

Investigation of students' knowledge application in solving physics kinematics problems in various contexts

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Abstract

The topic of students' application of conceptual knowledge in physics is constantly being researched. It is a common occurrence that students are able to solve numerical problems without understanding the concepts involved. The primary focus of this dissertation is to investigate the extent to which a group of first year physics students are able to identify and use the correct physics concepts when solving problems set in different contexts. Furthermore, this study aims to identify underlying factors giving way to students not applying appropriate physics concepts.

A questionnaire was designed in test-format in which all the problems dealt with two objects whose movement had to be compared to each other. The physical quantities describing or influencing the objects' movement differed in each consecutive problem; whilst the nature of the concept under consideration remained the same. The problems were set in various contexts namely:

- i. Formal conceptual questions, some with numeric values;
- ii. Questions set in every day context with/without numeric values;
- iii. Questions on vertical upward, vertical downward and horizontal motion.

The questionnaire was distributed to 481 students in the first-year physics course in 2014 at the Potchefstroom Campus of the North West University.

It was expected that the percentage of correct answers would reveal discrepancies in the responses to contextual, numeric and formal conceptual questions. The outcome of the statistical analysis confirmed this expectation. In addition, it seemed that only a few students were able to correctly identify the appropriate variables when considering vertical and horizontal movement while the majority of the students did not apply the same physics principle in isomorphic vertical upward and vertical downward problems. It appears that the context in which the question was posed determined whether the problem was seen as an item that would require "physics reasoning" or as a setting where physics reasoning did not apply. The results revealed students inability to relate physics concepts to appropriate mathematical equations. Two important results from this work are: (1) the presentation of a questionnaire that can be implemented to investigate various aspects regarding the contexts of physics problems; and (2) expanding the concept of context to include the direction of movement as a separate context.

Key terms: Conceptual knowledge, conceptual understanding, context of problem, direction of motion, naïve knowledge, variation theory.

Opsomming

Studente se toepassing van konsepsuele kennis in fisika is 'n onderwerp wat tans baie aandag geniet. Dit is algemeen bekend dat studente in staat is om numeriese probleme op te los sonder dat hulle werklik die beginsel wat betrokke is, verstaan. Die primêre fokus van hierdie skripsie is om die mate waartoe 'n groep eerste jaar fisikastudente die korrekte fisikabeginsels in verskillende kontekste identifiseer en gebruik tydens probleemoplossing, te ondersoek. Die studie het verder ten doel om onderliggende faktore wat daartoe lei dat studente nie die toepaslike fisikabeginsels herken of toepas nie, te identifiseer.

'n Vraelys met gelykvormige vrae waarin twee voorwerpe se beweging telkens met mekaar vergelyk word, is in toetsformaat opgestel. Die fisiese groothede wat die voorwerpe se beweging beskryf of beïnvloed het in elke opeenvolgende probleem verskil, terwyl die onderliggende beginsel wat ondersoek is, dieselfde gebly het. Die vrae is in verskillende kontekste aangebied, naamlik:

- i. Formele konsepsuele vrae, sommige met numeriese waardes;
- ii. Vrae in 'n alledaagse konteks met/sonder numeriese waardes;
- iii. Vrae oor opwaartse, vertikaal afwaartse en horisontale beweging.

Die vraelys is in 2014 deur 481 studente in die eerstejaar fisika kursus aan die Noordwes Universiteit (Potchefstroom Kampus) voltooi.

Die verwagting was dat die persentasie korrekte antwoorde teenstrydighede in die antwoorde op kontekstuele, numeriese en formele konsepsuele vrae sal aandui. Die uitkoms van statistiese analise het hierdie verwagting bevestig. Dit het verder geblyk dat slegs enkele studente in staat was om die toepaslike veranderlikes te identifiseer tydens die vergelyking van vertikale en horisontale beweging, terwyl die meerderheid nie dieselfde fisikabeginsels toegepas het op verwante vertikale opwaartse en vertikale afwaartse probleme nie. Dit blyk dat die konteks waarin die vraag gestel is bepaal of die vraag as 'n item wat "fisikadenke" vergesien word of nie. Die resultate het getoon dat studente se vermoë om fisika beginsels met die toepaslike wiskundige vergelykings te verbind, gebrekkig is. Twee belangrike uitkomstes van hierdie werk is: (1) die aanbieding van 'n vraelys wat gebruik kan word om verskeie aspekte rondom die konteks van fisika probleme te ondersoek; en (2) die uitbreiding van die betekenis van die begrip konteks om die rigting en vlak van beweging as 'n aparte konteks in te sluit.

Sleuteltermes: Konsepsuele kennis, konsepsuele begrip, konteks van die probleem, rigting van beweging, naïewe kennis, variasieteorie

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Chapter 1

INTRODUCTION AND OVERVIEW OF RESEARCH

1.1 Introduction

Research indicates that every student who enters introductory physics has a system of beliefs and intuitions about physics as a result from their personal experience and observations (Van Heuvelen, 1991:891; Halloun & Hestenes, 1985a: 1043; Piburn, Baker & Treagust, 1988:3; Singh, 2007:196; Sherin, 2006:535; Gönen, 2008:70; Kavanaugh & Sneider, 2007:21). Student beliefs about knowledge and knowing influence how they approach learning tasks as well as their personal goals and motivation (Muis & Gierus, 2014:411; Ogilvie, 2009:2). Some students believe learning consists primarily of absorbing information and they view physics as weakly connected pieces of information to be separately learned, equating learning physics with finding formulas and problem solving algorithms (Elby, 1999:S52; Ogilvie, 2009:2; Redish *et al.*, 1998:212), while others see physics knowledge as a coherent web of ideas and are able to monitor their understanding for consistency (Elby, 1999:S52).

In reality, physics is based on a small number of concepts which are the foundation for various applications (Van Heuvelen, 1991:892). Students should see physics knowledge in terms of the basic physics concepts tied together as a coherent web of ideas where learning involves relating fundamental concepts to problem-solving techniques, building their own understanding (Elby, 1999:S52; Ogilvie, 2009:2). The lack of perceived coherence is among the principal causes of students' failure to achieve understanding in science (Klopfer *et al.*, 1983:174). Helping students to understand the importance of consistency and coherence, and the difference between rote memorization and deeper understanding, is an important goal in physics education (Hedge & Meera, 2011:135).

Redish *et al.* (1998:218) found that students believe that science knowledge is irrelevant to their everyday lives. According to Finkelstein (2001:1) the context in which physics is taught is an integral part of the learning process, and certain features which promote or inhibit content understanding are inherent in a given context. Elby and Hammer (2010:409) present evidence that different patterns of reasoning in students' cognition regarding the nature of knowledge, and learning is activated by the context of physics problems.

1.2 Research problem and motivation for study

For many years researchers in physics education have focused on students' understanding or failure to understand specific content areas, such as mechanics, electric circuits, or heat and

temperature (Ince, 2012:158). Initial research in this area was meant to improve physics instruction and enhance the efficacy of physics teaching and learning (Hedge & Meera 2011:133). Educational research on school as well as introductory university physics classes over the past years has demonstrated that student learning is often significantly less than was expected and hoped for. Specific conceptual difficulties have been identified in a wide variety of topics and many studies in physics education indicate that conventional instruction fails to achieve desired objectives. Students leave introductory courses unable to reason qualitatively about physical processes (Van Heuvelen, 1991:891) and the failure rates of students in physics necessitate studies to attempt to address these issue (Ambrose, 2009:3).

The observation that students develop misconceptions is noted by much of the empirical research on learning science over the last twenty years (Gönen, 2008:70). Evidence is accumulating that misconceptions and the distortions they engender in students' comprehension of physics content material and instruction are among the principal causes of students' failure to achieve understanding in science (Klopfer *et al.*, 1983:174; Elby, 1999:S54; Hedge & Meera, 2011:133; Muis & Gierus, 2014:408; Ogilvie, 2009:2). Research results demonstrate that most students have descriptive and explanatory mental systems (naïve knowledge) that develop from their daily experience and that these naive theories stand in marked contrast to what students are expected to learn. These naive descriptive- and explanatory systems show significant consistency across various student populations, irrespective of age or nationality and are noticeably resistant to change through traditional instructional methods (Bozdogan & Demirba, 2009:145-156). Studies implemented in higher education show that the misconceptions of university students persist even after education on the subject is given and several applications are performed.

According to McDermott and Redish (1999:755) the discussion of student learning in physics has been largely student and content centred. The findings of research suggest the need for tools that can probe students' knowledge in terms of the interconnections between knowledge elements i.e. to determine students' level of conceptual knowledge and understanding (Beatty & Gerace, 2002:750). Students could have local knowledge of Newtonian mechanics but not be able to project it onto other representations of a problem however; knowledge and reasoning about the physical world described in Newtonian terms can be learned over the course of cognitive development (Sanborn *et al.*, 2013:411). Traditionally physics education researchers investigated content-specific knowledge by asking what students know about a specific topic (Springuel *et al.*, 2007:2). They then designed questions about the topic that they expected would reveal the ideas or knowledge that students have about that topic. Stiles (2006:3) suggests that questions should be changed to determine how well students understand concepts in science and whether teachers are merely evaluating how well they can recite

information. The responses on such questions may provide guidelines for teachers to develop evaluation procedures that measure understanding instead of merely how well a student has memorized data (Stiles, 2006:4).

The interpretation of observed or simulated motions and their algebraic or graphical representations had been the topic for most previous studies on kinematics (Elby & Hammer, 2010:412). Perceptions that students form based on their everyday-life observations, seldom correlate with the formal science conceptions and explanations of phenomena and students seem to respond differently to comparable questions in different contexts (Lemmer, 2013:239; Sherin, 2001:479). Lemmer (2013:239) also noticed variability in the students' responses with the type of motion (e.g. horizontal motion or vertical free fall). Few studies investigated if and to what extent, students are able to identify a common principle in problems set in various planes (Boudreaux *et al.*, 2008; Kohl & Finkelstein, 2006; Lemmer, 2013). While researchers go to great lengths to create environments supportive of activities which provide the opportunity for conceptual change in students, these environments, the context in which physics is taught remain under-theorized (Finkelstein, 2001:1).

The importance of Newton's second law in the teaching of introductory physics prompted investigation into the extent to which students recognise this law as a relationship between forces, mass, and acceleration that applies to vertical upward and downward motion and to horizontal motion in exactly the same way. No research on the influence of the direction of motion on student application of general physics concepts had been found yet. Since there is a lack of published work investigating the misconceptions that physics education students' have about up- and downward movement, this research was carried out to fill the gap. This study attempts to determine the extent to which students are able to transfer their physics conceptual knowledge to problems set in formal and everyday life contexts with objects moving in different directions and planes.

To expand our knowledge of student conceptual understanding in kinematics, isomorphic problems in different directions/planes were compiled and administered. A consequence of such a research is that it brings out the nature of student beliefs and the results of this study may provide guidelines to develop diagnostic questions that are more suitable to discern between student knowledge and student understanding of physics concepts.

1.3 Previous related research

1.3.1 Newtonian mechanics

Mechanics is an important topic taught mainly in the first course of physics and mastering the mechanics material is generally a prerequisite for admission to advanced topics. Knowledge of mechanics is therefore essential to students' performance in their physics courses (Flores *et al.*, 2004:460; Ince, 2012:158; Halloun & Hestenes, 1985a:1044). Newtonian mechanics comprises of kinematics and dynamics and in most introductory physics courses, considerable emphasis is placed on the application of Newton's second law. To apply Newton's second law students must be able to add force vectors to obtain a net force or a resultant (Flores *et al.*, 2004:464). Understanding of this law as applied to motion in vertical and horizontal planes is assumed when subsequent topics are presented in the introductory course and also in more advanced physics and engineering courses.

The complete overthrow of the Aristotelian picture of the universe, lead to the discovery of classical mechanics which replaced the Aristotelian view with a recognizably modern picture in which humankind no longer played a privileged role. The ground-breaking work of Copernicus, continuing with the researches of Galileo, Kepler, and Descartes, culminated in the monumental achievements of Newton. Two observed facts were central to Aristotle's theory of motion. Aristotle was convinced that different rules applied in movement of heavenly bodies – celestial motion –and movement on earth and he did not recognise the idea of inertia. Because he could not imagine what motion would be like without friction, he asserted that all motion was subject to resistance. His inability to recognise friction as a force like any other resulted in common misconceptions e.g. that heavy objects fall faster than lighter objects and that a constant force is needed to keep objects moving at constant speed thereby impeding the progress of physics for nearly twenty centuries (Hewitt, 2002:20-64).

Galileo found experimentally that an object with a mass twice that of another one did not fall twice as fast as the lighter one. He found that except for the small effect of air resistance objects of various weights, when released at the same time, fell together and hit the ground at the same time (Hewitt, 2002:20-64). Students are expected to learn concepts formulated by Galileo, namely that gravity is a non-contact force that acts at a distance, that free falling objects with different masses hit the ground at the same time and how objects in free fall accelerate (Kavanagh & Sneider, 2007:26). Although Galileo formulated his concepts after quantitatively investigating the movement of a ball along an inclined plane, he did not explain why objects with unequal masses would fall with the same acceleration. Newton's three laws provided an explanation for this and related phenomena.

Szymanski (2012:593) distinguish between fundamental and non-fundamental laws of physics. According to him fundamental laws of physics are absolute and nonmathematical and do not incorporate the concepts of space and time. These laws exist independent of the human mind. Non-fundamental laws of physics are stated by mathematical formulae that describe quantitative relations between the properties of matter, space, and time and are referred to as physical laws. For example, the law of force of attraction between objects with mass is a fundamental law but Newton's equations describing that attractive force and the effect thereof are non-fundamental physical laws.

Newton's second law requires two major ideas: the superposition of forces and an understanding of acceleration as a change in motion caused by the net force on an object (Wittmann *et al.*, 2009:301). The first law of motion, also called the law of inertia, describes objects moving with uniform velocity implying a state of equilibrium. The second law concerns objects that are accelerating, implying the presence of a net force. Changes in motion are produced by a force or a combination of forces resulting in a net force. A force is represented by a vector that indicates the action of one body on another either by actual contact or at a distance, as in the case of gravitational forces and magnetic forces. The net force on an object is represented by the resultant vector of a vector diagram consisting of all the acting forces. In Newtonian mechanics, space, time, and mass are absolute concepts, independent of each other. One of the fundamental principles of Newtonian mechanics indicates that the net force acting on a body is related to the mass of the body and the manner in which its velocity varies with time. This time related variance in velocity of an object is called acceleration. The concept pairs of distance and speed, displacement and velocity are related by time dependence. Speed is defined as the distance covered per unit of time where velocity is defined as the rate of change in the displacement of an object. Acceleration is defined as the rate at which velocity change, hence when an object is accelerated, the velocity changes resulting in changes in the displacement covered per unit of time. Galileo found a squared relationship between the distance covered by an accelerating object and the time it travelled, represented by the equation $x = \frac{1}{2} at^2$, where x represents the distance, a = the acceleration and t = the time interval. Combined with the definitions for speed, velocity and acceleration it results in the equations of movement used by physicists to describe and predict the movement of objects (Hewitt, 2002:20-64).

Since Newton developed his laws of motion and universal gravitation, classical mechanics could be represented in mathematical form. Newton realized that the mass of a body is an indication of its inertia and the effect of this inertia is taken into account in his second law of motion that draws an inversely proportional relationship between the effect of force acting on a body and the mass of the body (Hewitt, 2002:20-64). The concept of friction is included in the notion that

changes in an object's movement are due to the net or resultant force. The format of the mathematical equation representing Newton's second law of motion that contain both principles is $a = \frac{F_{net}}{m}$. For an object at rest or moving with constant speed i.e. zero acceleration, it means that the net force equals zero. Wittmann *et al.* (2009:302) argue that introducing the idea of a single force and helping students understand its effect as causing acceleration might be easier than dealing with many forces that somehow lead to no acceleration. For objects moving with equal acceleration the implication is that the ratio of the net force acting on each one, to their respective mass is the same hence the influence of mass as well as friction is already taken into account. Students should therefore be able to compare multiple objects' movement in terms of the distance, initial or final velocity or travelling time. Considering the familiar kinematic equations: $\Delta x = v_i \Delta t + \frac{1}{2} a \Delta t^2$; $\Delta v_f = v_i + a \Delta t$ and $\Delta v_f^2 = \Delta v_i^2 + 2a \Delta x$, it should therefore be clear that once the acceleration of an object is established, the effect on the other variables can be determined by using the equations of motion either in qualitative argument or by quantitatively substituting numerical values into the equations. Flores *et al.* (2004:465) report that students have difficulties with vectors and with their use in the context of Newton's second law.

