use appropriate methods to facilitate learning for the learners to develop correct and consistent scientific concepts. It was also suggested that the learners need to be made aware of their incorrect conceptual frameworks and rectify them by reallocating the concept to the scientifically correct framework (cf. par. 3.2). The concepts in science are interrelated; therefore educators should attempt to assist learners to develop scientific correct mental representations of force (cf. par. 3.3). This places an emphasis on the order of acquisition by the learner. An appropriate teaching strategy for the teaching and learning of force needs to be implemented should conceptual change be achieved with regard to Newton's second law (cf. par. 3.4). The cognitive conceptual change approach is divided into two main schools of thought as pointed out. The first and more direct method is the so-called "*cognitive conflict*" teaching strategy and the second, which has three underlying strategies, is

the “*development of ideas*” *teaching strategy* – as described. Both strategies are based on the principle of elaboration of relevant prior knowledge (cf. par. 3.5). It is clear that, in order to teach for conceptual change, relevant prior knowledge should be the starting point for the learning experience. The conflict between learners’ concept and the scientific concept will then motivate the learners to change their existing conceptual frameworks (cf. par. 3.5). It was also suggested that assessment should be continuous and that the learners should be cognitively involved during the lessons in order for the educator to adapt the lesson to the cognitive feedback received from the learners (cf. par. 3.6).

In Chapter 4 the researcher discussed an intervention based on conceptual development teaching strategies. The two strategies that were used was the cognitive conflict teaching strategy and the development of ideas teaching strategy. The cognitive conflict strategy is a direct teaching strategy, whilst the development of ideas strategy is an indirect teaching strategy. The researcher used a cognitive conflict teaching strategy to establish a bridging concept to be used as anchor during the development of ideas teaching strategy (cf. par. 4.7).

In Chapter 4, the mixed-methods research design used in this study, more specifically the sequential explanatory design, was described and visually presented (cf. par. 4.2). Aspects such as timing, weighting and mixing related to this design were explained. The rationale for the use of an underpinning philosophical worldview and the strengths and weaknesses related to this design were also described (cf. par. 4.2). The study population and sampling related to both the quantitative and qualitative methods were described (cf. par. 4.4.2). The quantitative and qualitative methods, including data collection and analysis related to these methods were presented separately (cf. par. 4.3 & par. 4.6).

The quantitative part of the study, more specifically a single group pre-test-post-experimental design that was the major focus of this study, was visually illustrated and discussed first. The revised Force Concept Inventory (FCI) that was used to collect quantitative data regarding the learners’ concept of forces and Newton’s laws of motion was described (cf. 4.4.1). Thereafter the internal and external validity and reliability related to the quantitative research were discussed (cf. 4.4.2). The quantitative data analysis, including the statistical programme and formulas used were also discussed (cf. 4.4.3).

The qualitative part of the study more specifically phenomenological research that was used to explain and support the quantitative data, was described (cf. par. 4.4.1). The qualitative data was collected by means of video-recordings, but qualitative data collection also included a discussion on the researcher’s role, the literature study that preceded the research, observations and field notes (cf. par. 4.5.2). Trustworthiness and credibility and data analysis

related to the qualitative part of the study were also alluded to (cf. par. 4.5.3). The ethical considerations related to this study were also explained (cf. par. 4.6).

In Chapter 5, the results of the quantitative and qualitative data analysis have been presented separately. Thereafter the integration of the entire analysis was discussed. The data collected through the revised FCI was used to calculate the learning gain of the interventions. Effect sizes were also calculated to determine the difference the intervention made (cf. par. 5.3). The quantitative data was divided into five groups of questions according to the concepts involved in and including Newton's second law of motion. The results of the force concept in the contexts of kinematics (cf. par. 5.3.2), contact forces (cf. par. 5.3.3), Newton 1 diagrams (cf. par. 5.3.4), Newton 1 explanatory (cf. par. 5.3.5) and Newton 2 (cf. par. 5.3.6), were discussed separately and the findings were summarised (cf. par. 5.4). Thereafter the qualitative data were analysed. The data was discussed in accordance with the teaching strategies with the main strategy conceptual development (cf. par. 5.5.1) and the two specific strategies used, namely cognitive conflict (cf. par. 5.5.1.1) and development of ideas (cf. par. 5.5.1.2). These were individually discussed, specific quotes were cited and the findings were summarised (cf. par. 5.5.2). Finally the two sets of data (quantitative and qualitative) were integrated and the combined results were discussed (cf. par. 5.6.). (Note: the findings will be discussed in the conclusions – cf. par. 6.3)

6.3 SUMMARY OF FINDINGS OF THE EMPIRICAL STUDY

6.3.1 Research question

The following conclusions that have been made concerning the research questions are as follows:

- The application of conceptual development strategies was an on-going event, and the construction of Newton's second law of motion is based upon knowledge structures like kinematics, contact force, Newton 1 diagrams and Newton 1 explanatory (cf. par. 5.4). The quantitative results indicate that there was an improvement in the students' force concept from their initial alternative conceptions such as that of an internal force. Especially the learners' understanding of contact forces and Newton's first law of motion yielded significant improvement as indicated by the high learning gains and effect size values (Table 6.1). The learners' scientific knowledge thus showed progress in the development of their conceptions of force towards an understanding of Newton's second law. The overall learning gain for all the questions was 0.19, which is low, but the effect size was 1.19. This indicates a practical significant difference between the students' responses in the pre- and post-tests, although some alternative conceptions still lasted.

Table 6.1: Effect size and learning gain per concept

Topic	Pre-test average	Post-test average	Effect size	Learning gain
1. Kinematics	20.11	30.98	0.28	0.15
2. Contact forces	30.43	50.44	2.12	0.52
3. Newton 1 diagrams	28.26	23.86	-0.08	-0.32
4. Newton 1 explanatory	21.2	47.28	0.89	0.3
5. Newton 2	31.16	29.71	0.02	-0.04
Total	131.16	182.27	1.19	0.19

From the results in Table 6.1 it is evident that the learners' conceptual understanding of their pre-knowledge of kinematics was lacking. It can be concluded that they were not able to link force concepts with kinematics concepts as expected in Newton's second law of motion. After the intervention the learners' ability to conceptualise contact forces improved significantly, which is clear from the high medium learning gain and high effect size. Newton 1 diagrams revealed a very low learning gain and effect size. Newton 1 explanatory questions displayed that a medium learning gain was achieved, although the effect size was high. Comparing Newton 1 diagram and Newton 1 explanatory result, it can be concluded that the learners are unable to recognise forces when looking at diagrams, but are able to recognise the force concept when the scenario is explained. The group of questions based on Newton's second law exhibited that the learners did not completely conceptualise the Newtonian force concept (cf. par. 5.4).