Klopfer *et al.* (1983:173) provide evidence for the existence of mental structures in novice students for such concepts as *speed*, mass, force, and gravity. Researchers have proposed that our understanding of mechanics reflects formal pre-Newtonian systems of ideas, e.g. Kavanagh and Sneider (2007:25) report that parallels between historical Aristotelian ideas and student thinking exist; such as that heavier objects fall faster. The resistance of students' naive conceptions to change is particularly noticeable in the context of mechanics and Klopfer *et al.* (1983:173) provide evidence that Aristotelian ideas persisted even in many students receiving high grades in introductory physics courses. Klopfer *et al.* (1983:173) demonstrate that the belief in the proposition, 'Heavier objects fall faster than lighter objects,' is not readily changed by instruction. According to Gönen (2008:70) students try to apply their misconceptions about basic physics laws to physics concepts, such as free-fall acceleration and gravitational acceleration, mass and weight, even after receiving instruction. Recent studies by e.g. Graham *et al.* (2013:84) confirm the remarkable continuation of this phenomenon. Halloun and Hestenes (1985b:1057) write that discrepancies between students' common sense concepts and Newtonian concepts describe what students need to learn.

1.3.2 Physics and mathematics

Bing and Redish (2006:26) relate physics students' progress with their ability to combine the symbols and structures of mathematics with their physical knowledge and intuition and they argue that difficulties experienced by students in this regard stem from an inappropriate

integration of two well established mental spaces. Torigoe and Gladding (2011:133; 2006:153) document that students find symbolic versions of questions more difficult than numeric ones. According to the study by Planinic *et al.*, (2012:1393) teachers often think that students find mathematics more difficult than physics, because the physics context should be more familiar than the mathematics context. However, literature in physics education research indicates that it is common for students who learn only how to solve standard numerical questions to have very poor understanding of concepts (Bing & Redish, 2006; Gunstone & White, 2012). It is possible for students to solve some physics and statistical problems without understanding the principle involved and still do well in tests (Jones *et al.*, 2011:379; Kim & Park, 2002:759; McBride, 2012:276; Redish *et al.*, 2006:293, Torigoe & Gladding, 2011:133, 2006:153; Vondracek, 1999:32), in fact, it seems that students may not overcome conceptual difficulties even after solving large numbers of traditional problems (Kim & Park, 2002:759).

1.3.3 Context of physics

Sanborn *et al.* (2013:437) contend that although physical theories attempt to provide a consistent explanation for all physical phenomena, people do not seem to display such consistency. According to Stewart *et al.* (2007:13) studies of the effects of problem context have evolved to investigate the consistency of student misconceptions and the consistency of the reasoning behind those misconceptions. Researchers have had difficulty explaining how people's responses appear to reflect different systems of ideas depending on the particular problem that they have been given. Research indicates that when students have to analyse forces in unfamiliar situations and the possible influence of those forces on the motion of an object, they rely on their experiences, regardless of their high school physics background (Macabebe *et al.*, 2009:106; Redish *et al.*, 1998:212). Although students believe that they are learning about the real world when they study physics, the influence of context on their reasoning reveals a gap between physicists' and students' perception on the domains of applicability of physics concepts. Students shape and are shaped by the contexts in which educational endeavours occur (Finkelstein, 2001:1). Students may believe that physics is related to the real world in principle, but they may also believe that it has little or no relevance to their personal experience. This can be problematic because students fail to connect physics to their daily lives.

Klopfer *et al.* (1983:178) maintain that student beliefs parallel the descriptive aspects of Aristotelian physics. They gave the example of students who believe that in free fall, two objects of the same size and shape but different mass will fall at approximately the same speed. However, when the same students are asked to compare the approximate times for two objects of different mass to slide down an incline, they predict that the time for the more massive object

will be significantly less. Klopfer *et al.* (1983:178) claim that their research indicates that it is the students' conflicting knowledge rather than a lack of prior knowledge that makes learning mechanics so difficult.

Although researchers in physics education have focused on student understanding of specific content areas, such as mechanics for many years (Ince, 2012:160), physics is often considered difficult, boring, detached from daily experience, and according to the view of most students, socially not very attractive (Leonard *et al.*, 1996:1496). Students should be able to identify the major physics principles and concepts that are used to solve problems, articulate the rationale for using a particular principle or concept, and describe how principles and concepts are applied to construct solutions. Many students view physics as a sequence of specific situations for which they must memorize applicable equations without recognizing the connections between these situations. In contrast, many instructors view Newton's second law as a unifying theme, connecting many of the ideas of introductory mechanics (Flores *et al.*, 2004:464). By connecting the ideas in introductory physics lectures, students may then see physics as a discipline with small number concepts i.e. in a unified way (van Heuvelen, 1991:895).

1.4 Aims and objectives

Science instruction usually aims at achieving two goals: the acquisition of a body of organized knowledge in a particular domain and the ability to solve problems in that domain consequently most physics faculties want students to see physics as a coherent, consistent structure (Redish *et al.*, 1998:216). In Bozdogan and Demirba's (2009:148) opinion one of the most essential aims of science education is to enable students to explain daily events from a scientific point of view by using the information they acquired.

When students understand physics concept, not only can they solve the problem, they can transfer what they know to unique situations (Concannon, 2012:14). Heyworth (1999:195) describes the ability to explain many complex phenomena with a few simple laws and principles as the scientific worldview's major strength. According to Singh (2007:196) learning physics requires the unpacking of the few principles and concepts that are condensed into a mathematical form – physics equations – and understanding their application in various contexts where the same law of physics applies but Ambrose (2009:3) points out that research in physics education has demonstrated that physics majors often do not develop a working knowledge of basic concepts in mechanics, even after standard instruction in mechanics courses.

The aim of this study is to investigate what naïve or physics knowledge students use when solving kinematics problems in various contexts, as well as the way they apply that knowledge.

This research aims to clarify what students regard as “various contexts”, to determine what the context in which problems were set tell us about student application of the underlying physics concepts. A central goal of this work has been to explore the ways in which students make, or do not make, appropriate connections between physics concepts and the elementary mathematics that they are expected to use. The intention with this investigation is to characterize difficulties regarding direction as a context and thereby lay the foundation for the improvement of instruction and evaluation. The researcher hopes that an investigation in the effect of direction of motion as a context may contribute towards the assessment of student understanding. Hopefully the design of course instruction and evaluation will be modified to enhance students’ understanding instead of procedural knowledge, resulting in students’ view of physics as a coherent field of study rather than a collection of individual facts.

The objectives of the research are to:

- Analyse whether students recognise the same physics principle when it occurs in problems set in different contexts,
- Compare students’ competencies in different contexts using descriptive statistics,
- Probe conceptual knowledge and reasoning of a selected group of students during interviews on the results of the questionnaire,
- Determine conceptual deficiencies such as misconceptions in students’ responses.

1.5 Research questions

The main question this research attempts to answer is: To what extent do the first year university students use physics principles in solving kinematics problems?

In order to obtain realistic, reliable and valid answers the following secondary questions were asked:

- (1) To what extent does students’ naïve and conceptual knowledge influence their ability to recognise underlying physics concepts in isomorphic problems?
- (2) What information regarding students’ application of conceptual understanding is revealed by the context of physics problems?
- (3) To what extent do students use physics principles to reason qualitatively to promote a stronger coherence of kinematics and connect appropriate equations to physics principles?

- (4) To what extent do students experience conceptual deficiencies and what is the nature and effect of such possible conceptual deficiencies?

Comparison of the responses may indicate which different situations physics problems are set in, are viewed as separate contexts. Suggestions for alternate teaching strategies for improved application of conceptual knowledge should follow from the results.

1.6 Overview of Research

The context of a problem generally refers to the physical background against which problems are posed. Finkelstein (2001:1) disagrees with this simplified definition and highlights the importance of context as an integral part of the learning process because certain features which promote or inhibit construction of content understanding, are inherent in a given context. These features influence students' understanding because the context is not only a backdrop to the problem but determines the problems' relevance to them. The contexts investigated in this research are formal conceptual context, formal numerical context, and every day context with and without numerical values. To investigate the effect of direction of motion as separate contexts an additional feature to the contexts as listed above was added. The direction of movement was set as vertical upward, vertical downward or horizontal in isomorphic items. For differentiating between the contexts; F = formal conceptual; C = contextual; N = numeric was used. The direction of motion was indicated by: $\uparrow$ = upward; $\downarrow$ = downward or $\rightarrow$ = horizontal.

The research sample consisted of 481 students enrolled for first-year physics at the North-West University at the Potchefstroom Campus in 2014. The chosen methodology was an explanatory sequential mixed methods design because the study consisted of both quantitative and qualitative parts which were conducted consecutively. All stipulated ethical requirements were adhered to. Ethical clearance was received, ethical clearance number NWU-00053 – 14 - A3, and each participant signed a consent form, see Appendix C.

In Chapter 1 the motivation for this study due to the identification of a gap in the literature in terms of students' perception of direction of movement as a distinctive context is discussed. A brief overview of relevant literature as well the aims and objectives of this research is given followed by the research questions that guided the study.

In Chapter 2 a comprehensive overview of existing literature in the body of knowledge regarding physics education and student knowledge is given. The study is set against an epistemology theoretical framework and the literature focused on student perception of learning and knowledge in physics, the relationship between mathematics and physics and students' perception on the relevance of physics concepts in everyday life.

Chapter 3 comprises of solid explanations about the choice of methodology and application of the methods used for and during the investigation. Detailed descriptions on the various methods of data processing are also included.

In Chapter 4 the results of the research are presented, analysed and discussed followed by the conclusion of the study in Chapter 5.

Chapter 2

LITERATURE STUDY

2.1 Introduction

Physics education research in studying student understanding of the basic concepts of physics, has made significant progress over the past years and much has been learned about what students know and how they learn (Gönen, 2008:70). Students apply different reasoning methods based on their beliefs about what type of reasoning is appropriate for the situation or their general beliefs about how a physics problem should be addressed (Stewart *et al.*, 2007:1; Graham *et al.*, 2013:84). It has often been assumed that misconceptions in physics about force and motion are part of an alternative framework and that conceptual change takes place when that framework is challenged and replaced with the Newtonian framework, but Graham *et al.* (2013:84) report that ideas on changing these alternative structures are not coherent. They report variation of ideas that conceptual change consists of the development of scientific ideas that can exist alongside ideas of the everyday instead of replacing concepts, conceptions or ideas. Some points that the physics education literature reflect on, include the nature of physics knowledge (2.2), knowledge and understanding (2.2.7), the context in which physics is placed (2.2.11), the role of conventional teaching (2.3) and learning and teaching theories (2.4 -2.4.3).

2.2 The nature of physics knowledge

2.2.1 Theoretical framework

Tannen (1977:506) describes the set of expectations individuals bring to a social situation as framing. These expectations affect what people notice and how they think to act. Put more simply: a framing is a person's generally tacit answer to the question, "What sort of activity is this?" (Tannen, 1993:6). She maintains that conversation is a matter of understanding context and expected meaning rather than interpreting semantics. It seems that the same rings true for students' perception of the nature of physics. Research indicates that students' epistemological beliefs affect various facets of learning such as their mind sets, metacognitive practices, and study habits in a physics course (Elby, 1999:S53; Hedge & Meera, 2012:1; Muis & Gierus, 2014:411; Ogilvie, 2009:2). In cognitive learning models, views about learning are entangled with views about knowledge and knowing (Elby & Hammer, 2010:409).

A growing body of research on personal epistemologies indicates that how students understand the nature of knowledge, knowing, and learning, affects how they reason and learn (Elby & Hammer, 2010:409; Hammer, 1994:151). Hedge and Meera (2012:1) correlate students'

understanding of physics with their associated knowledge structure. Student epistemology is defined as the implicit assumptions and beliefs held by students about the nature of knowledge and learning. Student beliefs about knowledge and knowing influence how they approach learning tasks, impact a variety of learning outcomes and influence students' personal goals and motivation (Muis & Gierus, 2014:411; Ogilvie, 2009:2). According to Muis and Gierus (2014:411) the certainty and simplicity dimensions of knowledge represents students' individual beliefs about the nature of knowledge. The dimension of certainty range from a belief that knowledge is fixed to a belief that knowledge can develop and improve, whereas the simplicity component reflects knowledge as simple or complex. Researchers on epistemic beliefs initially assumed that these beliefs generalized across domains (Muis & Gierus, 2014:411) and they did not consider whether beliefs were specific to a particular domain but Ogilvie (2009:3) reports differences within categories of knowledge between students majoring in different disciplines. Jonassen (1997:65) agrees with Ogilvie (2009:3) by stating that a given individual may hold different beliefs about knowledge simultaneously as they think and work in different disciplines because problem solving in different contexts and domains calls upon different skills.

2.2.2 Levels of epistemological sophistication

Students' view of knowledge reflects their level of epistemological sophistication. In Elby and Hammer's (2010:409) opinion rote-based study habits stem from naïve *epistemological* beliefs; that knowledge consist of isolated fragments and facts of absolute truths from external sources of knowledge whether they should be authority figures or the authority of textbooks (Elby, 1999:S53; Ogilvie, 2009:3). Some students believe learning consists primarily of absorbing information. They view physics as weakly connected pieces of information that are separately learned, equating learning physics with finding formulas and problem solving algorithms. Sophisticated students who see physics knowledge in terms of basic physics concepts tied together as a coherent web of ideas (Elby, 1999:S52; Ogilvie, 2009:3) are able to monitor their understanding for consistency (Elby, 1999:S52). One of the approaches to epistemology, rationalism, is based on logical reasoning as a method for constructing knowledge. Hedge and Meera (2011:135) point out that learning processes in physics can be used as a method for validating epistemological beliefs, specifically in the context of physics problem solving because the ability to solve physics problems is considered as an index of effective physics learning. Hedge and Meera (2012:1) notice that students regard physics problem-solving as very difficult, which they ascribe to the complexity of processes involved in solving of physics problems. According to Hedge and Meera (2011:135) research has probed into students' physics problem solving processes and has attempted to associate them with underlying epistemological beliefs. The research helps in generating strategies for effective problem solving and in validation of epistemological beliefs in the context of physics problem solving. Helping students to

understand the importance of consistency and coherence, and the difference between rote memorization and deeper understanding, is an instructional goal on its own (Hedge & Meera, 2011:135).

Muis and Gierus (2014:411) distinguish between naïve and sophisticated epistemological beliefs regarding the source of knowledge; with beliefs ranging from knowledge being isolated fragments to interrelated ideas (Ogilvie, 2009:3). The dimensions *justification for knowing* (a term used by Muis and Gierus (2014:411) or the *structure of knowledge* (a term used by Ogilvie, 2009:3) reflect either a naïve belief that knowledge is justified by relying on experts, or a sophisticated believe that knowledge is developed by personal and collective effort. Elby and Hammer (2010:409) agree with Ogilvie (2009:3) and Muis and Gierus (2014:411) in stating that these opposing epistemological beliefs enable students in some circumstances to view knowledge as something than can be passed from the source of knowledge (authority) to the recipient (student) while in other circumstances knowledge can be viewed as something that can be figured out. Elby (1999:S52) contends that helping students to understand the importance of consistency and coherence of physics knowledge highlights the difference between rote memorization and deeper understanding. Learning physics involves refining rather than selectively ignoring their everyday thinking.

2.2.3 The nature of students intuitive knowledge

Research reporting the existence and range of misconceptions (alternative conceptions) that physics students have, had been published for many years (Ambrose 2009; Benckert, & Pettersson 1997; Beatty & Gerace, 2002; Bing & Redish, 2006; Bozdogan & Demirba 2009; Concannon, 2012; Cracolice *et al.*, 2008:873; Elby, 1999:S52; Enghag *et al.*, 2007; Gönen, 2008; Graham *et al.*, 2013:84; Halloun & Hestenes, 1985a; Hammer, 1994; Hogan, 1999; Klopfer *et al.*, 1983:173). Park *et al.* (2009:14) also refers to various studies (Griffiths & Preston, 1992; Harrison & Treagust, 1996) reporting on student learning difficulties arising from such alternative conceptions. Research on misconceptions range from reporting on the existence of such misconceptions, to the difficulties arising from the misconceptions (Redish *et al.*, 1998:212) to applying Bayesian inference to Newtonian physics principles to explore the foundations of misconceptions (Sanborn *et al.*, 2013:411).

Research indicates that every student who enters introductory physics has a system of beliefs and intuitions about physics as a result from their personal experience and observations (Van Heuvelen, 1991:891; Halloun & Hestenes, 1985a:1043; Piburn, Baker & Treagust, 1988:3; Singh, 2007:196; Sherin, 2006:535; Gönen, 2008:70; Kavanaugh & Sneider, 2007:21). These experiences lead them to develop concepts of their own about how the world functions;

consequently students tend to misinterpret material in introductory physics courses (Redish *et al.*, 1998:212; Van Heuvelen, 1991:891; Ince, 2012:161).

2.2.4 Description of misconceptions

Various terms appear in literature to describe the pre-existing misinterpretations that students have about physics phenomena e.g. misconceptions, naïve knowledge, intuitive knowledge, intuitive beliefs, initial knowledge, to name but a few. Accordingly, a variety of definitions is also found. Schuster and Undreiu (2009:266) describe misconceptions as “*Experiential-intuitive reasoning* (EIR)” that involves primitive intuitive ideas arising from life experiences with the world and how things behave. Misconceptions in science education are also defined as ‘an intuition that is incorrect’ (Kavanaugh & Sneider, 2007:21), students having misunderstandings, false information and opinions about the concepts of the course subjects, (Bozdogan & Demirba, 2009:146), concepts acquired from experiences that do not correspond with the scientifically accepted concepts, (Erdogan, 2003 as cited by Bozdogan & Demirba, 2009:146), incorrect beliefs that are unacceptable and contrary to science (Chambers & Andre, 1997 cited in Bozdogan & Demirba, 2009:146) or the personal experiences contradicting scientific facts and preventing teaching and learning of scientifically proven concepts (Çakir & Yürük, 1999 as cited in Bozdogan & Demirba, 2009:146).

2.2.4.1 Features of misconceptions

Klopfer *et al.* (1983:174) describe general features of misconceptions about motion. They write that students’ concepts are poorly differentiated and students use terms like *speed*, *velocity* and *acceleration* indiscriminately. Students subsequently do not perceive any difference between two statements such as ‘the speed of an object is proportional to the net force on the object’; and ‘the acceleration of an object is proportional to the net force on the object’. Students get confused by the seemingly contradictory definitions and remain ignorant of the abundant conceptual information contained in definitions of physics concepts and/or laws. Although students’ conceptual knowledge structures and the meaning they attach to terms may be incorrect from the physicist’s point of view, the existence of such concepts is unmistakable.

Klopfer *et al.* (1983:174) argue that misconceptions develop because everyday meanings that students attribute to physics terms differ from the meaning that physicists attribute to the same terms. They support their argument with an example that students usually define acceleration as speeding up, while physicists define acceleration as any change in velocity with time i.e. moving faster or slower or changing direction. They speculate that propositions about motion concepts are imprecisely formulated probably due to students having vague meanings for technical terms. Finegold and Gorsky (1991:97) describe the potential lack of shared

understanding of scientific words that are integral to the concepts under consideration as a challenge. Alonzo and Steedle (2009:417) show that students hold multiple interpretations of the word “force” that differs from the specific meaning used by physicists, probably because the “scientific” word also has a range of everyday meanings. They report research that identified multiple well-defined, internally consistent meanings for the word “force” that students have, none of which is consistent with the physicist’s meaning of force.

When information learned in science is inappropriately linked to existing naive conceptions, false truths - a naive conception wrapped in “scientific evidence” – arises (Klopfer *et al.*, 1983:174). A naive proposition, e.g. 'Heavier objects fall faster than lighter ones,' is often observed in its “schooled” form as: 'Heavier objects fall faster than lighter ones *because* gravity pulls harder on heavier objects'. The naive misconception may be reinforced in this way because it is now supported with a reason that the students view as a 'scientific fact'. Halloun and Hestenes (1985b:1057) point out that students' basic physical knowledge provides the conceptual vocabulary they use to understand physical phenomena. If basic physics concepts of Newtonian mechanics are wrong, it means that alternative misconceptions about mechanics are firmly in place. If the students only picks up a few isolated facts, they will not only fail to understand much of the material but in dressing up their misconceptions in scientific jargon they may mistakenly believe that they have learned something about science (Klopfer *et al.*, 1983:174).

2.2.4.2 Effect and range of misconceptions

Naïve concepts are often not easily matched with the concepts taught in physics courses (Redish *et al.*, 1998:212). Because students tend to misinterpret elementary concepts taught in introductory physics courses, they find it difficult to obtain the appropriate outcomes (Stewart *et al.*, 2007:2). Klopfer *et al.*'s (1983:178) work on mechanics also shows that students' existing knowledge can adversely affect their ability to learn from science instruction, a notion Minstrell (1982:11) agrees with. Bozdogan and Demirba (2009:146) maintain that the misconceptions acquired as a result of students' experiences are major obstacles to producing new information and providing meaningful learning experiences. They cite studies which reported that the same misconceptions existed in different education systems in different countries (Shipstone *et al.*, 1988, cited by Bozdogan and Demirba, 2009:146) and that these misconceptions could be found at any level of schooling from primary school to university (Kabapinar, 2007 cited by Bozdogan and Demirba, 2009:146).

According to Bozdogan and Demirba (2009:146) studies implemented in higher education reveal that the misconceptions of university students persisted even after an education on the subject was given and several applications were performed. Kavanaugh and Sneider (2007:21)

report that many high school and college students, who have no difficulties solving numerical problems involving gravity, hold qualitative misconceptions similar to those held by much younger students. This occurrence raises concern but should not be much of a surprise in the light of the evidence presented by Park *et al.* (2009:14) that misconceptions are even present in textbooks and curriculum material. They cite research that analysed the representation of concepts regarding gravitation in textbooks and curriculum materials and found similar alternative conceptions. The study by Bozdogan and Demirba (2009:146) aligns with previous studies and they warn that if misconceptions are not remedied at primary and secondary schools, it would be more difficult to remedy it during the period of university training. Kavanaugh and Sneider (2007:21) write that the finding that even college physics students have significant misconceptions about free fall, underscores the importance of effective teaching at the middle and high school levels. They also raised concern that studies have found that few teachers are aware of their students' misconceptions or know what to do about them. Van Heuvelen (1991:892) maintains that students should realise that a small number of concepts are the foundation for various applications and that physics teachers should provide instruction to that avail.

2.2.4.3 Misconceptions and Newtonian physics

Sanborn *et al.* (2013:430) hail the discovery of Newtonian mechanics as a major intellectual achievement. As its principles remain difficult for people to learn explicitly; Newtonian physics and intuitive physics seem far apart but Sanborn *et al.* (2013:430) argue that with progress of cognitive development, people learn how to interact with and reason about a physical world that is described in Newtonian terms. Klopfer *et al.* (1983:178) reveal that students' failures to argue about the physical world around them were not due to an absence of theories, but rather to the persistence of naive theories that stand in marked contrast to what students are expected to learn.

Many of the misconceptions relating to motion concur with the descriptive aspects of Aristotelian physics (Klopfer *et al.*, 1983:178; Kavanaugh & Sneider, 2007:24; Halloun & Hestenes, 1985b:1057). One misconception concerning motion of objects is Aristotle's assertion that the speed of a falling body is proportional to its weight (Kavanaugh & Sneider, 2007:24; Halloun & Hestenes, 1985b:1057). Sanborn *et al.* (2013:411) state that the power of physical theories, whether they are Aristotelian, medieval impetus, Newtonian, or modern, is that they attempt to provide a consistent explanation for all physical phenomena. Kavanaugh and Sneider (2007:21) suggest that parallels between historical theories about the world like those formulated by Aristotle and students' thinking, such as "heavier objects fall faster," provide valuable insights into the origin of certain misconceptions.

Kavanaugh and Sneider (2007:21) state that students are expected to learn how objects accelerate in free fall; why objects with different masses hit the ground at the same time and that gravity is a force that acts at a distance. Many students “know” that in free fall, two objects of the same size and shape but different mass falling from the same height; will reach the bottom at the same time. However, when these same students are asked to compare the approximate speed for the two objects they predict that the heavier object would have the faster speed. According to Kavanaugh and Sneider (2007:21) a diversity of misconceptions regarding falling objects exist, such as that bodies fall because they are not supported and things fall because they’re “heavy”. Klopfer *et al.* (1983:178) in turn report that when students had to compare the movement of two objects of different mass sliding down an incline, they predict that the time for the more massive object would be significantly less.

Inconsistencies regarding the effect of air resistance in students’ perceptions of gravity are also noticed in students’ reasoning about friction in a horizontal plane. Singh (2007:196) reports that in research consisting of isomorphic problem pairs (IPP), students had difficulty in transferring their reasoning from their intuitive knowledge of situations involving friction to a problem without friction. The fact that students did not take advantage of problems not involving friction (which turned out to be easier for them) to answer the corresponding problem involving friction suggests that the misconceptions about friction were quite robust. Halloun and Hestenes (1985b:1056) put forward the idea that it would not be sufficient to simply test students’ initial knowledge of Newtonian mechanics but that instructors need to ascertain students’ common sense knowledge of mechanics, because the discrepancy between their common sense concepts and the Newtonian concepts describe what students need to learn. Klopfer *et al.*’s (1983:178) research parallels the findings of numerous researchers studying other science fields indicating that it is not the students’ lack of prior knowledge that makes learning mechanics so difficult, but rather the conflict in their knowledge.

Kavanaugh and Sneider (2007:21) suggest that learning experiences that focus on students’ abilities to answer questions about how and why things fall, might help them develop more correct models of the world. By asking questions such as these students may develop understanding of the fundamental ideas of the classical theory of gravity (Newtonian) before the mathematical argument, that objects with different masses in free fall will accelerate at the same rate, is introduced (Kavanaugh & Sneider, 2007:21). Students should have a clear understanding of what the term free fall means and what the conditions for free fall are. The concept of net force “causing” the acceleration should be clarified for students to be able to change their intuitive framework. The term free fall means that the force of gravity is the only (net) force acting on the object, therefor the acceleration due to the force of gravity is the same for all free falling objects.

2.2.5 Students' perception of knowledge and learning

The system of beliefs and intuitions that students entering an introductory physics course bring with them, acts as a common sense theory of how the physical world works and influences what he uses and hears in the physics course (Halloun & Hestenes, 1985b:1056). Redish *et al.* (1998:218) found that students view science knowledge either as fixed, memorization-intensive and irrelevant to their everyday lives or as understandable, interpretive, and integrated. Students who emphasize science as a collection of facts fail to see the coherence of the structure of physics knowledge and those students are unable to notice errors in their reasoning or evaluate a recalled item through cross checks (Redish *et al.*, 1998:212) (refer to paragraph 2.2.2 epistemological sophistication).

According to Klopfer *et al.* (1983:178) research investigating student perception of knowledge and learning began with the observation that students who do well on textbook problems often do not apply the principles they have learned to predict and describe actual physical events in physics. Elby (1999:S53) reports that most students think that the activity to learn physics concepts is unrelated to trying to obtain high marks in the course. He provides evidence of students who report that they spend much more time focusing on formulas and practice problems than they would, if grades did not matter. It seems that many students believe that a deep understanding is not necessary to obtain high grades. Elby (1999:S53) doubts that students' comfort level with rote learning is because of a choice they made but thinks that it has evolved as result of students' knowing 'what works'. Lo (2012:214) reports her study where students were grouped according to their perception of learning and knowledge. She noticed that students' ways of dealing with learning tasks were influenced by their conceptions of the meaning of learning. One group saw learning as merely a task of memorising and reproducing which could be forgotten once it was finished. For another group the learning was much deeper. They perceived learning as being more than a task; as increasing and applying their knowledge, developing conceptual understanding by seeing something in a different way. This result concurs with Tannen's (1993:3) notion that students act according to their expectations based on their framing of what kind of activity they were engaged in.

Redish *et al.* (1998:212) notice that students' expectations of a physics course determine what they listen to and what they ignore in the information provided by the instructor. Their expectations also affect which activities they select in constructing their knowledge base and in building their own understanding. Klopfer *et al.* (1983:178) claim that previous thinking about the role of knowledge in learning emphasized learning as positive transfer of knowledge. This leads to a kind of examination-oriented learning (Lo, 2012:214) where students could succeed without developing an understanding of the nature of science or how to learn science (Redish *et*

al., 1998:212). Students with inappropriate expectations and attitudes, such as those who prefer memorizing to understanding, may work extremely hard but still find that they are unable to succeed in higher physics education.

Hutchinson and Elby (2013:195) describe two different perceptions that students have regarding the answers required of them, namely answer making and sense making. Answer making refers to a perception that in certain contexts, answers in terms of formal classroom knowledge, usually a formula or a rule in introductory physics are required regardless of whether the answer reflects the student's real opinion. Sense making refers to a view that producing an answer involves more than implementing physics class ideas by drawing on the broader set of the learner's experiences. Ideally, sense making would lead to reconciling physics class ideas and students experiences in moments of inconsistency. Lo (2012:220) notices that current reforms seem to treat the learning of knowledge and the cultivation of higher order thinking capabilities as mutually exclusive to each other. She is concerned that the approach is either back to basics with a focus on the mastery of subject knowledge, or to cultivate higher-order thinking capabilities.

2.2.6 Students' view on problem solving

Although problem-solving plays a very important role in building cognitive knowledge, it is a common occurrence that students are able to solve numerical problems without understanding the concepts involved (Cracolice *et al.*, 2008:873; Hedge & Meera, 2012:1; Kim & Park, 2002:759; Concannon, 2012:14). Van Heuvelen (1991:892) reports that students viewed problem solving as attempts to determine the value of one or more unknown quantities. Sherin (2001:479) conducted research on students' use of equations in physics in terms of symbolic forms – a structure where a pattern of symbols in an equation is associated with a conceptual framework. Students' epistemological belief that physics is merely a collection of concepts and equations seems to be deeply rooted in their minds (Hedge & Meera, 2011:135) (refer to paragraph 2.2.3). According to Ogilvie (2009:3), the problem-solving challenge in physics is for students to use their conceptual understanding of both physics and mathematics to solve quantitative problems. Ogilvie (2009:5) has documented that physics students expect to solve problems by searching for an equation that simply contains the same variables in the problem statement instead of using conceptual understanding of either the physics or mathematical domains. This mode of problem-solving rather than the use of a relevant physical principle can be ascribed to the instructional and evaluation practices that encourage dominant rote learning (Hedge & Meera, 2011:135). Students with a prevailing belief that problem-solving is being able to apply procedures that knowledge is a series of isolated facts, spend their study time memorizing facts rather than building an organized structure of concepts they could draw on as

they attempt to solve novel problems (Ogilvie, 2009:5). Cracolice *et al.* (2008:873) report that the majority of students in high school and college chemistry courses rely almost exclusively on algorithmic approaches to quantitative problem solving. Cracolice *et al.* (2008:873) describe algorithmic problems as those problems that can be solved by using a memorized set of procedures in contrast to conceptual problems that require the student to work from understanding of a concept/principle to get to the solution to the problem.