- The *qualitative data* revealed that the learners' (who partook in this study) conceptualisation of Newton's second law of motion did improve, since the learners immediately recognised the mistakes made when confronted with the anchor concept. Considering the two sub-categories it became evident that the learners conceptualised the concepts during the intervention (cf. par. 5.5.2). The cognitive conflict teaching strategy was effective in establishing a bridging concept of force (the anchor concept, cf. par. 4.7), and a definition of force was established and was acceptable to all concerned. It can also be concluded that the development of ideas teaching strategy seemed to be successful if considering the results of qualitative data. The learners were able to make the changes to their conceptual frameworks (cf. par. 5.5.2), but were not reinforced sufficiently to reflect in the post-test.
- The data from *both datasets (integrated data)* revealed that the conceptual development teaching strategy for the initial part of the teaching sequence, the cognitive conflict teaching strategy, was effective. It was evident that for the development of idea teaching strategy the two data sets revealed mixed results (cf. par. 5.6). The qualitative data during the development of ideas teaching strategy during the latter part of the

intervention revealed that conceptual development occurred in the learners' conceptual frameworks, short-term changes occurred during the intervention. The quantitative data testing the concepts developed during the latter part of the intervention while the development of ideas teaching strategy was used, Newton 1 diagrams and Newton 2 concepts, showed insignificant learning gained due to inadequate reinforcement of the new conceptual framework (cf. par. 5.6). These concepts are also the very difficult concepts for learners to conceptualise.

- What is clear, though, is that when an educator starts explaining a new concept, it is beneficial to use the cognitive conflict teaching strategy instead of just challenging the learners' conceptual framework. It will also provide the educator with valuable information about the extent of the learners' novice concept, alternative conception if any and their misconceptions.

6.3.2 Hypotheses

The following conclusions were made concerning the hypotheses:

6.3.2.1 Hypothesis 1

The conceptual development teaching strategies are effective in the formation of scientific concepts on Newton's second law of motion in Grade 11 learners.

The following conclusion that has been made concerning hypothesis 1 (cf. par. 1.5.1) is as follows:

- Although the overall learning gain was only 0.19, the teaching strategies were effective in the formation of scientific concepts in Grade 11 learners (who partook in this study), since the qualitative data and most of the quantitative data show that the learners' understanding of the force concept was developed towards the Newtonian force concept.

6.3.2.2 Hypothesis 2

The learners gain in knowledge of Newton's laws of motion and will achieve medium learning gain $g > 0.3$.

The following conclusion that has been made concerning hypothesis 2 (cf. par. 1.5.2) is as follows:

- The learners' gained knowledge of Newton's laws of motion since kinematics, contact forces and Newton 1 explanatory concept showed medium learning gains of $g > 0.3$ when looking at the quantitative data.

6.4 LIMITATIONS OF EMPIRICAL STUDY

The following factors had a limiting effect on this study:

- The intervention could only be conducted in one school due to logistical restraints. Therefore the results are only applicable to learners with similar background as the respondents who partook in the study. After considering the data it can be contended that it is advisable to do the study in more schools, thereby including a more diverse group of learners and more respondents, making random sampling. This will make generalisation to the population possible.
- During the first week of the intervention the school that the respondents in the sample attended, received notification from the Department of Education that they had to write the provincial examination papers, implying that the examinations started two weeks earlier than planned. The afore-mentioned reduced the length of time that the researcher had at his disposal to complete the intervention. This resulted in less time to develop the concepts, less time for learners to fix the concept through repetition and exercises and less time to revise the content with the learners. As a result the concepts couldn't be practiced enough by the learners. The former may have affected the attrition and in so doing also the learning gain adversely (cf. 4.4.2).
- As the mathematical component of Newton's laws became difficult the learners started losing concentration easier. This is an indication that the learners' mathematical tools were not to the required standard. This was especially evident with the learners that were not taking mathematics, but rather took mathematical literacy (cf. par. 2.3).
- During the intervention some learners involved in provincial sport teams missed some days during the intervention and also at times a whole group of learners were called out of the class. Therefore lack of maturation could have played a role during the intervention, which meant that, at times, the intervention was not as effective as the researcher planned (cf. 4.4.2).
- An overseas rugby team practiced on the field next to the class room during the week Newton's second law was done, which may have distracted the learners' attention and may have affected the learning gain adversely (cf. par. 4.5.2.3).

6.5 RECOMMENDATIONS

6.5.1 General recommendation

The following general recommendation can be made:

- Educators should use conceptual development teaching strategies to make the work comprehensible for the learners. It will assist the learners to form a scientific correct knowledge framework of the force concept.
- It is also suggested that the teaching sequence should be looked at in the new curriculum for Physical Sciences teaching. For example, in Grade 10 the learners are currently expected to calculate forces between charged objects, but the concept force is only done in Grade 11. It is suggested that the definition of force is explained before the learners are expected to understand the concept of forces between two charged objects and ultimately apply the concept in calculations. It is suggested that the definition of force should be moved to Grade 10. This should contribute to strengthening the concept of force in the learners' long-term memory so that it forms part of the learners' conceptual framework of force. It is expected to enhance the elaboration of the conceptual framework when the learners get to Grade 11 when they are introduced to Newton's laws of motion.

6.5.2 Recommendations concerning future research

The following recommendation can be made concerning future research:

- A follow-up study can be done with a more diverse group of learners, including male and female learners from diverse socio-economic backgrounds.
- If more respondents are included in a future study, a random sample can be drawn to make generalisation of the results possible and relevant to a larger population.
- In a future study a control group can be used to distinguish between the effectiveness of different teaching strategies.
- The influence of some environmental factors can be addressed by changing the environment in a later study. Remove the learners from their environment and choose a venue with less distractions.
- A study can also be undertaken to investigate the influence different environments have on learning by conducting the same type of study and comparing the results.
- A future study can be done testing a single teaching strategy running over a shorter period of time or testing a conceptual development teaching strategy only on Newton's second law of motion.

6.6 FINAL CONCLUSION

Findings from both quantitative and qualitative datasets revealed that learning gain was achieved during the first part of the intervention when the definition of force was established. This showed that the cognitive conflict teaching strategy was effective within this study. The data further revealed that the second part of the intervention, the development of ideas teaching strategy dealing with Newton's first law and second law, was successful to develop the learners' conceptual framework towards Newton's second law of motion. Since the construction of Newton's second law of motion concept is built on the pre-knowledge which is kinematics, contact forces and Newton's first law of motion, one can conclude that the learners' scientific knowledge of Newton's second law of motion improved. It can be concluded that the group of Grade 11 learners were able to develop their existing conceptual framework into a more scientific correct framework through the conceptual development teaching strategy.

The findings ensuing from this study can be used to inform the teaching and learning of Physical Sciences concepts in the Further Education and Training Phase in South Africa. The study can also inform the education and training of Physical Sciences educators that should improve the understanding of Physical Sciences concepts among learners and result in improved learner performance and attitude towards Physical Sciences.

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Annexure A



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16 November 2010

Dear Sir PERMISSION TO CONDUCT RESEARCH WITHIN THE PROVINCE

The following lecturers of the North-West University, together with post-graduate students enrolled at the university, are conducting research on "Design research: Aligning curriculum, instruction and assessment for improved Physical Sciences education in South Africa":

Dr Miriam Lemmer (Project leader)

Dr Sello Rapule

Dr Colin Read

Mr Nico Morabe

Ms Marie du Toit.

We hereby kindly request your permission to conduct the research with Physical Sciences teachers and learners within the North-West province. The results and recommendations of the research will thereafter be made available to the teachers and the public at large.

An important outcome of the research is the development of a resource tool kit that consists of apparatus and worksheets for practical work. These evidence-based kits will be submitted to the Department of Education to distribute to schools as resource tools. In-service and pre-service teachers will be trained in utilising these kits in the Physical Sciences classrooms. The project will also contribute to capacity building of lectures and post graduate students.

As schools will be randomly selected to participate in this research, the following conditions apply:

- Teachers and learners will participate on a complete voluntary basis. No pressure will be placed on anybody to participate.
- There is no harm to the participants.
- Before conducting research at a school, permission of the headmaster will be requested.
- Only teachers and learners who voluntarily gave written consent will participate in this research. They may withdraw at any point during the research.
- All information will be treated as confidential.
- The identities of the participants or their schools will not be revealed and every participant and school will remain anonymous.

Your assistance in this regard will be highly appreciated as we trust that the outcomes of the research will enhance Physical Sciences teaching and learning within the province.

Yours sincerely

A handwritten signature in dark ink, appearing to read 'M Lemmer'.

M Lemmer
Senior lecturer

Annexure B

Informed consent

THE RESEARCH AIM AND OBJECTIVES OF STUDY IS AS FOLLOWS:

General research aim

The aim of this study was to determine the effectiveness of conceptual development teaching strategies applied to Newton's second law of motion to Grade 11 learners.

Specific research objectives

The specific objectives of this study were to:

Compile a theoretical framework through a literature study on

- how learners form concepts in their memories;
- conceptual change strategies for facilitating the development of science concepts;
- learners' alternative conceptions related to Newton's laws of motion.

Perform a baseline study to determine the Grade 11 learners' alternative conceptions and conceptual resources for the learning of Newton's second law of motion.

Design an intervention that utilises conceptual development teaching strategies to elaborate and transform learners' existing knowledge structures through accommodation and association of new knowledge.

Determine the effectiveness of the intervention to facilitate understanding of Newton's second law in the Grade 11 learners.

- Teachers and learners will completely participate on a voluntary basis. No pressure will be placed on anybody to participate.
- There is no harm to the participants.
- Before conducting research at a school, permission of the headmaster will be requested.
- Only teachers and learners who voluntarily gave written consent will participate in this research. They may withdraw at any point during the research.
- All information will be treated as confidential.
- The identities of the participants or their schools will not be revealed and every participant and school will remain anonymous.

Your assistance in this regard will be highly appreciated as we trust that the outcomes of the research will enhance Physical Sciences teaching and learning within the province.

Name: Grade:
Gender: Date:
Participant number:

I understand that participation in this research project is completely voluntary and no pressure may be placed on me to participate. I understand that it will not count any mark. I hereby give permission that this questionnaire may be used for research purposes.

.....
Signature

Annexure C

Newton's first two Laws of motion: A teaching sequence

1. General unit plan for Newton's first two laws of motion.

The following Table 1 gives the planning for teaching Newton's first two laws of motion.

Table 1: Unit plan for teaching Newton's laws of motion.

KNOWLEDGE AREA	MECHANICS
MODULE	1
Unit 1	Force and Newton's Laws of motion
Resources	Physical Sciences theory and workbook Physical Sciences and technology animations Worksheets 1 to 10
Time	Three weeks
Core knowledge	Objects in contact exert forces on each other (e.g. normal force, frictional force): ➤ Define force: Push/pull that can cause an effect on object. ➤ Effects of forces on object. ➤ Types of forces: Contact or non-contact. ➤ State Newton's First Law: An object continues in a state of rest or moving with constant velocity unless it is acted on by an unbalanced (net) force ➤ Know that a surface in contact with the object exerts two types of contact forces, a normal force and a friction force perpendicular and parallel to the surface, respectively. ➤ Distinguish between static and dynamic friction forces and explain why there is difference. ➤ Calculate the value of the static friction force for an object at rest and of the dynamic friction force for a moving object. ➤ Solve problems for objects on a horizontal surface and on an incline. A nett force causes an object to accelerate (Newton's Second Law): ➤ State Newton's Second Law in the special case of constant mass: the nett force exerted on an object equals its mass times its acceleration. ➤ Draw force diagrams for objects at rest, moving with constant velocity and accelerating. ➤ Draw free body diagrams for objects at rest, moving with constant velocity and accelerating. ➤ Calculate the acceleration of a single object on which several forces act simultaneously. ➤ Calculate the acceleration of two objects that are joined together, e.g. two masses joined by a string.
Possible misconceptions of force by learners	1. An object will slow down if there is no nett force. 2. A force is needed to keep a body moving even on a frictionless surface. 3. The motion will follow the path of the stronger force on the object. 4. Passive forces don't exist (tables don't exert a normal force). 5. Normal forces won't exceed the weight (active force) on an object. 6. An object with a constant (non-zero) nett force will have a constant speed. 7. Faster moving objects have larger forces acting on them.

	8. A constant force accelerates a body, until the body uses up all the power of the force. 9. The nett force must be in the direction of motion, so objects will travel along a line in that direction. 10. Objects can be trained to follow a certain path by forces, and will continue along that path, even after the forces are removed. 11. Heavier objects fall faster than light objects. 12. Objects will point in the direction of their velocity. 13. Force must be positive, plotted above the time axis. 14. Strings transmit (unchanged) an external force acting on one object to another object.		
Practical investigation	Friction Newton's second law		
Assessment methods	Class test	Controlled test	Post-test
	Practical Investigations	Class work	
Resources	Power point, Physical Sciences & Technology, Physical Sciences workbooks and worksheets		

2 Specific work schedule

The teaching sequence starts with the learners' concept of force, and then scaffolds are prepared to develop the force concept.