Elby and Hammer (2010:409) are of the opinion that personal epistemologies are not haphazard and incoherent but Sanborn *et al.* (2013:415) express the opinion that the stability of students' systems of ideas relies on persistent cueing by features of the context. Since equations are mathematical constructs, Rebello and Rebello (2011:311) consider this approach a productive way of interpreting how students think about equations. They conclude that equations into which values are plugged in to solve a physics problem are common mathematical resources that novice students tend to cue, a way that is consistent with other literature on physics problem solving (Hedge & Meera, 2011:135). Rebello and Rebello (2011:311) support their opinion with the example that a student might adopt an active approach to learning in a setting where reformed curricular materials and instruction prompt that framing, but the student might shift back to rote learning, when those cues are removed. Alonzo and Steedle (2009:417) feel that the reasoning students apply in different situations, and the consistency with which students respond, poses a challenge to determining the level of their conceptual understanding while Lo (2012:222) points out that the capability to engage in an inquiry process to solve problems can only be built on a deep understanding of the subject knowledge.

2.2.7 Knowledge and understanding

Conceptual understanding and problem-solving are constantly being researched with much time devoted to the instruction and assessment thereof (Schuster & Undreiu, 2009:265; Piburn *et al.*, 1988; Gönen, 2008:70; Hedge & Meera, 2012) but Leonard *et al.* (1996:1496) report that students' conceptual understanding after completing a traditionally taught physics course is much weaker than anticipated.

According to Ambrose (2009:3), students' reasoning is inconsistent as they sometimes seem to operate using loosely connected or spontaneous ideas. Some conceptual and reasoning difficulties seem to be deeply entrenched and will require specific instructional strategies aimed at resolving their cognitive conflict. Hillel (2005) highlights the need for students to develop a conceptual understanding of physics rather than merely developing the ability to solve problems. This view is underwritten by Park *et al.* (2009:14) who advocate the creation of appropriate methods to evaluate students' levels of conceptual understanding.

Cognitive scientists (Beatty & Gerace, 2002:751) distinguish between different kinds of knowledge; *declarative or* explicit knowledge, a term to describe facts that can be stated and *procedural* knowledge, which is knowledge of how to perform operations, knowledge that according to them can be demonstrated but not stated. In the physics domain researchers differentiate between the types of knowledge using different terms or descriptions. Weinberger (2009) distinguishes between things that are known and things that are understood, the latter being related to understanding, allowing for greater nuance by connecting multiple ideas. Given the extent to which understanding is embedded in physics education research it is important to examine what students' conceptions of understanding in the context of physics are (Irving & Sayre, 2013:198). Irving and Sayre (2013:198) list some conceptions that students have of what understanding of physics entails. Students think they understand physics when:

- they can use and apply understanding to solve problems.
- they can use, visualize and apply concepts in different contexts.
- they can teach someone else.
- they can explain concepts in more than one way by using analogies.
- they understand physics concepts deeply and can apply mathematical models to it.

Hedge and Meera (2011:135) cite research (Reif *et al.*, 1976) indicating that problems requiring substitution of numerical values and calculating an answer require very little strategy where more detailed strategy is needed for solving context rich problems. They propose that successful solving of problems in various contexts can be indicative of effective physics learning. Sherin (2001:479) researches students' use of equations in physics in terms of symbolic forms. The ability to associate a conceptual schema with a pattern of symbols in an equation and the ability to use appropriate equations for physics concepts is a skill only mastered by physicists with deep, well developed conceptual understanding. Students often do not use equations to help them solve non-numerical problems (Hedge & Meera, 2011:135). It seems that students perceive the use of mathematics in physics learning more than an 'inconvenience' than a tool for quantification of ideas.

2.2.8 Conceptual development

Minstrell (1982:11) suggests that a way to enhance concept development is to juxtapose a diversity of situations (isomorphic situations) in which the concept is applicable, including situations in which students would fall back on their naïve knowledge. By comparing the various situations while applying the same concept students realize that their naïve knowledge is inconsistent with the concept. This realization encourages them to seek a resolution to their internal conflict and as a result, their conceptual understanding is increased (Ogilvie, 2009:3;

Minstrell, 1982:11). Research on student epistemology indicates that students are only motivated to develop these skills when they realize that something in their beliefs is impacting their ability to make progress, i.e., there must be some epistemic doubt or acknowledgment that there is a need to change. Tannen (1993:5) states that shifts in and adjustment to frames are often triggered by conflict in schemas in an attempt to balance the competing and conflicting schemas.

Irving and Sayre (2013:198) outline a suggestion of how students' conceptual understanding may develop. Redish *et al.* (1998:212) equal memorising equations and definitions without conceptual understanding to learning a language by memorising text without knowing the meaning of the words. Irving and Sayre (2013:198) suggest that students, who attempt to learn a passage by memorizing through reciting, will not understand the deep implication of such a passage. When students memorize a passage in an attempt to learn and "know" the passage, they may not be able to understand the whole or even parts of the passage when they read it for the first time. However, different parts will come into focus each time the students read the passage again. As different parts of the passage become clearer through repeated reading, the students' understanding of the whole passage becomes clearer and deeper. This kind of repetition is different from mechanical memorisation characterised by rote learning (Irving & Sayre, 2013:198).

Knowing how experts think is important for more effective teaching and to provide students with problem-solving feedback (Schuster & Undreiu, 2009:266.) According to Rebello and Rebello (2011:311), research in the area of problem-solving agree that novice students often seek an equation or formula in which they can plug in known quantities and calculate the quantity asked for in the problem, while experts tend to focus on deep structure. Studies demonstrate that experts and novices are distinguished not just by the content of their knowledge stores, but also by their organization of that knowledge (Beatty & Gerace, 2002:751). According to these studies, experts have contextually appropriate knowledge and access to that knowledge due to the interconnections between knowledge elements structured around key principles. Rebello and Rebello (2011:311) also provide evidence that experts usually start with qualitative conceptual analysis of the problems to be solved and Leonard *et al.* (1996:1495) also report that novice students are apparently unable to identify the major laws of principles that could be applied to solve the problem. Hedge and Meera (2011:131) argue that the process of concept learning has a productive and very important role in building cognitive cognizance to increase students' ability to apply concepts for it has the potential to strengthen the processes associated with learning. Minstrell (1982:11) reports that instruction that focused on concept development resulted in students changing their conceptual understanding, willing to hold and use the physicist's view of concepts. Stewart *et al.*'s (2007:2) research noted that novice problem

solvers view problems differently than expert problem solvers, an observation also reported by Sabella and Redish (2007:1017). Stewart *et al.* (2007:2) ascribe this difference to problem context instead of actual problem structure.

Sanborn *et al.* (2013:411) debate that while people believe they understand how everyday physical objects behave; their intuitive understanding appears to be inconsistent with Newtonian mechanics. Because the Newtonian physics principles remain difficult to learn, Newtonian physics and intuitive physics might seem far apart. Jonassen (1997:65) explains that transferring knowledge from a mathematical to a physics domain is particularly challenging because only a few physics principles and concepts are condensed into a compact mathematical form i.e. physics equations. Learning requires unpacking those equations and understanding their applicability in a variety of contexts that share deep features, e.g., the same law of physics may apply in different contexts. According to Jonassen (1997:65) cognitive theory suggests that knowledge is encoded in memory in the context in which it was acquired (a feature described by the information theory of learning) and if the source and target of transfer knowledge do not share surface features, transfer can be difficult.

Osborne (2013:265) proposes that students' ability to explain and evaluate phenomena scientifically increase with deeper conceptual understanding. Stiles (2006:4) suggests that evaluation procedures that measure understanding instead of just how well a student has memorized data should be developed. Weinberger (2009) claims that students' understanding can be tested by asking questions that go beyond what is explicitly known in the subject. Hawkins *et al.* (2011:207) state that methodologies for gathering information about students' ideas and thinking can be improved by varying the types of questions. They claim that information gathered by such improved methodologies has the potential to impact on instruction in physics courses by providing more detail about the ideas students are bringing into physics courses. Hawkins *et al.* (2011:207) argue that these questions may also provide some insight into how students think about physics through contrasting responses to different questions.

2.2.9 Qualitative reasoning

Cracolice *et al.* (2008:873) argue that the development of cognitive skills should be a central goal for any high school or college science course because students with poor reasoning skills cannot solve conceptual problems. They hypothesize that poor reasoning skills is one *cause* of the gap between conceptual and algorithmic problem-solving ability, as the lack of reasoning skill leaves students with no choice except to memorize algorithms. Their argument is supported by studies reported by Piburn *et al.* (1988:3) who found that reasoning ability was the only variable that related consistently and significantly to the number of misconceptions in students' epistemological beliefs.

Schuster and Undreiu (2009:266) identify different types of reasoning strategies, of which two are described here:

- Principle-based reasoning (PBR), problem solutions are obtained by a systematic application of fundamental physics concepts and principles, a strategy mostly followed by physicists.
- Case-based reasoning (CBR) drawing by association on features of recalled similar cases. Previously compiled knowledge is retrieved and adapted to the current case, instead of than constructing a principled solution based on fundamental concepts often applied by students with insufficient conceptual knowledge.

Schuster and Undreiu (2009:266) propose principle-based reasoning (PBR) for solving problems by systematically applying fundamental physics concepts and principles. According to Cracolice *et al.* (2008:873), students with poor reasoning skills find it very hard to solve conceptual problems. Although it is logical to identify the physical principle applicable to the situation, students' weak ability to associate a conceptual framework to the physical principles acts as a major obstacle in problem solving (Hedge & Meera, 2012:2). Leonard *et al.* (1996:1496) report that both students and instructors benefit from the use of qualitative problem solving strategies. When solving problems novice students resort to manipulating equations in an attempt to isolate the desired unknown and seldom consider conceptual knowledge that undergirds the mathematical solution (Leonard *et al.*, 1996:1496). Schuster and Undreiu (2009:266) contend that in learning a concept students build up and organize knowledge as a network of connected knowledge elements, ideas, and relationships instead of exhibiting fragmented and compartmentalised knowledge base as are reported by Hedge and Meera (2012:2) and Stewart *et al.* (2007:2).

Van Heuvelen (1991:892) lists possible reasons for students' lack of qualitative reasoning abilities. It seems that students do not understand the meaning of basic quantities and concepts in physics representations. This observation is supported by examples such as student think that in kinematics, objects at the same position have the same velocity. Students also confuse acceleration with velocity (Klopfer *et al.*, 1983:173; Alonzo & Steedle, 2009:417; Finegold & Gorsky, 1991:107). Van Heuvelen (1991:892) found that students have little opportunity to develop special techniques needed to construct representations of physics problems. He documents his research indicating that students' qualitative reasoning skills can be improved by solving problems in different representations. Another factor contributing to students' poor reasoning skills may be the introduction of new concepts before misconceptions are removed. The resulting confusion in their thinking framework, contributes to their structure of understanding consisting of random facts and equations with no coherence in their body of

knowledge. Ogilvie (2009:4) notes that more successful novices recognise that they need a structure that is consistent with respect to the rest of their domain knowledge. He reports results that students who focused on constructing a coherent structure of physics concepts showed a larger gain on conceptual understanding than students who approached their learning tasks in a rote fashion. According to Ogilvie (2009:4) it is essential for students to realize that problem solving is more than applying an ever-expanding list of procedures to tasks. He believes this realization is the key for students to develop their problem-solving skills and strengthen their abilities to tackle ill-structured and open-ended challenges.

2.2.10 The relationship between mathematics and physics

Sanborn *et al.* (2013:430) describe the discovery of Newtonian physics as a major intellectual achievement and Kavanaugh and Sneider (2007:21) maintain that mechanics could only be represented in mathematical form after Newton developed his laws of motion and universal gravitation. Quale (2011:612) contends that it is well known that the physical sciences are highly mathematics-intensive disciplines, i.e. they make extensive use of mathematics in the formulation of scientific laws and the investigation of the consequences of those laws. Szymanski (2012:590) argues that the mathematical formulae that describe quantitative relations between the properties of matter, space, and time are inventions by physicists. He emphasizes, however, that it is only the mathematical statements of physical laws that exist in the human mind, not the physical phenomena that they describe (Szymanski, 2012:590). He states that using mathematical fields to describe physical interactions has been particularly successful because such fields considerably simplify the formulations of physical laws. According to Fink and Mankey (2010:273) physics is a problem-solving discipline, and they propose that problem solving and questioning should be a standard goal of all education; a view shared by Jonassen (1997:65) who argues that problem solving is among the most meaningful and important kinds of learning and thinking.

The important role that mathematics plays in physics has often been documented in research studies (McBride, 2012; Kavanaugh & Sneider, 2007; Hewitt, 2002; De Cock, 2012; Redish *et al.*, 2006). This view is supported by Bing and Redish (2009:1) who describe mathematics as the language in which physical laws and relations are expressed and applied but warned that the numbers substituted in a physics formula always have a deeper meaning than just being the result of a calculation. Students often look for equations to manipulate in order to isolate the unknown that must be determined (Van Heuvelen, 1991:892) and are unable to identify the major law or principle that describes the specific situation (Leonard *et al.*, 1996:1496). Writing down an equation that represents the problem is a useful way to summarize the information (Singh, 2007:196) but this can add to students' inability to identify the underlying concept,

especially if the law or concept which is represented by the equation is only stated verbally (Leonard *et al.*, 1996:1496).

2.2.10.1 Students' use of equations in problem solving in physics

Ogilvie (2009:3) reports that high school students believed that understanding mathematics meant being able to solve problems in a very short time and that success in mathematics is achieved by performing tasks exactly as instructed by the teacher. The belief that problem solving consist of following a set of prescribed rules lead students to search the textbook for procedures without applying reasoning as to which methods were most appropriate. Ogilvie (2009:3) reports that the lesser students believe in fixed learning and the more they believed that mathematics was useful, then the better they performed on mathematical problems. Students think that the principle objective of problem solving in physics is to manipulate equations that leads to the solution and that the underlying physics principles are conclusions that has little relevance to obtaining (i.e. calculating) the answers to problems (Leonard *et al.*, 1996:1496). In algorithmic teaching students first identify the target variable to be calculated, they choose an equation that contains all the appropriate variables and then calculate the unknown quantity (McBride, 2012:275; De Cock, 2012:1). Equation hunting (Hedge & Meera, 2012:2) promotes rote learning that affects problem solving ability and causes students to disregard the concept features of a problem. Students need knowledge and skills to be able to choose the most appropriate of related different representations of a concept, when solving a problem (De Cock, 2012:1).

According to Leonard *et al.*, (1996:1498) beginner students often do not understand the conditions under which equations are applicable and what their restrictions are. Experienced physicists start to solve novel problems by qualitatively analysing the underlying concepts and principles and then identify possible mathematical representations of the concepts that can be implemented in solving the problem (Leonard *et al.*, 1996:1498; Schuster & Undreiu, 2009:265; Van Heuvelen, 1991:891; Sherin, 2006:535). Both Singh (2007:196) and Leonard *et al.* (1996:1499) maintain that there are but a few principles and concepts in physics that are condensed into compact mathematical equations which represents the relationships of the applicable variables. According to Van Heuvelen (1991:893) students do not understand the meaning of basic quantities and concepts represented in all representational formats. Hedge and Meera (2012:2) found that the weak association of students' conceptual framework to the physical principles was a major deterrent in problem solving. Students' tendency to view equations merely as mathematical representations instead of relations between physical quantities attributed to their inability to connect the symbols to the physical quantities. According to Concannon (2012:22) students should be able to understand and transfer simple

concepts to more complex problems but Singh (2007:196) argues that unpacking these mathematical forms and understanding how to apply them in various contexts makes transfer in physics quite challenging.

Students have various mathematical skills that they apply through manipulation of equations to solve physics problems, but physics principles are not necessarily involved (Redish *et al.*, 2006:293; McBride, 2012:276). On average, students seem to be more successful when they are able to identify the physics formulae and then match the necessary algebraic techniques to solve the problem (McBride, 2012:275; De Cock, 2012:1). Students are rarely asked to interpret their results and as a result, they do not appreciate the links between the mathematical processes they are using and the physics they are studying (Redish *et al.*, 2006:293). It is important though, that students understand how mathematics is used to describe physical phenomena. Mathematics is not only used to solve equations in physics but also to describe and understand physical systems. Redish (2005:1) and McBride (2012:276) emphasise that physicists and mathematicians use variables differently and that similar symbols have different meanings in mathematics and physics equations, leading to physicists being selective how they use their mathematics to solve physics problems. Where mathematical equations at school level describe the relationship between two variables, physics equations describe the relationship between more than two variables at a time (Redish, 2005:3). In physics as well as in chemistry equations are interpreted through knowledge of physical systems, which changes the perspective in which the equation is regarded. The physical quantity that is represented by the symbol determines how the mathematics should be interpreted (Bing & Redish, 2009:2).

2.2.10.2 Meaning of symbols in mathematics and physics

Redish (2005:3) emphasises that while variables in algebra are often represented by x , y , or z , with constants represented by specific numbers, a variety of symbols is used in physics. These symbols have specific meanings because they represent concepts such as speed or force, contrary to mathematics where the symbols only represent numerical values. Mixing physical meaning with mathematical symbols influences the way physicists interpret symbols as well as the way equations are viewed (Redish, 2005:4). Woolnough (2000:264) warns that more attention should be given to students' transfer of knowledge to the physical realm. Several studies support the notion of students' inability to link mathematics and physics knowledge (Planinic *et al.*, 2012:1395; Woolnough, 2000:265; Bing & Redish, 2009:1; McBride, 2012:275). It seems that student knowledge is very compartmentalized and that stronger links should be established between mathematics and physics during teaching (Planinic *et al.*, 2012:1395). This argument is supported by Redish *et al.* (2006: 294) as well as Van Deventer and Wittmann (2007:211) who found students' knowledge to be very fragmented and compartmentalized due

to lack of assistance given to students to link newly acquired knowledge to previously learned knowledge.

While the poor level of knowledge transformation was previously ascribed to a lack of students' mathematical knowledge, recent studies indicate that it may be due to the difference of the context in which the mathematical knowledge is applied (Harvey, 2012; Hedge & Meera, 2012:1; Jonassen, 1997:65). Teachers fail to realise that mathematics is used in a different context in physics and although the format of equations may look alike, the symbols used in the equations have a very different meaning than in mathematics (Redish, 2005:4). By aligning physics and mathematics teaching and vocabulary, teachers will be able to show students that the equations used to predict motion of objects are the same for both physics and mathematics (Harvey, 2012:122). It is possible for students to solve some physics problems without understanding the principle involved and still do well in tests (Jones *et al.*, 2009:379). A survey of physics teachers indicated that some students do lack mathematical skills (Planinic *et al.*, 2012:1410). However, the results also indicated that mathematical knowledge is not a guarantee for success on corresponding physics problems. Woolnough (2000:264) suggests that even those students who do well in mathematics and physics do not make substantial links between these contexts.

2.2.10.3 Use of equations in reasoning

Although solving the majority of physics problems require mathematical techniques (McBride, 2012:275), mathematics in science is more than mere calculating answers to equations. Kinematic equations, velocity, acceleration, and projectile motion are all topics where physics and mathematics can be integrated (Harvey, 2012:122). To acquire expertise in physics one must learn to use mathematics effectively and efficiently in a physics context. It involves integrating a variety of concepts and skills such as mathematical calculation, blending additional information with mathematics, and recognising physical meaning from mathematics (Bing & Redish, 2009:1). Although Potgieter *et al.* (2008:211) found that teachers thought physics items such as velocity and acceleration are closer to real life and would be easier for students, several studies suggest the opposite (Beichner, 1994:750; Redish, 2005:6; Redish *et al.*, 2006:299; Van Deventer & Wittmann, 2007:210; De Cock, 2012:9; Harvey, 2012:122). Instructors should therefore address the problems as they are and not as the instructor imagine them to be (Trowbridge & McDermott, 1981:511). Instructors often do not realise what students perceive as complex problems. By doing "reverse engineering" of a problem, the complexity of a seemingly simple problem can be appreciated (Redish *et al.*, 2006:293). Instructors should realise that they need to work on student conceptual understanding and integrating of mathematics and physics as well as building stronger links between mathematics and other

related subjects (De Cock, 2012:13). Helping students to learn to recognise what tools are appropriate in what circumstances is critical (Redish, 2005:8).

Hedge and Meera (2012:2) made an interesting observation that many students are unable to proceed in conceptual problem solving even when they have access to the relevant equations. This observation was also noted by Woolnough (2000:264). Hedge and Meera (2012:2) are of the opinion that the physics terms in the problem statement act as trigger for the search of an equation and the inability to do so may hinder the problem solving completely. According to Hedge and Meera (2012:2) students' weakness in connecting the symbols to the physical quantities can be an indication that students tend to look at equations in physics as mathematical executions instead of relations between physical quantities, an observation also noted by Redish (2005:4). Equation hunting causes students to skip the concept features of a problem and promotes rote learning which influences their problem solving ability (Hedge & Meera, 2012:2). Many students memorize formulas and problem-solving algorithms, instead of trying to understand the concepts (Elby, 1999:S52). Kavanaugh and Sneider (2007:21) report on students' abilities to solve quantitative problems of the type typically encountered in textbooks. Evidence suggests however, that even after solving a large number of textbook problems, students still have conceptual difficulties with physics (Kim & Park, 2002:762) while Fink and Mankey (2010:273) also contend that the process of rote learning - following a procedure without understanding- is ultimately not effective.

Hedge and Meera (2012:3) propose that the weak association of students' conceptual framework to physics principles acts as a major deterrent in problem solving. Hewitt (as cited by Woolnough, 2000:259) suggests that reducing the emphasis on numerical and algebra-based problem solving may enhance students' development of physics concepts. Stiles (2006:5) raises the question whether conventional evaluation determined what students actually comprehend or merely how well they can recite information. Ogilvie (2009:2) presents evidence that the strategies taught in schools and universities simply require finding and applying the correct formulae or strategy to answer well structured, algorithmic problems, and as a result most students struggle when faced with complex and open-ended tasks. This opinion is shared by Cracolice *et al.* (2008:873) who compared student performance on algorithmic versus conceptual problems and reported that experience with an algorithmic approach does not facilitate students' conceptual understanding. Hedge and Meera (2012:3) are of the opinion that to transform a student from a concept learner to a problem solver, the student must develop a strong appreciation for the interplay of mathematics in physics learning although the algorithmic teaching of mathematics does not aid the conceptual understanding of physics (Cracolice *et al.*, 2008:873). The influence and consequence of learning mathematics not as a tool in physics but "only as mathematics" has been investigated in various contexts

(Hedge & Meera, 2012:3). The lack of studies exploring how students relate given resources such as equations, to various types of physics problems and contexts and how they ascertain the meaning and applicability of that resource is pointed out by Rebello and Rebello (2011:311). Fink and Mankey (2010:278) contend that although support is divided between the importance of increased conceptual understanding and those who advocate increased problem-solving skills, change in both areas is necessary and inevitable.

In contrast to the perception of physics consisting of problems to be solved mathematically, physics problems situated in everyday practice are more complex than mere calculations. Jonassen (1997:65) defines problems in terms of domain, type, process and solution. The content that defines the problem elements (concepts rules and principles) make up the problem domain. The problem type determines the combination of concepts and rules applicable to the problem, and the procedures for action to solve the problem. Traditional end-of-chapter problems are usually well structured within well-defined parameters and require the application of a limited number of rules and principles to solve whereas ill-defined everyday physics problems pose multiple solution paths, fewer parameters which can be manipulated, and uncertainty about the concepts, rules, and principles to be used for obtaining the solution (Jonassen, 1997:65). Solving these kinds of problems require deeper understanding of physics concept and principles. According to Hedge and Meera (2012:3) it seems that good conceptual clarity can enable a student to solve a problem successfully. However, research results show that problem solving ability does not emerge as a consequence of conceptual clarity alone.

2.2.11 Context

Lo (2012:110) contends that the external environment (context) can influence students' overall understanding of an object of learning because the context determines the relevance to them. According to Finkelstein (2001:1), context is central to student learning, not as the backdrop or an analytically separate factor, but as an integral part of the learning process, because certain features that promote or inhibit construction of content understanding, are inherent in a given context. A main consequence of content that has been explicitly taught and deep compartmentalised learning outcomes is that students develop a limited ability to solve physics problems (Hedge & Meera, 2011:135). While researchers go to great lengths to create systems of activities which provide the opportunity for conceptual change in students' naïve knowledge the environments in which the systems of activities occur; the context which promote student learning, remain under-theorized (Finkelstein, 2001:1). He maintains that certain features that promote or inhibit construction of content understanding are inherent in a given context. From his perspective, conceptual change is mutually established by the individual and the context. Stewart *et al.* (2007:1) report that studies on problem context investigated the consistency of

student misconceptions and the consistency of the reasoning behind those misconceptions. Elby and Hammer (2010:409) present evidence (Louca & Elby, 1999:2; Hammer & Kagey, 2004, as cited in Elby and Hammer, 2010:409) that the context of physics problems activated different patterns of reasoning in students' cognition regarding the nature of knowledge, knowing and learning.

Sanborn *et al.* (2013:411) state that physical theories attempt to provide a consistent explanation for all physical phenomena. Researchers have proposed that students' general understanding of mechanics reflects formal pre-Newtonian, Aristotelian systems of ideas (Sanborn *et al.*, 2013:415; Hedge & Meera, 2011:136; Van Heuvelen, 1991:892; Redish *et al.*, 1998:214). It is however difficult to explain people's inconsistent responses that seems to reflect different systems of ideas depending on the particular problem that they have been given with these proposals. Stewart *et al.* (2007:1) state that an "unsure state of student knowledge" reveals itself in performance that differs according to the context of a question. Sanborn *et al.* (2013:411) contend that misconceptions in a student's knowledge may cause sensitivity to the physical context - the physical background against which the problem is posed. They wrote that a student might adopt an active approach to learning in a setting where reformed curricular materials and instruction cue and scaffold that framing. However, the student might shift back from treating knowledge as personally constructed to rote learning when those cues are removed.

2.2.11.1 Effect of every day context

Studies on the effect of everyday context on problem solving have been widely published (Enghag *et al.*, 2007:450). Hedge and Meera (2011:135) write that in the context of physics, the strategy for problem solving depends on the nature of the problem. By contextualising physics problems Stewart *et al.* (2007:1) state that the problem solving becomes meaningful and interesting to learners and relevant to their own lives. In addition, contextualising physics problems helps students to understand that learning physics involves refining rather than selectively ignoring your everyday thinking, the difference between rote memorization and deeper understanding and the importance of consistency and coherence (Hedge & Meera, 2011:135).

Hutchinson and Elby (2013:195) notice that many of their students behaved as if common sense ideas about the physical world have no role to play in learning physics. Students' inability to draw conclusions based on everyday observations seems to arise from inconsistencies in their beliefs about classroom physics and real-world physics (Reif *et al.*, 1976; Hammer, 1994b; cited by Hedge & Meera, 2012:1) and those inconsistencies in students' beliefs prove to be a major obstacle in students' ability to draw conclusions from everyday observations of the

physical world (Hedge & Meera, 2012:1). They maintain that compartmentalised learning can possibly be the cause of students' difficulties to solve problems in different contexts. Benckert and Pettersson (1997) compare students' approaches between real-world and numerical physics problems. They maintain that in real-world problems there is a motivation for the students to want to know about the actual events while with numerical problems students just want to find an answer to compare with the answer in the textbook; the so called "chug and plug" approach. They found that students were actually less keen to solve problems without a distinct answer and developed and tested an approach that would help students in physics courses to integrate the conceptual and mathematical aspects of problem solving. According to Benckert and Pettersson (1997) context-rich group problems focused students' reasoning on the physics concepts that should be applied rather than which formulas should be used. They propose that students should decide which variable, physics concepts and principles would be useful to answer before mathematical manipulation of formulas began. The most important point in the context-rich problem is asking for an answer that can be interesting to know.

2.2.11.2 Compartmentalized knowledge

Muis and Gierus (2014:411) present evidence that high school students reveal different beliefs about knowledge in physics when the focus was on the procedural aspects compared to when the focus was on conceptual knowledge. They also support previous research, (Elby, 2001; Hammer, 1994; Hammer & Elby, 2003; Hogan, 1999) which indicate that students view procedural knowledge and conceptual knowledge as two distinct bodies of knowledge with separated spheres of applicability (Ogilvie, 2009:4). Hedge and Meera (2011:135) present evidence that students' knowledge base appears to be fragmented and Stewart *et al.* (2007:1) confirm that a large number of students exhibit compartmentalised learning. Students' belief that physics knowledge is applied differently in different domains is, according to (Ogilvie, 2009:5), a strong barrier to improving students' conceptual understanding because the process of learning physics involves the use of non-intuitive and abstract concepts/ideas as well as the use of reasoning tools of unfamiliar nature (Hedge & Meera, 2012:6). Ince (2012:161) aimed to identify students' understanding of physics in daily life and determine physics students' skills to associate between general physics knowledge and everyday life. He contends that to learn meaningfully, students need to see a relation between the everyday phenomena and physics concepts. Ogilvie (2009:4) documented studies (Lising & Elby, 2005:372) supporting these results. Ince (2012:161) notes that students often have difficulties in explaining real-life phenomena with physics concepts and Lising and Elby's (2005:372) findings suggest that students often overlook fundamental principles and are therefore not able to associate them with daily situations. Ince's (2012:161) reports that physics is often considered as having little to do with the real world and more to do with formulas to solve text-book problems. As a result,

many students focus on solving physics problems with mathematical formulas to pass courses without learning to think; views also expressed by Muis and Gierus (2014:411) and Benckert and Pettersson (1997).

Sanborn *et al.* (2013:415) argue that students could have local knowledge of Newtonian mechanics that corresponds to their perceptual variables, but not be able to project it onto other representations of the problem. Hedge and Meera (2012:1) found that problem solving ability gets affected by the nature of different representational formats and that different representational formats have varied appeals to learners. Alonzo and Steedle (2009:417) feel that the reasoning students apply in different situations, and the consistency with which students respond, can provide valuable information about their developing understanding. Bozdogan and Demirba (2009:146) found that the usage of different representational formats during instruction contribute to guiding students' approach to and ability in problem solving, an opinion shared by Alonzo and Steedle (2009:417) who indicate that students do not respond consistently to similar problems set in different contexts. Sanborn *et al.* (2013:411) report that people show sensitivity to irrelevant information and one of the most essential aims of science education is to enable students to take advantage of the information and the techniques they acquired to explain daily events from a scientific point of view and use them in their daily lives. Enghag *et al.* (2007:464) state that it is important in physics education that valuable lesson-time is used effectively and focuses on clear goals. Thus, it is necessary for students to learn the concepts meaningfully at the introductory education level, because correctly acquired scientific concepts enable lifelong learning by building up the basis of further levels of schooling (Bozdogan & Demirba, 2009:146).

2.2.11.3 **Bridging the gap**

Enghag *et al.* (2007:450) reflect on how to bridge students' everyday life views into physics understanding. They report that many students show low conceptual understanding, view physics classrooms as "unfriendly places to be in" and find physics courses both demanding and boring. Enghag *et al.* (2007:450) argue that the real-life context plays an important role in students' ability to visualise the problem. Benckert and Pettersson (1997) also want the physics content to be placed in a context that is interesting for students, by connecting physics content to phenomena in everyday life. Benckert and Pettersson (1997) call problems in everyday context context-rich problems. Jonassen's (1997:68) term "ill-structured problems" describes problems that emerge from a specific context and require the integration of several content domains. He maintains that problems situated in everyday practice are much more interesting and meaningful to students, who have to define the problem and determine what information and skills are needed to help solve it. Jonassen (1997:68) highlights some features of ill-

defined problems (set in everyday context). He states that the concepts, rules and principles necessary for the solution of ill-defined problems are not obvious, that the relationships between these concepts, rules and principles are inconsistent and that no general rules or strategies are offered.