2.1 The general concept of force

The learners were introduced to force in Grade 9, defining force as a pull or a push which can have the following effects on another object:

- Make it change direction
- Accelerate
- Decelerate
- Change shape
- Rotate

The learners are confronted with the idea that a force does not always have an effect on an object. After looking at a few examples the term balanced and unbalanced forces are introduced. This leads to the nett unbalanced force, which is the vector sum of all the forces acting upon an object. This links forces with vector and scalar quantities done in Grade 10 mechanics by the learners.

$F_{\text{net}} = F_1 + F_2 + F_3 \dots$, where F_1 , F_2 and F_3 represent various forces acting upon an object.

Force is a **vector** quantity, hence the magnitude and the **direction** in which a force acts is important. The resultant (F_{res}) or nett (F_{nett}) force can be described as a single force that has the same effect on an object as a number of forces acting simultaneously on the object. When the sum of the forces acting on an object is **zero**, the **forces are in equilibrium** or the forces are **balanced**. When the forces are balanced the object will remain stationary or will be moving at a constant velocity. The abbreviation for force is **F** and it is measured in **Newton (N)**.

The following progress is to differentiate between contact and non-contact forces. **Non-contact forces** act on objects from a distance, like **magnetic forces**, **electrostatic forces** and **gravitational forces**, while **contact forces** exist when one object touches another or lies on a horizontal or inclined plane, like **frictional forces (F_f)**, **normal forces (F_n)**, **air resistance**, **tension (F_t or T) in a rope or cable** and **forces applied directly to an object**.

Forces can also act at an angle on an object and will have two components: One is **parallel to the contact surface** and the other is **perpendicular to the contact surface**.

Looking closer at the different type of contact forces, we can identify seven.

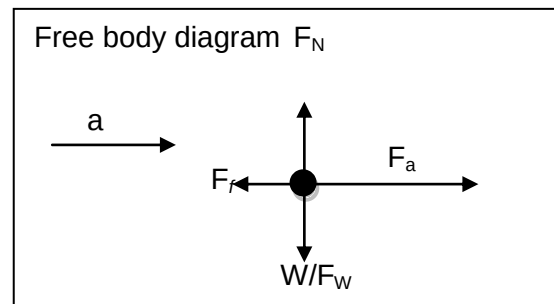
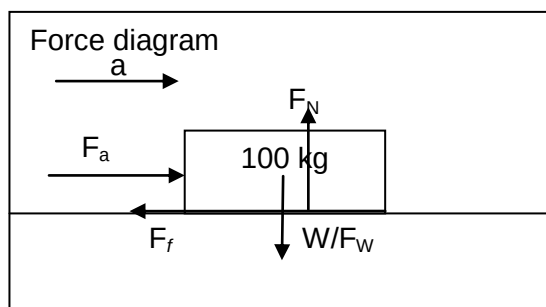
- **Applied force (F_a or F_{applied}):** This is a force applied to an object by another object or person. This force may be applied in a straight line to the direction of motion or may be applied at an angle to the direction of the motion.
- **Frictional force (F_f or f):** When an object is in contact with a surface and moves or tries to move across the surface, then the surfaces exerts a frictional force on each other. Frictional force always acts in the opposite direction to the motion parallel to the surface touching the object.
- **Gravitational force or weight (F_g or W):** The force of attraction between a planet (e.g. the earth) and an object on it is known as gravitational force. The direction of this force will always be vertically downwards towards the centre of the planet. The force of gravity is equal to the object's weight on that planet and acts from the centre of gravity of the object. It is calculated with the following formula: $F_g = W = mg$, where **m** is the mass and **g** is the gravitational acceleration on the planet.
- **Normal force (F_N or N):** The normal force, also known as supporting force, acts in the direction perpendicular from the surface on or against which an object rests.
- **Tension (F_T or T):** The force which is produced when a cable or string is applied to an object on the one end and the cable or string is pulled tight or a force is applied to the other end of the string. The tension in a string or cable is of the same magnitude everywhere in the string or cable, but the direction may differ. We assume that the mass of the string or cable is negligible, otherwise it will add to the total mass of the system.
- **Air resistance (F_{air} or F_f):** The air resistance is a force that is exerted on a moving object by the air particles when objects move through air. The direction is always opposite to the direction of motion.
- **Spring force (F_{spring}):** These are forces exerted by a compressed or expanded spring on objects.

2.2 Force diagrams and free body diagrams

Force diagram (Figure a) shows the object and all the forces that act on it, represented by arrows magnitudes and the directions of the forces. Weight is a non-contact force and is represented by an arrow that points from the centre of gravity of the object vertically downwards.

With a **free body diagram** (Figure b), on the other hand, the object is represented as a dot and all the forces are drawn as arrows that point away from the dot.

The following is an example of a force of 100 N that is applied to a crate with a mass of 20 kg which is initially at rest. The crate moves to the right and the frictional force between the crate and the surface is 20 N.



F_N normal force of surface on the crate, acting upwards.

$W = F_G$ gravitational attraction force of earth on crate (weight), acting downwards.

F_f frictional force of surface on crate will be in the opposite direction to motion.

F applied force acting on crate in direction of motion.

2.3 Newton's first law of motion

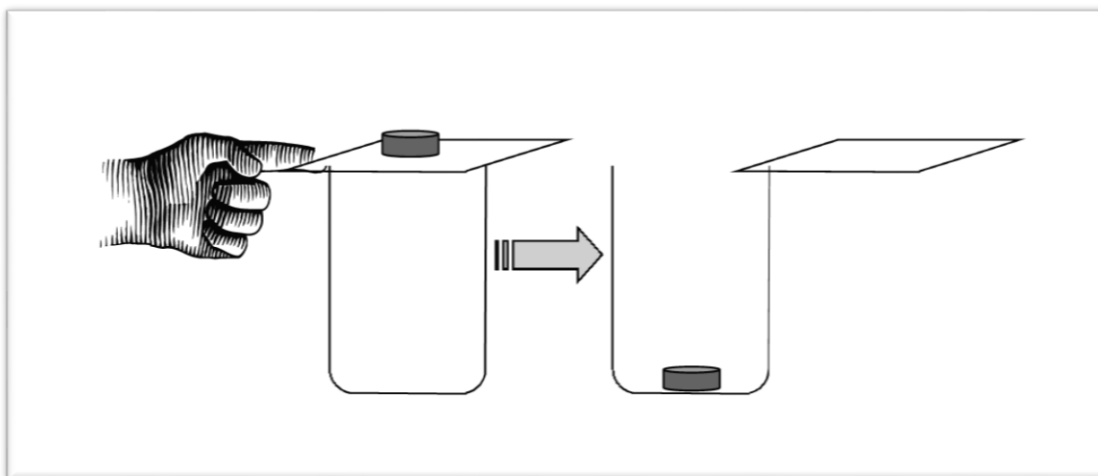
Newton's first law of motion is defined as (*Philosophiae Naturalis Principia Mathematica*):

Everybody perseveres in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impress'd thereon.