Halloun and Hestenes (1985b:1058) write that a physics problem can be simplified by cleaning it of distracting elements such as friction or air resistance. Such simplification displays a general physical law that is present in the everyday world but “hidden” by the distracting factors. However the students may fail to make the link believing that the phenomenon does not occur naturally in the everyday world, or is irrelevant to it. Sanborn *et al.*'s (2013:394) explanation for students' failure to make the connection is that people can only reason about one-dimensional quantities. They suggest that people can extract certain pieces of information from problem statements, but when the decision requires the use of additional sources of information, for example “without friction” as additional information, they are unable to combine them effectively. Another example of compartmentalized knowledge is given by Finegold and Gorsky (1991:104) as well as Halloun and Hestenes (1985b:1063) who found that students thought specific rules exist for specific situations. They report that while Newton's first law account for the behaviour of both objects at rest and objects in motion, students are convinced that the force law for objects at rest on surfaces differed from the force law for objects suspended from strings. Finegold and Gorsky (1991:104) found little relationship between students' frameworks for these two conditions (objects on horizontal plane at rest and objects suspended vertically) across different problem situations. The results of Ince's (2012:161) study show that students enter physics courses, unable to apply physics knowledge to everyday situations and while having some naive conceptions about force and motion, gravitation and physics in daily situations. Sanborn *et al.* (2013:411) found that students could have knowledge of Newtonian mechanics but were unable to project it onto other representations of the problem. They contend that people only have an accurate conception of Newtonian mechanics within situations that match their terrestrial experiences.

Hedge and Meera (2011:135) express the opinion that passive learning creates a knowledge base in learners that is predominantly fact based, authority driven and formal in nature and that such knowledge is the underpinning on which learners generate their epistemological beliefs. These beliefs are exposed when posed with a context rich problem (CRP) situation. Ogilvie (2009:3) argues that students have to believe that standardized procedural approaches will not be sufficient for solving engineering and scientific challenges therefore they should develop their ability to solve ill-structured problems. Benckert and Pettersson (1997) state that CRP's enhance coherence in students' reasoning by improving their problem-solving abilities and deepen their conceptual understanding of physics. Enghag *et al.* (2007:463) argue that the

CRP approach offers a way of conceptualising “successful” physics learning and contribute to students’ developing a coherent perception of physics. Jonassen (1997:65) reports that studies indicate that performance in solving well-defined problems and performance on ill-defined tasks are independent, because ill-defined problems engage a different set of epistemic beliefs. Although he feels that more research is needed to substantiate this finding, it is obvious that well-structured and ill-structured problem solving engage different reasoning skills.

2.3 Conventional instruction

2.3.1 Introduction

Redish *et al.* (as cited by Finkelstein; 2001:1) describe the classic “instructionist” or “transmissionist” model for delivery of education as: “the student as an empty vessel and instruction as the delivery of reified (made concrete) decontextualized knowledge”. The student then possesses information that can be called upon as necessary. According to Finkelstein (2001:2) this model is a reasonable description of the practice of physics education found at the majority of high schools and introductory college level classrooms in the United States. Halloun and Hestenes (1985a:1044) provide evidence that student’s initial knowledge state determined their ability to process information and that this ability hardly improves throughout a conventional physics course. Klopfer *et al.* (1983:181) note that in past thinking about the role of knowledge in learning, emphasis has been on learning as positive transfer of knowledge and Kavanaugh and Sneider (2007:21) report that problem sets and exams typically tested students’ abilities to solve content-based problems. Elby & Hammer (2010:416) are convinced that thinking of knowledge as propagated stuff coheres with thinking that learning is accumulation of that stuff. By memorizing information, features of the context as filtered through students’ previous experiences tend to activate knowledge as propagated stuff, contributing to a view of learning as accumulating information.

According to Hutchinson and Elby (2013:197) a primary objective in teaching introductory physics is to help students to understand physics concepts effectively, while a secondary objective is to enable students to use their knowledge to analyse new physics situations effectively (Leonard *et al.*, 1996:1495). Research by Stewart *et al.* (2007:1) indicates that even after completion of an introductory physics class students’ knowledge of physics is fragmentary, incomplete and still contains significant misconceptions. Osborne (2013:265) argues that it may be due to school science education still being dominated by lower level cognitive demands e.g. recall and science being presented as static bodies of knowledge, focusing on vocabulary and algorithms. Ogilvie (2009:2) reports observations made in an effort to analyse the tasks addressed in mathematics classrooms and noticed that teachers mostly asked students to solve familiar work rather than novel challenges. Osborne (2013:265) contends that students emerge

from their education believing that knowledge with the status of a fact is the apotheosis of scientific achievement. Research done by Halloun and Hestenes (1985b:1056) indicates that the common sense beliefs students have, are very stable and that conventional physics instruction results in little change. Hedge and Meera (2012:3) report various studies (Hammer, 1994; Redish *et al.*, 1998) where the limitation of the conventional content transfer mode of learning in physics education is exposed. Beatty and Gerace (2002:751) support this view of ineffective introductory instruction, noticing a growing consensus among educational researchers that traditional problem-based assessments are not reliable tools for guiding pedagogical intervention. They advocate the need of new instruction and assessment tools grounded in the results of cognitive science research. Osborne (2013:265) believes that the prevailing pedagogy dominated by transmission prevents the development of higher order reasoning skills such as comparison, contrast and evaluation necessary to develop the ability to interpret and argue evidence for scientific ideas. He maintains that few students develop an understanding of the overarching conceptual coherence and the nature of the discipline itself in conventional education.

Ogilvie (2009:2) maintains that most students struggle when faced with complex and open-ended tasks because the problem solving strategies taught in schools and universities simply require finding and applying the correct formulae or strategy to answer well-structured, algorithmic problems i.e. a problem-based strategy. Teachers often create situated learning instead of facilitating students' understanding of physics concepts and consequently students' knowledge of physics concepts is relative to how familiar the problem they are trying to solve is to them (Concannon, 2012:14). In Schuster and Undreiu's (2009:266) research, the phenomenon of students' inclination to retrieve previously compiled knowledge and adapting these to the current case instead of constructing a principled solution, is called case-based reasoning.

According to Hedge and Meera (2012:6), students are trained in problem solving by resorting to the practice of solving the end of chapter problems. This generates an approach of solving physics problems by identifying the 'chapter' to which the problem belongs. They maintain that better understanding of the difficulty in solving a physics problem can be obtained by careful examination and analysis of steps taken by a student when presented with a physics problem. A consequence of such a research is that it brings out the nature of student beliefs and the internal representations they hold while the outcome of the research findings can enhance the effectiveness of instruction by identifying and analysing students' learning difficulties. Stewart *et al.* (2007:1) propose that one effect of the incomplete state of student knowledge is that the student's application of knowledge is uncertain. As a result, students sometimes answer correctly on a question, but incorrectly on a closely related question.

Minstrell (1982:11) raises the concern that explanations given for physics phenomena are often unclear to students. For example: students are unsure of the nature of gravity and the conception that heavier objects fall faster than lighter objects is as old as Aristotle. In an attempt to address and correct this misconception teachers use the authority of a statement such as “its Newton’s law” to justify the incorrectness of the Aristotelian view, assuming that the meaning and implications of Newton’s law are obviously clear to all students. Such explanations only add to students’ confusion and do not contribute to develop conceptual understanding. Observations made by Redish *et al.* (1998:215) documented that students’ beliefs in the structure of physics knowledge often worsen as the result of taking physics courses, calls for reformed courses that improve student conceptual understanding.

Halloun and Hestenes (1985b:1057) believe that individual instructors can hardly be blamed for the failure of conventional instruction as they cannot consider common sense misconceptions without knowing what they are and how they can be changed. Ince (2012:161) reports research that claims that 52% of physics teachers are of the opinion that teaching physics through everyday contexts has improved students understanding of physics, but 25% think that contexts do not help students understand. Every experienced instructor has acquired a store of incidental insights into student misconceptions but this by itself leads to incidental improvements of instruction at best, if these insights are not made available to the physics teaching community (Park *et al.*, 2009:14). Halloun and Hestenes (1985b:1060) agree that the full value of such insights can be realized only when they are incorporated into a program of systematic pedagogical research aimed at the development of a practical instructional theory.

2.3.2 Skills required of students

Ogilvie (2009:2) argues that technological society needs individuals entering the workforce to have strong problem solving skills. Solving complex real-world problems requires deep, organized conceptual understanding, relevant procedural knowledge, and metacognitive strategies. Benckert and Pettersson (1997) observed that while solving ordinary, end- of- chapter textbook problems group students’ discussions tended to revolve around what formulas they should use while, in real-world problems there is a motivation for wanting to know about the actual events. According to Osborne (2013:265), assessing what is necessary for solving complex real-world problems depends on a deeper understanding of the nature of the performance and the knowledge base required for the display of higher-order thinking and reasoning. Students should be able to formulate potential solution strategies, implement courses of action, and evaluate the viability of their solution from multiple perspectives (Ogilvie, 2009:3). He emphasizes that educators should help students develop and practice these stronger approaches to more complex problems. Osborne (2013:265) maintains that education

of future scientist should be foundational and promote building knowledge of the basic concepts and language of the discipline. He contends that scientific reasoning is domain specific, dependent on knowledge of the content and concepts of the science; knowledge about standard procedural methods and how such procedures support the claims that scientists advocate. Schuster and Undreiu (2009:266) advocate *principle-based reasoning* (PBR), where problem solutions are obtained by a systematic application of fundamental physics concepts and principles.

Smith and Wittmann (2008:2) propose a methodology for testing student knowledge that moves beyond analysis of student learning defined by correct responses, on questions defined solely by content. Springuel *et al.*'s (2007:2) remark that student responses should be analysed in ways that allow the most common incorrect answers to give as much information as the correct responses. Halloun and Hestenes (1985b:1058) note that errors could reveal a lot about how students think and as far as misconceptions go, errors tend to fall in patterns indicating common misconceptions.

2.4 Learning theories

2.4.1 Information processing theory

According to Heyworth (1999:195), the main approach of research that investigate problem solving stems from the information-processing theory that describes mainly two mental processes involved in problem solving. The first process involves constructing representations of the problem, based on conceptual understanding of the information given in the problem statement. The second process involves retrieving previously acquired information and data and establishing links to guide the procedure of searching for a solution (Heyworth, 1999:196). According to Jonassen (1997:65) information processing theories conceive of learning outcomes as generalizable skills that can be applied to any content domain. He contends that instructional designs for well-structured problems are rooted in information processing theory while Muis and Gierus (2014:411) and Elby (1999:S52) argue that implementing information processing learning and teaching practices contribute to rote learning. Students apply different reasoning methods based on their beliefs about what type of reasoning is appropriate for the situation (Stewart *et al.*, 2007:1). Some students believe that physics learning consists primarily of absorbing information, retaining formulas and problem solving algorithms while others think that learning involves relating fundamental concepts to problem-solving techniques (Elby, 1999:S52). This perception of learning stems from the cognitive information processing learning theory, which describes the process in which information is received, processed and released when needed.

The information-processing model explains learning in terms of the three components of memory, namely the sensory memory, short-term or working memory and long-term memory. New information that comes to a person's attention through the sensory memory activates existing resources and these are processed, combined and transformed in the working memory before the knowledge is stored in the form of networks of connections between knowledge elements in the long term memory (Redish, 2004 as cited in Lemmer, 2013:242). The context in which concepts are presented plays a major role in the retrieval of specific information from the long-term memory (Weiten, 2007 in Lemmer, 2013:242). Various researchers reported evidence that students' knowledge of physics concepts and problem solving abilities are relative to how familiar the problem they are trying to solve is to them (Concannon, 2012:14; Hedge & Meera, 2012:6; Ogilvie, 2009:4).

Beatty and Gerace (2002:751) report a growing consensus among educational researchers that traditional problem-based assessments are not reliable tools for diagnosing students' knowledge. In addition research found students learning to be compartmentalised and that students' have much difficulty in solving problems in different contexts (Hedge & Meera,

2012:1). Students are increasingly confronted with different types of physics problems requiring different problem solving skills and different types of knowledge (Muis & Gierus, 2014:411; Heyworth, 1999:195; Jonassen, 1997:65).

2.4.2 Constructivism

Finkelstein (2001:2) maintains that most current theories of student learning in physics fall into the constructivist camp that focuses on the student as an active agent who constructs an understanding of content. This mode of learning is described as a lifelong, effortful process where a student's previously constructed understanding of the world is built upon during the learning process. When students learn, they arrive with some existing knowledge (about the world) which affects how they learn. The state of students' prior knowledge and the role that it serves has been the subject of some debate (refer to paragraph 2.2.2). Jonassen (1997:65) proposes that well-structured problems are based on information processing theories of learning, while the model for solving ill-structured problems relies on constructivist and situated cognition approaches to learning. According to Lo (2012:191) the 'constructivist' theories of knowing contend that existing knowledge is used to build new knowledge. She disagrees with the notion that students should always be allowed to construct knowledge for themselves and argues that appropriate and timely instruction is sometimes necessary. She maintains that most constructivists support student discovery and learning under the direction and support of an instructor (Lo, 2012:191). Ince's (2012:161) view that students who make meaningful connections between physics knowledge and concepts and everyday experience are able to solve context rich problems is supported by Hillel (2005) who maintains that students need to develop a conceptual understanding of physics. Students who want to become creative scientists will have to take charge of building their own understanding (Redish *et al.*, 1998:212). Experienced students see physics knowledge in terms of basic physics concepts tied together as a coherent web of ideas and think that learning involves relating fundamental concepts to problem-solving techniques (Elby, 1999:S52; Ogilvie, 2009:2).

Bransford (as cited in Jonassen, 1997:66) maintains that information processing theories view learning as a skill that can be generalized and applied to any content domain but Jonassen (1997:66) argued that problem solving is dependent on the domain and context according to constructivism and situated cognition theories. He argues that different skills are involved in solving problems in different contexts and domains, hence problem solving in different contexts and domains calls upon different skills. According to Singh (2007:196) cognitive theory suggests that knowledge is encoded in memory in the context it was acquired and that transfer can be difficult if the contexts of the encoded and intended knowledge do not share the same

features. From this perspective, conceptual change is mutually established by the individual and the context - the central principle of contextual constructivism (Finkelstein, 2001:4).

2.4.3 Theory of instruction: Variation theory

Lo (2012:193) alleges that constructivists made little progress to develop constructivism from a learning theory into an instructional theory. She claims that there is no obvious evidence to show that the learning principles derived from constructivism lead to effective learning and suggest that constructivism remains more of a philosophical framework than a theory that allows precise description of instruction or design strategies. Lo (2012:193) contends that teachers are concerned whether the teaching strategies produced from learning theories are practicable in actual classroom situations. In Lo's (2012:103) opinion all learning theories should be extended to learning and teaching principles if they are to be useful to teachers. Variation theory is a theory of learning and experience that explains how a learner might come to see, understand, or experience a given phenomenon in a certain way, which is a promising approach to improving the teaching of physics (Suhonen *et al.*, 2007:16). The theory can be applied to design variations in teaching that clearly highlight the different aspects of physics concepts.

Variation theory was developed from phenomenography; a research method aimed at uncovering and describing the different ways in which people experience or understand a particular phenomenon (Park *et al.*, 2009:14). Although phenomenography was originally a descriptive and analytical methodological approach, Holmqvist *et al.* (2008:86) contend that phenomenography is currently explanatory rather than descriptive. According to Park *et al.* (2009:14) phenomenography is concerned with identifying variation in understanding, while variation theory is concerned with explaining how such variation occurs.

Variation theory is based upon the assumption that all learning is dependent on variation in the environment (Holmqvist & Mattisson, 2008:31). According to Suhonen *et al.* (2007:15) the foundation of variation theory is based on the concept that people become aware of a phenomenon through the way that it varies in its environment, an opinion shared by Lo (2012:103) who states that "one cannot discern through "sameness". Variations help in identifying a phenomenon but there are also variations in the way that individuals recognise or are aware of a phenomenon. Variation theory maintains that learning consists of becoming aware of the variation in the ways in which that phenomenon or concept can be experienced. Variation theory allows for teachers who know how different students understand certain concepts to develop personal teaching strategies to address students' specific needs (Holmqvist & Mattisson, 2008:32). As students become aware that other students' experience the same phenomena differently than they do, they learn something about that concept they had not known previously (Park *et al.*, 2009:14). It is therefore important to unpack student

conceptions and identify the ways in which their conceptual understanding differs from those of other students.

Lo (2012:194) believes that variation theory links what is to be learned with how it is to be learned. When guiding students to develop abilities such as higher order thinking, communication skills and learning how to learn, consideration must be given to the content or subject matter that can best help to develop such capabilities. Lo (2012:194) points out that the capability to engage in an inquiry process to solve problems can only be built on a deep understanding of the subject knowledge. Holmqvist and Mattisson (2008:32) write that the goal of variation theory is to explain how different experiences can be converted into a common understanding of a learning object. Holmqvist and Mattisson (2008:32) believe that although theory focuses upon the content of what is to be taught rather than on other structures that influence learning they believe that the limits of what a student can learn is determined by the way in which the learning object is presented in the classroom. From Suhonen *et al.*'s (2007:16) perspective, those variations that help present the critical aspects of a phenomenon are effective and not simply those that show how the phenomenon differs from some other phenomenon.

Variation theory has three integral components (Holmqvist & Mattisson, 2008:34; Suhonen *et al.*, 2007:16; Lo, 2012:104; Park *et al.*, 2009:14) which constitute preconditions for learning: discernment, simultaneity and variation. Suhonen *et al.*'s (2007:16) description of discernment is that the aspect under examination must vary while all other aspects remain constant. According to him to learn implies that different aspects or features of the phenomenon are allowed to change position, becoming more or less prominent while the rest of the features retreat into the background making it possible to discern what is to be learned. By Lo's (2012:110) definition a student has learnt something when his perception of that thing changed. He may have acquired a more in-depth or broader understanding.

The second feature of variation theory is simultaneity. Suhonen *et al.* (2007:16) use the term fusion to describe several critical aspects that must be considered together. To learn a specific feature of a concept, it must be experienced together with some other features of the concept that are not important in that particular situation to identify the different features of the concept. This involves recognising that some features are not critical to the identification of that phenomenon (Suhonen *et al.*, 2007:16).

The third feature of variation theory is variation, i.e. opposites and deviations (Holmqvist & Mattisson, 2008:34). Implementing Variation Theory means that if students are supposed to focus on a particular critical feature, they must experience the variation of that critical feature (Lo, 2012:103). A person's understanding of a phenomenon is the result of observing how it

deviates from the normal pattern (Suhonen *et al.*, 2007:16). Suhonen *et al.* (2007:16) remark that the teacher needs to understand what the critical aspects of a concept are and which variations that can be used to make the critical aspects visible to the student. Hedge and Meera (2012:2) motivate that the usage of different representational formats is also a factor that guides student ability in problem solving.

Concannon (2012:14) contends that rather than creating the situated learning, physics teachers should facilitate students' fluent understanding of physics concepts. Lo (2012:214) maintains that mastery of existing knowledge and gaining deep conceptual understanding provides the foundation for students to resolve new problems. In her opinion students need two important capabilities to solve new problems. They have to see that there are multiple ways to solve problems and they must be able to apply the knowledge and capability that they already possesses.

Research by Elby (2001:S54) indicates that some students believe learning consists of just absorbing information and they view physics as pieces of information that are not really connected and should be learned separately. Other students equate physics with a coherent web of ideas to be tied together (Elby, 2001:S54). Students with the latter view understand the importance of deeper understanding; that learning physics involves refining your everyday thinking and that exposure to a variety in instruction and contexts of problem solving may contribute to improved connections between physics principles and their everyday applicability.

2.5 Evaluation of students' knowledge

Changing instruction starts by asking questions like how well do students understand concepts in science and are teachers evaluating what students actually comprehend or merely how well they can recite information (Stiles, 2006:4). Stiles reflects on the value of tests are and what they actually mean. Hestenes, Wells and Swackhamer (1992:141-158) developed the standardised *Force Concept Inventory* (FCI) test that can be used for various purposes, one of which allows for the evaluation of conventional instruction's effectiveness in modifying a student's initial common sense misconceptions. Halloun and Hestenes (1985a:1047) advocate the design and validation of an instrument for assessing mathematical knowledge as well as beliefs about physical phenomena of beginning physics students. They argue that because students' understanding of physical phenomena depended on their conceptual vocabulary based on their basic physical knowledge, low scores on a physics diagnostic test meant that basic concepts of Newtonian mechanics were missing; and alternative misconceptions about mechanics are firmly in place.

Smith and Wittmann (2008:2) contend that it is inappropriate to categorise and group student responses to physics questions solely on the basis of agreeing with correct Newtonian principles. With standardised tests students' responses are evaluated based on their agreement with a physicist's viewpoint without regard for why students might choose incorrect answers. Smith and Wittmann (2008:12) feel it is often an insufficient method for determining how students reason about scenarios in a physics context. Stewart *et al.* (2007:1) suggest ways to compile questions that enable one to determine the effect of context on student responses. They argue that most physics questions can be rewritten in various ways, changing the wording, the physical system, or the distracters to yield a related question that tests the same physical concept. The combination of such related (isomorphic) questions will reveal the effect of context changes. For example Huffman and Heller (cited in Steward *et al.*, 2007:1) found that students are using fragmented pieces of knowledge to understand forces depending on how familiar the student is with the context of the question.

Finkelstein (2001:4) suggests creating environments that support student learning of concepts. He proposed that the environments should have sufficient constraints and opportunities so that students engaging in an activity become acquainted with the concept at-hand. Alignment of context and concept assures that the concept itself becomes meaningful and instrumental for the students while the concept becomes a tool for the task at-hand. It is necessary to connect the symbols and abstractions (e.g. equations or diagrammatic representations) with the concept to allow transfer. Finkelstein (2001:4) feels the environment should support the development of conceptual understanding in a specific situation to enable students to apply this concept to various other situations in a useful manner i.e. the ability to transfer such understanding to relevant new situations.

2.6 Summary

In this chapter a comprehensive overview of existing literature relevant to this study was given. The research study was set in a theoretical framework and the literature focused on the nature, type and effect of students' intuitive knowledge. Students' and physicists' views on knowledge and problem solving were compared and discussed and the relationship between mathematics and physics was highlighted. The effect of contexts on physics knowledge was emphasized during the discussion on learning and instruction and the literature review concluded with a brief report on evaluation of student knowledge.

The next chapter contains extended information on how this research was planned and executed to accomplish the aim of the study namely to determine students' competence to apply conceptual physics knowledge to solve kinematics problems in various contexts. Detailed

descriptions on the various methods of data processing as well as determination of reliability are also included.

Chapter 3

METHOD OF RESEARCH

3.1 Introduction

This chapter describes how this research was planned, executed and the results analysed. The purpose was to accomplish the aim of the study namely to determine students' competence to apply conceptual physics knowledge to solve kinematics problems in various contexts and seek to illuminate possible reasons for inadequate acquisition and application of conceptual knowledge. The term Research Design is explained first (3.2) followed by a description of the chosen approach; the paradigm that guided the choice of methods (3.3), sampling (3.4), data collection (3.6) and analysis (3.7).

3.2 Research Design

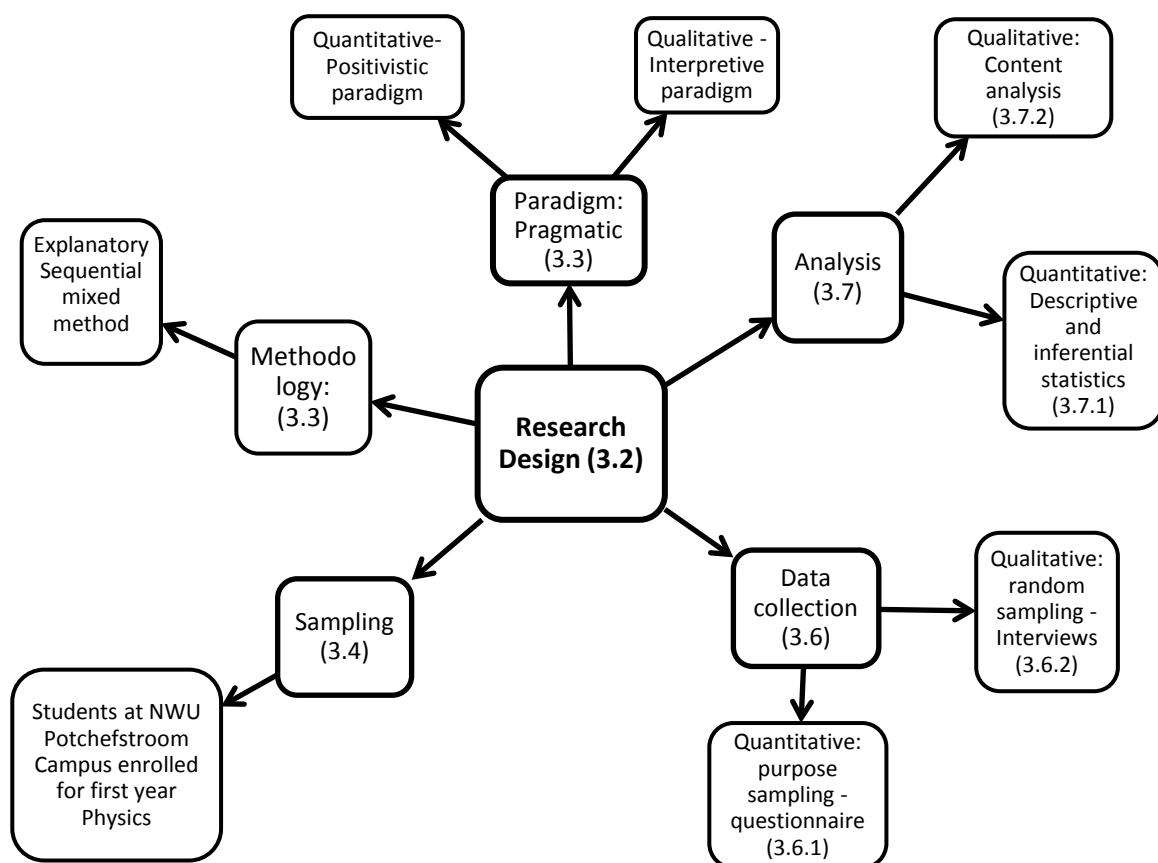


Figure 3-1: Schematic representation of the Research Design

The term *Research Design* refers to the decisions a researcher makes regarding the way the research will be approached. It describes how the researcher plans to proceed to answer the research questions (De Vos *et al.*, 2011:73). Figure 3-1 is a schematic representation of the Research Design. The numbers appearing in the diagram refer to the paragraphs where the specific aspects of the design is addressed in this chapter, e.g. the philosophical foundation of this research, the paradigm, is described and discussed in paragraph 3.3. The research design also guided the selection of the methodology - the approach to the inquiry. The type of design or model provided specific direction for logistical procedures of sampling, data collection and data analysis (De Vos *et al.*, 2011:109; Creswell, 2009:11).

3.3 Research paradigm and method

The research design states the paradigm that guides the approach to the problem and interpretation of the results. This mixed method study was based on the pragmatic paradigm i.e. it was not committed to one system of philosophy or reality but emphasized the research problem and used different approaches to best identify and understand the problem (Creswell, 2009:10). Pragmatism provided the opportunity to use multiple methods, different worldviews and different forms of data collections and analysis (Creswell, 2009:11). Combining quantitative and qualitative methods allow for more complete analysis of the research problem because the methods complement each other (Maree *et al.*, 2007:263).

This project not only attempted to determine possible relationships between physics concepts and different contexts but also tried to find explanations for observed discrepancies; therefore a mixed methods design was chosen. The chosen methodology was an explanatory, sequential, mixed methods design, because the study consisted of both quantitative and qualitative parts that were conducted consecutively. Figure 3-2 (Maree *et al.*, 2007:266) is a schematic representation of this design.

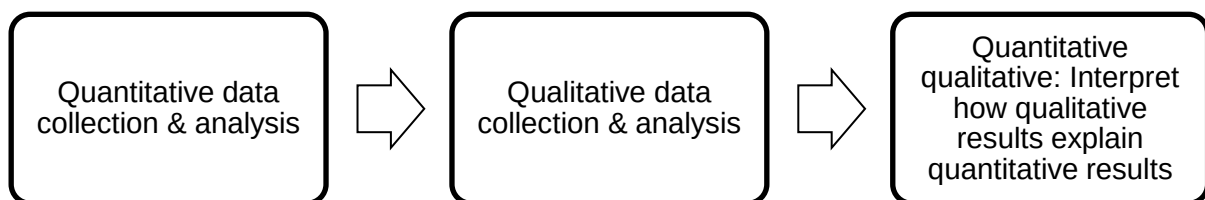


Figure 3-2: Schematic representation of Explanatory Sequential Mixed Method Design

The sequential explanatory design was especially useful since unexpected results were acquired in the first phase (quantitative part) which was clarified during the second (qualitative)

phase (Hedge & Meera, 2012:3). Hedge and Meera (2012:2) documented that the recent trend in physics education research was to use the data drawn from the statistical analysis (first phase) and to choose a few items for student clinical interviews. Analysis of the interviews revealed the microstructure of the students' responses. The nature of the sequential explanatory design is straightforward and the stages of the research are clear and separated (Creswell, 2009:221; Maree *et al.*, 2007:266). According to Creswell (2009:211), the time involved in collecting data in two separate stages is its main weakness. The data for the first stage were collected in a short time over two consecutive days, but the second stage was executed three months later due to the statistical analysis of the data of the first stage that had to be completed to identify what information had to be acquired during the interviews. The students were also not available for interviews earlier due to exams and the holidays that followed. However, lectures in the topic of mechanics had been finished before the questionnaire was completed and none of the students participating in the interview had received formal tuition in mechanics between completion of the questionnaire and participation in the interviews.

The first phase of the study, the quantitative part, was done from a positivistic paradigm, a view of knowledge as being real, objective and represented by use of quantitative methods (De Vos *et al.*, 2011:51). The data were acquired by means of a questionnaire compiled according to the objectives of the study (paragraph 1.4), to reveal trends regarding the respondents' conceptual knowledge and application of such knowledge. Items investigating students' conceptual knowledge versus conceptual understanding were included. The extent to which students were able to apply conceptual knowledge in everyday contexts was investigated therefore items containing options based on commonly held beliefs were carefully compiled to reveal the existence of common misconceptions. The researcher wanted to determine whether such misconceptions existed among the students and the extent of its' influence on the students' ability in solving kinematic problems in various contexts.

Analysis of the qualitative data collected from interviews with participants was based on an interpretative philosophy; a methodology required to reach an interpretative understanding and to appreciate the subjective explanation provided by the participants (De Vos *et al.*, 2011:309). The second phase consisted of semi-structured interviews of participants in an attempt to clarify results obtained from the first phase. The interpretative approach was aimed at identifying and understanding the deficiencies in students' conceptual understanding of the physics principles involved in free falling motion. The qualitative part of the study required that respondents would explain some of their answers in the questionnaire. This method of data collection is in line with the trend in physics education research as pointed out by Hedge and Meera (2012:2). The reasons some of the students offered explained the nature of problems that manifested in

completion of the questionnaire. During the interviews, students' ability to translate verbal forms of physical concepts into schematic (diagrams) or mathematical (equations) representations and the effectiveness of the translation was examined, as is suggested by Hedge and Meera (2012:6). While analysing the students' explanations, the researcher tried to determine why the students had those misconceptions that were revealed in the quantitative part of the study, and identified possible reasons why the concepts were difficult to integrate. Students' ability to use symbolic representations of physics principles to help them apply their physics conceptual knowledge was also investigated. Using symbolic representations can help students to adjust their intuitive thinking framework in order to solve problems in contexts that differed from contexts they were familiar with (Bing & Redish, 2009:1). This aimed to add to the existing body of knowledge and understanding by providing an indication as to what basic conceptual understanding is essential for effective application of physics concepts in contextual mechanics problems and how the relationships between physics quantities i.e. equations, can be applied as thinking tools to help their knowledge transfer.

3.4 Sampling

The convenience sample consisted of 481 students enrolled for first-year physics at the North-West University at the Potchefstroom Campus in 2014 during a practical/tutorial session. The questionnaire was completed after the topic of mechanics was concluded. The demographic information of the research population is given in Table 3-1 and Table 3-2. As indicated in Table 3-1, 76% of the students enrolled for the first year course in physics at the university, the year following completion of grade 12 while 17% of the students had a gap of one year between completing grade 12 and commencing their study of first year physics. For only 6.87% of the students the interval between completing grade 12 and starting the first year physics course was more than one year.