Or in more simple terms:

An object will remain at rest or will continue to move at a constant speed in a straight line ($\therefore$ at a constant velocity) unless acted upon by an external non-zero nett (unbalanced) force.

To demonstrate Newton's first law a coin is placed on a flat, smooth piece of cardboard on top of a beaker with a wide mouth. The card is flicked horizontally with your finger by applying a force to it. The coin falls in the beaker as in the following figure.

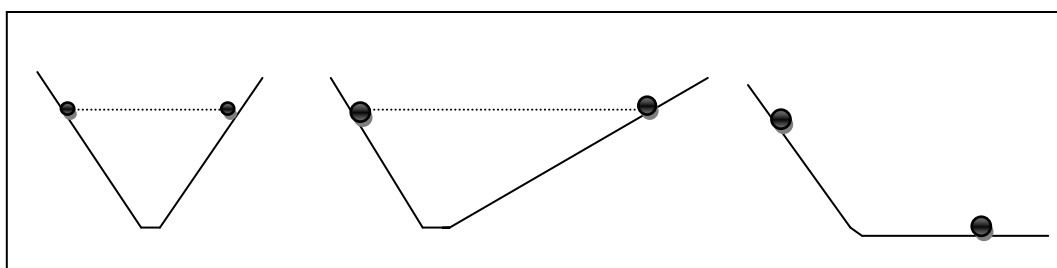


Other everyday examples are also discussed.

- A car which is travelling fast when the driver suddenly applies the brakes.
- A book lies on the dashboard of a car. The car suddenly pulls away.
- A fridge stands on the back of a delivery van which suddenly turns a corner.
- A magician pulls a tablecloth out from beneath the cutlery on a dinner table and the cutlery remains on the table.

This law is also known as the law of inertia, and inertia is the property of an object that causes it to resist any change in its state of motion i.e. an object persists in its state of rest or of uniform motion. Inertia is not a force, but it is a property of every object that has mass i.e. *the mass of an object is a measure of its inertia.*

Galileo designed an experiment in which he allowed a ball to roll across a smooth track as shown in the following figure.



A moving object will continue to move at a constant speed in a straight line unless acted upon by an external non-zero net force. Once an object moves, its inertia causes it to continue moving and, if at rest; its inertia will resist any force trying to set the object into motion. A moving object resists any proposed change in its speed or direction of motion.

2.4 Static and kinetic (dynamic) friction

Friction is a contact force that exists when two objects are in contact with each other. Solid surfaces are actually quite rough when viewed from close up. When objects move or attempt to

move while in contact with each other, the rough bits hook against each other and oppose the motion.

Frictional forces act along the common surface of the objects that are in contact and in the opposite direction to the motion. We get two types of friction, namely **static friction**, when object is at rest on a surface and **kinetic friction**, when an object moves relative to the surface on which it rests.

There are two factors influencing the friction force and that is the normal force and the nature of the surface. If the normal force or the force with which the two surfaces push against each other is increased the friction force between the surfaces will increase. A rough surface will increase the friction forces between the surfaces. The surface area has no effect on the friction forces between the surfaces.

2.3.5 Newton's second law of motion

FROM Philosophiae Naturalis Principia Mathematica of Isaac Newton his second law is given as

"The alteration of motion is ever proportional to the motive force impress'd; and is made in the direction of the right line in which that force is impress'd."

or

If a nett (resultant) force acts on an object, the object will accelerate in the direction of the nett force. The acceleration is directly proportional to the nett force and inversely proportional to the mass of the object. ($F = ma$)

or

The nett (resultant) force that acts on an object is equal to the rate of change in its momentum and is in the direction of the change in momentum.

- The **mass** of the object must remain **constant**.
- If m constant then $a \propto F_{\text{net}} \therefore F_{\text{net}} = ma$
- From this equation the Newton can be defined as the unit of force.
- One Newton is the force which gives a mass of 1 kg an acceleration of $1 \text{ m}\cdot\text{s}^{-2}$.
- Nett force = Vector sum of all the forces acting on the object.

$$F_{\text{nett}} = ma = \sum F$$

The following scenarios are looked at:

1. *An object resting on a horizontal surface is acted upon by horizontal forces that have the same direction.*

2. *An object resting on a horizontal surface is acted upon by forces that act horizontally but in opposite directions.*
3. *An object resting on a horizontal surface is acted upon by a force that is exerted at an angle to the horizontal surface. The force acting on the object can be a push or a pulling force. These forces have an influence on the normal force which influences the friction forces acting on the object.*
4. *An object resting on an inclined plane is stationary. Only weight and friction act on the object.*
5. *When an object is moving at a constant velocity down or up an inclined plane. The applied force is equal to the friction force when the object moves upwards and the force parallel to the surface due to gravity is equal to the friction force.*
6. *An object is moving down an inclined plane and accelerates positively. The force parallel down the slope is greater than the friction forces.*
7. *An object that moves upward along an inclined plane and that accelerates positively when a force F is applied to it. The force parallel to the surface up the slope is greater than the friction force and the force parallel to the surface down the slope.*
8. *An object of mass m that hangs from a cable or person is standing in a lift. When the object is not moving or moving at a constant velocity the tension in the cable (F_T) = the gravitational force (F_g). When the object moves faster down or slower up, the acceleration of the object will be downwards implying that *tension in the cable* (F_T) < the gravitational force (F_g). When the object moves faster up or slower down, the acceleration of the object will be upwards and will result in *tension in the cable* (F_T) > the gravitational force (F_g).*

Annexure D
Force questions

Please:

Mark your answers on the answer sheet.

Mark **only one** answer per question.

Do **not** skip any question.

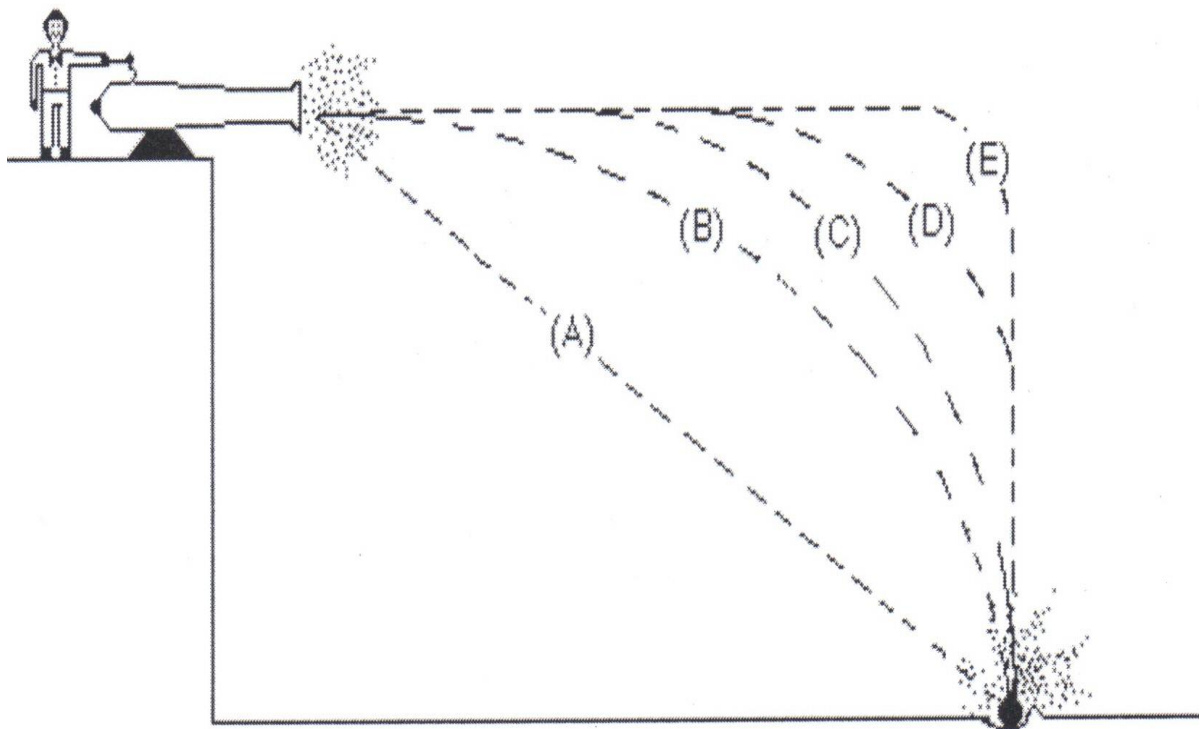
Avoid guessing. Your answers should reflect what **you** personally think.

Write only your allocated number on the answer sheet.

Do **not write** anything else on this questionnaire.

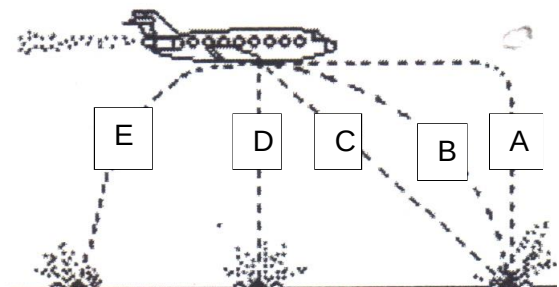
You have 45 minutes to answer the paper.

1. A ball is fired by a cannon from the top of a cliff as shown in the figure below. Which of the paths would the cannon ball most closely follow?



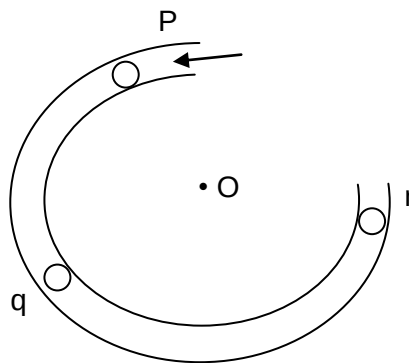
2. A bowling ball accidentally falls out of the cargo bay of an airliner as it flies along in a horizontal direction.

As observed by a person standing on the ground and viewing the plane as in the figure at right, which path would the bowling ball most closely follow after leaving the airplane?



USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT TWO QUESTIONS (3 AND 4).

The accompanying figure shows a frictionless channel in the shape of a segment of a circle with centre at "O". The channel has been anchored to a frictionless horizontal table top. You are looking down at the table. Forces exerted by the air are negligible. A ball is shot at high speed into the channel at "P" and exits at "r".



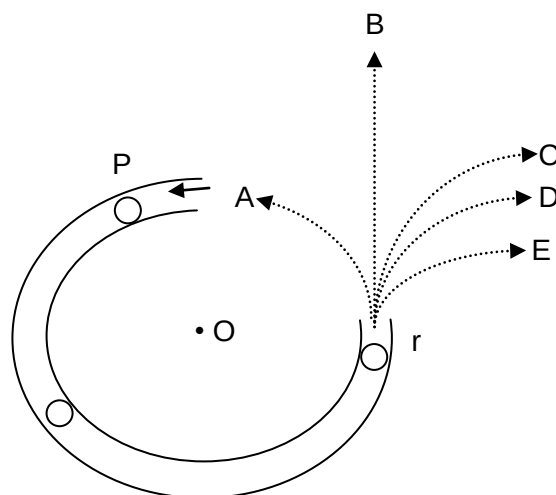
3. Consider the following distinct forces:

1. A downward force of gravity.
2. A force exerted by the channel pointing from q to O.
3. A force in the direction of motion.
4. A force pointing from O to q.

Which of the above force(s) is/are acting on the ball when it is within the frictionless channel at position "q"?

- A. 1 only.
- B. 1 and 2.
- C. 1 and 3.
- D. 1, 2, and 3.
- E. 1, 3, and 4.

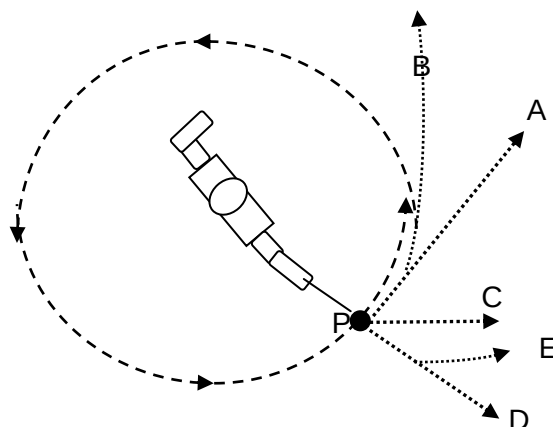
4. Which path in the figure at the right would the ball most closely follow after it exits the channel at "r" and moves across the frictionless top?



5. A steel ball is attached to a string and is swung in a circular path in a horizontal plane, as illustrated in the accompanying figure.

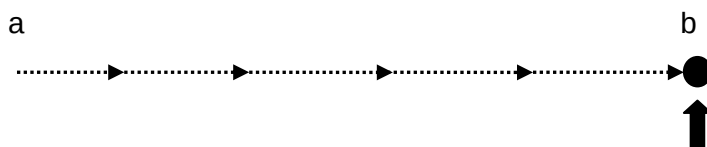
At point P indicated in the figure, the string suddenly breaks near the ball.

If these events are observed from directly above as in the figure, which path would the ball most closely follow after the string breaks?

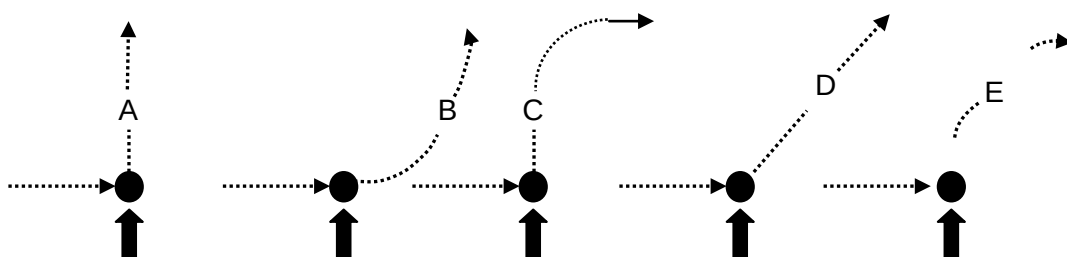


USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT QUESTIONS (6 THROUGH 8)

The figure depicts a hockey puck sliding with constant speed v_0 in a straight line from point “a” to point “b” on a frictionless horizontal surface. Forces exerted by the air are negligible. You are looking down on the puck. When the puck reaches point “b”, it receives a swift horizontal kick in the direction of the heavy print arrow. Had the puck been at rest at point “b”, then the kick would have set the puck in horizontal motion with a speed v_k in the direction of the kick.

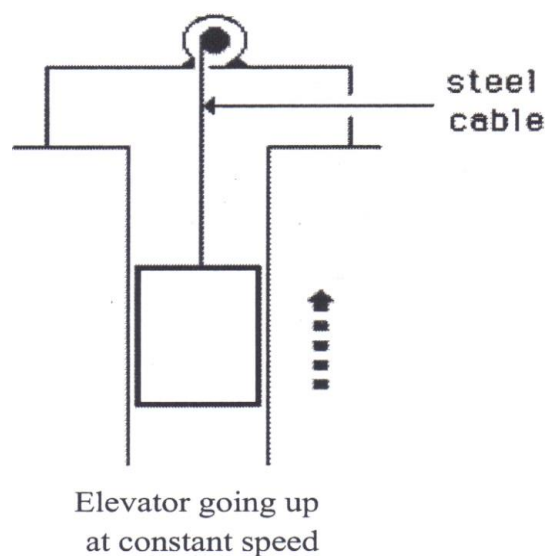


6. Which of the paths below would the puck most closely follow after receiving the kick?



7. Along the frictionless path you have chosen in Question 6, the speed of the puck after receiving the kick:
- A. continuously increases.
 - B. is constant.
 - C. continuously decreases.
 - D. increases for a while and decreases thereafter.
 - E. is constant for a while and decreases thereafter.
8. Along the frictionless path you have chosen in Question 6, the force(s) acting on the puck after receiving the kick is/are:
- A. a downward force of gravity only.
 - B. a downward force of gravity, and a horizontal force in the direction of motion.
 - C. a downward force of gravity, an upward force exerted by the surface, and a horizontal force in the direction of motion.
 - D. a downward force of gravity and an upward force exerted by the surface.
 - E. none (No forces act on the puck).

9. An elevator is being lifted up an elevator shaft at a constant speed by a steel cable, as shown in the figure below. All frictional effects are negligible. In this situation, forces on the elevator are such that:
- the upward force by the cable is greater than the downward force of gravity.
 - the upward force by the cable is equal to the downward force of gravity.
 - the upward force by the cable is smaller than the downward force of gravity.
 - the upward force by the cable is greater than the sum of the downward force of gravity and a downward force due to the air.
 - none of the above (The elevator goes up because the cable is being shortened, not because an upward force is exerted on the elevator by the cable).



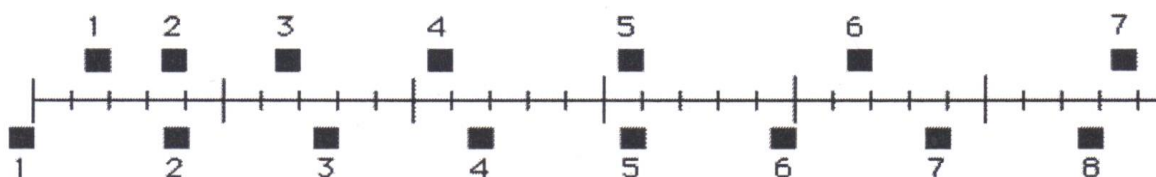
10. The figure below shows a boy swinging on a rope, starting at a point higher than A. Consider the following distinct forces:

- A downward force of gravity.
- A force exerted by the rope pointing from A to O.
- A force in the direction of the boy's motion.
- A force pointing from O to A.

- 1 only.
- 1 and 2.
- 1 and 3.
- 1, 2, and 3.
- 1, 3, and 4.



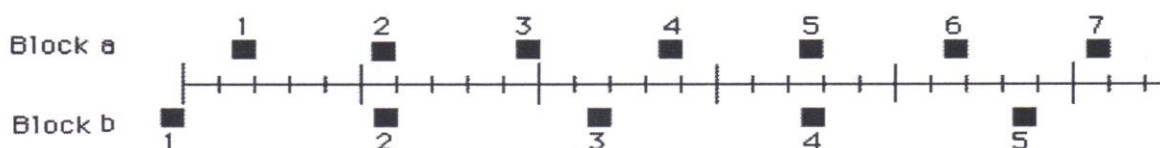
11. The positions of two blocks at successive 0.20 second time intervals are represented by the numbered squares in the figure below. The blocks are moving toward the right.



Do the blocks ever have the same speed?

- A. No
- B. Yes, at instant 2.
- C. Yes, at instant 5.
- D. Yes, at instants 2 and 5.
- E. Yes, at some time during the interval 3 to 4.

12. The position of two blocks at successive 0.20 second time intervals is represented by the numbered squares in the figure below. The blocks are moving toward the right.

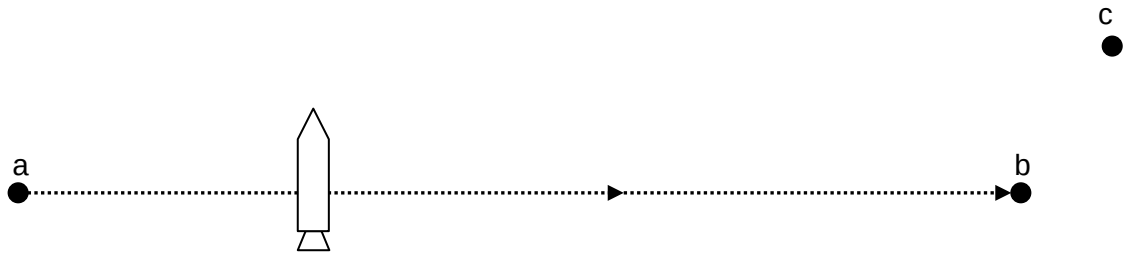


The accelerations of the blocks are related as follows:

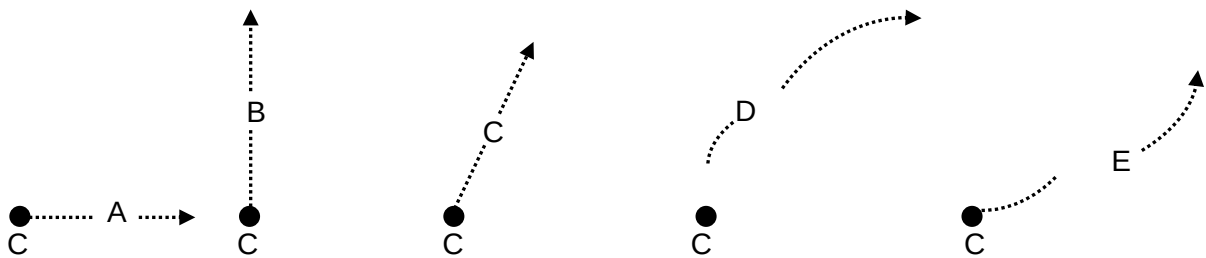
- A. The acceleration of "a" is greater than the acceleration of "b".
- B. The acceleration of "a" equals the acceleration of "b". Both accelerations are greater than zero.
- C. The acceleration of "b" is greater than the acceleration of "a".
- D. The acceleration of "a" equals the acceleration of "b". Both accelerations are zero.
- E. Not enough information is given to answer the question.

USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT QUESTIONS (13 THROUGH 15)

A rocket drifts sideways in outer space from point “a” to point “b”, as shown below. The rocket is subject to no outside forces. Starting at position “b”, the rocket’s engine is turned on and produces a constant thrust (force on the rocket) at right angles to the line “ab”. The constant thrust is maintained until the rocket reaches a point “c” in space.



13. As the rocket moves from position “b” to position “c” its speed is:
- A. constant.
 - B. continuously increasing.
 - C. continuously decreasing.
 - D. increasing for a while and constant thereafter.
 - E. constant for a while and decreasing thereafter.
14. At point “c” the rocket’s engine is turned off and the thrust immediately drops to zero. Which of the paths below will the rocket follow beyond point “c”?



15. Beyond position “c” the speed of the rocket is:

- A. constant.
- B. continuously increasing.
- C. continuously decreasing.
- D. increasing for a while and constant thereafter.
- E. constant for a while and decreasing thereafter.

16. A woman exerts a constant horizontal force on a large box. As a result, the box moves across a horizontal floor at a constant speed " v_0 ".

The constant horizontal force applied by the woman:

- A. has the same magnitude as the weight of the box.
- B. is greater than the weight of the box.
- C. has the same magnitude as the total force which resists the motion of the box.
- D. is greater than the total force which resists the motion of the box.
- E. is greater than either the weight of the box or the total force which resists its motion.

17. If the woman in the previous question doubles the constant horizontal force that she exerts on the box to push it on the same horizontal floor, the box then moves:

- A. with a constant speed that is doubled the speed " v_0 " in the previous question.
- B. with a constant speed that is greater than the speed " v_0 " in the previous question, but not necessarily twice as great.
- C. for a while with a speed that is constant and greater than the speed " v_0 " in the previous question, then with a speed that increases thereafter.
- D. for a while with an increasing speed, then with a constant speed thereafter.
- E. with a continuously increasing speed.

18. If the woman in Question 16 suddenly stops applying a horizontal force to the box, then the box will:

- A. immediately come to a stop.
- B. continue moving at a constant speed for a while and then slow to a stop.
- C. immediately start slowing down to a stop.
- D. continue at a constant speed.
- E. increase its speed for a while and then start slowing down to a stop.

19. An empty office chair is at rest on a floor. Consider the following forces:

- 1. A downward force of gravity.
- 2. An upward force exerted by the floor.
- 3. A nett downward force exerted by the air.

Which of the force(s) is/are acting on the office chair?

- A. 1 only.
- B. 1 and 2.
- C. 1 and 3.
- D. 2 and 3.
- E. 1, 2, and 3.

20. Despite a very strong wind, a tennis player manages to hit a tennis ball with her racquet so that the ball passes over the net and lands in her opponent's court.

Consider the following forces.

1. A downward force of gravity.
2. A force by the "hit".
3. A force exerted by the air.

Which of the above force(s) is/are acting on the tennis ball after it has left contact with the racquet and before it touches the ground?

- A. 1 only.
- B. 1 and 2.
- C. 1 and 3.
- D. 2 and 3.
- E. 1, 2, and 3.

Annexure E

Participant number: Date:

Grade: Gender:

Write only your allocated number on the answer sheet.

	A/B/C/ D/E	Comment
1		
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Thank you for your cooperation.

Annexure F



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Statistical Consultation Services

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Fax: (018) 299 2557

23 April 2014

Re: M.ED. of Mr CH Meyer (student no 10606637)

We hereby confirm that the Statistical Consultation Services of the North-West University had analysed the data and assisted with the interpretation of the results. However, any opinion, findings or recommendations expressed in this document are those of the author and the Statistical Consultation Services of NWU (Potchefstroom Campus) do not accept responsibility for the statistical correctness of the results reported.

Kind regards

Erika Fourie

Statistical Consultant: Statistical Consultation Services

Annexure G

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Maart 2014

Hiermee verklaar ek, Cliff Smuts, dat ek die tesis van Carel Hendrik Meyer ter verkryging van die graad M.Ed aan die Noordwes-Universiteit taalkundig versorg het, en daarby gekontroleer het dat alle bronne wat vir die navorsing gebruik is, in die teks en in die Bibliografie aangedui is.

Baie dankie.

Cliff Smuts