Table 3-1: Student distribution according to the year grade 12 was completed

Year in which gr 12 was completed	Number of students	Percentage of students %
2013	365	76.04
2012	82	17.08
2011	17	3.54
2010	2	0.42
2009	5	1.04
2008	4	0.83
before 2008	5	1.04

The distribution of students according to the physics module, physics course and their gender is given in Table 3-2. Of the 481 students who participated in the research 226 were enrolled for the calculus based physics module of which 160 were natural science (BSc) and 64 were engineering (BIng) students. The number of female students in the calculus-based course was 36, much less than the number in the non-calculus based course, 146. The majority of the students were males.

Table 3-2: Student distribution according to physics module, course and gender

Physics module	Total number of students	BIng	BSc	Female students	Male students
FSKS 111 calculus based	226	64	160	36	190
FSKS 113 non-calculus based	255	1	254	146	105
Total number:	481	65	414	182	295

Participants for the interviews in the second phase were randomly selected students from both modules who indicated that they would be willing to participate in an interview. Four students were interviewed individually and the interviews were videotaped, transcribed and analysed for patterns and trends in the data.

3.5 Research procedure of empirical study

Figure 3-3 is a schematic representation of the procedure that was followed to obtain and analyse the data in the empirical study.

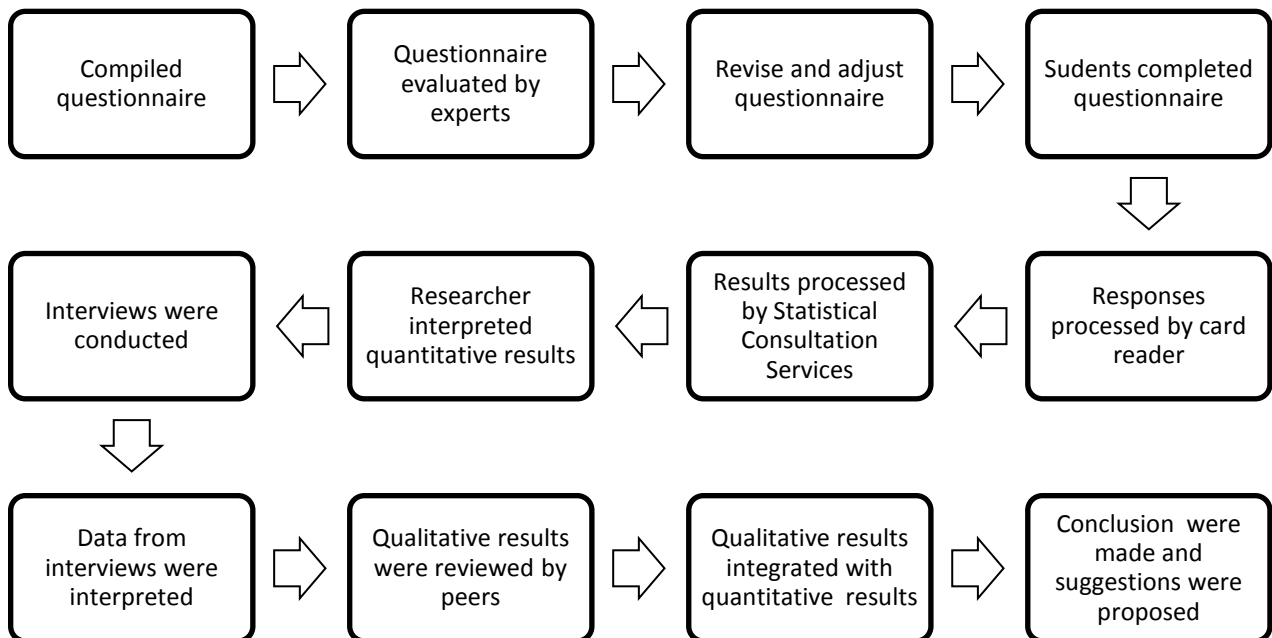


Figure 3-3: Schematic representation of the research procedure

The questionnaire used in the first (quantitative) phase of the empirical study was critically evaluated by three research experts in the field of teaching mechanics. Some diagrams and sentences were modified according to the advice of the critics.

The questionnaire was completed by students enrolled for first year physics by using response cards. Students indicated the options they chose for each question by colouring the number representing that option on the response cards. The results were processed by means of an electronic card reader and the results converted into the Excel format of the Microsoft Office 2010 program for Windows.

The quantitative results were summarized and analysed by the Statistical Consultation Service of the North-West University, Potchefstroom Campus, after which the descriptive statistics were interpreted to reveal trends and indicate what inferential statistics had to be used. The results of the first phase served to indicate which information had to be obtained from the interviews (second phase).

During the interviews the participants provided explanations and reasons for their choice of options in the questionnaire. These explanations and reasons were interpreted to clarify the trends observed in the first phase of the research. The qualitative results were analysed and integrated with the quantitative results.

3.6 Data collection

3.6.1 Data collection for the quantitative part of the research

McMillan and Schumacher (cited by Maree *et al.*, 2007:155) define survey research as using questionnaires or interviews to assess the current status, opinions, beliefs or attitudes of a known population. Quantitative research methodology is often used in natural science research as the results can be represented by numbers and values. It is valuable to support results with mathematics calculations and statistics, because the analysis indicates the validity and reliability of relationships between the concepts under investigation. The data for the quantitative part of the research was acquired by means of a multiple-choice questionnaire (refer to Appendix A, paragraph 6.1). A multiple-choice questionnaire (MCQ) is a highly structured device that allows us to collect quantifiable data in order to attach numbers or values to the results (Maree *et al.*, 2007:184 ; De Vos *et al.*, 2011:249) and statistical calculations provided us with ways to determine the practical significance of relationships and perhaps predict probable correlations not previously foreseen. MCQ is widely used in physics education research (Gunstone & White, 2012:4; Hedge & Meera, 2012:3). A short list of well-known studies that used MCQ include: McDermott *et al.* (1987:504), Hestenes, Wells and Swackhamer (1992:141-158) (FCI), Hestenes and Wells, (1992:159) (MBT), Alonzo and Steedle (2009:408), Lemmer (2013:247), Hedge and Meera (2012:4), Gönen (2008:73), Palmer (1997:681-696) and Elby (2001:S62).

The large number of participants in this study encouraged the use of a multiple-choice questionnaire that could be processed by using an electronic card-reader. Steinberg *et al.* (1996:25) agreed that MCQ can be completed by large numbers of students but warned that the results should be interpreted carefully especially where complex situations are concerned. However, Alonzo and Steedle (2009:390) presented evidence that MCQ appear to be more valid indicators of students' conceptions than open-ended questions and provided more precise diagnoses of students' learning progression. In the quantitative part of the study the extent to which students were able to apply conceptual knowledge in formal and everyday contexts was investigated. The multiple-choice questionnaire (in this study) contained formal conceptual items, items set in everyday context and some conceptual items with numerical values. These items allowed comparison of students' conceptual knowledge versus conceptual understanding and investigated students' ability to apply physics conceptual knowledge in various contexts.

3.6.1.1 Design of questionnaire

The questionnaire consisted of multiple-choice items with four options for each item. The options provided were carefully chosen to include distracters that would reveal misconceptions students may have in order to determine the extent of its influence on their competence in solving mechanics problems. For some items the same option was given twice but with different reasons why the option would be considered correct. Stewart *et al.* (2007:2) argued that most physics questions could be rewritten in various ways, changing the wording, the physical system, or the distracters to yield a related question that tests the same physical concept. In each isomorphic question the movement of two objects had to be compared when one or more of the physical quantities were changed and the effect of the change had to be predicted. The problems are called isomorphic because students had to apply the same physics principle to solve the problems. The use of these isomorphic problems allowed comparison of students' responses to items with different contexts (Singh 2007:197). Students' responses served as guidelines to determine which setting (context) would be the more reliable indication of their conceptual understanding of the relationships of force, mass, acceleration, velocity and time. The effect of context changes arises from the combination of such related (isomorphic) questions (Stewart *et al.*, 2007:2). It was expected that students who attained and understood the conceptual knowledge would use physics thinking frameworks in unfamiliar contexts. In accordance to Elby and Hammer (2010:432) and Halloun and Hestenes (1985a:1043) who advocate the use of problems to distinguishing conceptual knowledge from conceptual understanding isomorphic problems in different directions/planes were administered.

The questions were carefully selected and compiled to determine:

- the extent to which everyday context influenced student reasoning;
- the influence of the direction of movement on students' responses;
- possible misconceptions students might have;
- the extent to which students adapted to a physics thinking framework and the use of non - numeric equations to do so; and
- Which, if any, of the questions could serve as reliable indicators of student conceptual understanding?

The majority of questions did not require numerical calculations in order to determine whether students were able to apply equations without values, i.e. using symbols, to aid their reasoning. The questionnaire contained formal conceptual questions, questions set in everyday context

and some contextual questions with numerical values. To investigate the effect of direction of motion on students' responses paired items set in vertical upward and vertical downward direction as well as paired items set in vertical and horizontal direction were included. To compare the results and acknowledge the fact that the type of problem is decisive in determining the nature of difficulty, items that validate specific collective components were compiled or selected. The items were grouped as Group A, B and C according to the underlying variables, described in paragraphs 3.6.1.1.1. - 3.6.1.1.3. The questions of the various groups were distributed over the questionnaire to avoid leading students in the application of the specific principle.

The questionnaire was mostly self-compiled with the following exceptions:

- Item 6 was adapted from question 1 of the Force Concept Inventory; FCI- by Hestenes, Wells and Swackhammer (1992).
- Items 11, 13 and 17 were adapted from questions 2 and 24 of The Energy and Momentum Concepts Survey (EMCS) by Rosengrant and Singh (2003).
- Item 16 was adapted from question 10 of The Mechanics Baseline Test (MBT) by Hestenes and Wells (1992).

3.6.1.1.1 Group A items

Items 6, 7, 16, 17, 20 and 22 in the questionnaire were grouped as group A. The physics principle in all these items was: objects in *free fall* have equal acceleration, i.e. gravity exerts a force on any object with such magnitude that it results in all objects having equal acceleration. Free fall meant that the force of gravity was the only force acting on the object, thus the effect of friction or air resistance were regarded as negligible. With no opposing force acting on the objects their motion was not influenced by their mass, hence when released from or projected to the same height, the time needed to cover the distance would be the same and they would travel at the same speed at any given time. The researcher expected that students who attained and understood this conceptual knowledge would use physics thinking frameworks in contexts that might otherwise have triggered their intuitive knowledge (heavier objects fall faster – refer to paragraph 2.2.3). In each item two balls with unequal mass covered the same distance. Either the initial or the final speed was given or could be deduced. In none of the items diagrams were given to assist the students, i.e. all the items were verbal representations of the settings.

In items 6 and 17 the students had to compare the travelling time of two falling objects, in items 7, 16 and 20 either the initial or the final speed had to be compared, and in item 22 the height

that the objects reached had to be compared. To investigate the effect of direction of motion on students' responses, two items, 20 and 22, were set in vertical upward and the other four in vertical downward direction. Items 6 and 20 were identical except that the balls were projected upward to reach a certain height in item 20 whereas in item 6 they were dropped from the same height.

Three of the items, 6, 7 and 20, were presented in a formal physics setting while the others were set in everyday context (referred to as contextual items). In two of the contextual items numerical values were given which the students could use to help them solve the problem. Item 6 was used as a question to which the other items were compared.

3.6.1.1.2 Group B items

Items 8,9,11 and 12 in the questionnaire were grouped as group B. Group B consisted of two sets of items in formal conceptual context, all supported with diagrams. In the first set (items 8 and 9), the balls moved vertically downwards and in the second set (items 11 and 12) the blocks were moved along a horizontal plane. In items 8 and 11 the students had to determine which of the two objects would cover a certain distance first and in items 9 and 12 the objects' final velocity had to be compared. In both sets of items the two objects of unequal mass were moved simultaneously from rest with equal constant acceleration but over different distances. Both sets were represented verbally as well as pictorial as labelled diagrams representing the settings were given. The settings of items 8 and 9 are often found in school textbooks and the sets of items of group B were included to determine whether students' comprehension of the relationship between mechanics concepts was influenced by the plane in which the objects moved. Students often ascribe free falling objects' motion to a common misconception - the "fact that the gravitational force on all objects are the same," without considering the force/mass ratio, because they do not understand the physics principle involved in free fall namely that all objects in free fall experience equal gravitational acceleration (Kavanaugh & Sneider, 2007:23). The researcher wanted to determine if a similar misunderstanding regarding the force and acceleration relationship applied to movement in a horizontal plane. The movement of objects of unequal mass along vertical and horizontal planes differ in the respect that no equal acceleration is implied in horizontal movement when friction and air resistance are ignored.

3.6.1.1.3 Group C items

Group C consisted of items 10, 11, 13, 18 and 24. In items 10, 18 and 24 the masses of the objects were equal where in items 11 and 13 the objects had different masses. In items 10, 18 and 24 the settings were identical; two objects fell from rest from different heights in the absence of air resistance with the lowest object only started moving when the other object

passed it on its way down. Because air resistance was ignored all the objects experienced equal gravitational acceleration. In item 13, two objects at unequal distances from a wall, moved from rest along the frictionless horizontal plane. The nearest object only started moving when the other object passed it on its way and students had to deduce that they would have the same acceleration. The underlying principle in all the items was that the objects had the same acceleration but different initial speeds for the distance they travelled together. Students had to determine which object would reach the ground first.

Item 10 was a formal conceptual item, while items 18 and 24 were set in everyday contexts with item 24 containing numerical values. Settings similar to item 24 are often found in exam questions and exercise books for grade 12 learners. Item 11 and 13 were both set in a horizontal plane. In both cases friction had to be ignored so the applied force was the only force acting on the objects i.e. equal to the net force. In item 11 the acceleration was given as identical where in item 13 the students had to deduce that the accelerations would be the same. One object's motion was initiated before the other one and the time taken to cover the same final distance had to be compared. In items 10, 13 and 18 the option of one object reaching the ground/wall first were given twice but with different explanations why that would be the case. All items were supported with labelled diagrams.

The rationale for including this group was to investigate the effect of multivariate physics quantities on students' application of physics concepts. The number of physical variables that had to be taken into consideration in items 11 and 13 seemed more than those in group A. With the distance and the masses being different it looked as if in item 11 four variables and in item 13 five variables had to be considered. As their accelerations were equal however, the object's initial velocity for the distance they travelled together was the only variable that was decisive to which object would reach the wall first. In items 10, 13, 18 and 24 the objects' masses were kept the same to eliminate the effect of the misconception that heavier objects fall faster. With this compilation we attempted to illuminate students' perception of the relationships between acceleration, velocity, time and distance.

3.6.2 Data collection from interviews

The research tool for the qualitative part of the research was a semi-structured interview schedule. Qualitative research surveys are mostly done by means of open-ended questionnaires and/or the use of scaled instruments (Steinberg *et al.*, 1996:24). By Steinberg *et al.*'s (1996:25) account examining questions can be developed from the information acquired in the interviews. Instead of following the "protocol analysis" where the researcher restricts interference to a minimum (Maloney, 2011:9) we opted for "verbal analysis" where the researcher probed the students for self-explanations.

The semi-structured interview approach was aimed at determining reasons for students' choice of options and identifying elementary principles that lacked in students' thinking framework that prevented development of conceptual understanding and application of physics concepts. The researcher wanted to determine whether the think-aloud protocol (as promoted by Hutchinson & Elby, 2013:195), resulted in qualitative reasoning as was discussed in chapter 2, paragraph 2.2.7. Participants were asked to explain why they chose a specific option on some of the items in the questionnaire. If the explanation was incorrect or if they struggled to choose an option, they were encouraged to identify the variables that were applicable and later also to use equations that described the problem to aid their reasoning. The interviewer probed the participants regarding concepts that needed explanation or elaboration to clarify the applicable principles in the respective item. Students' responses were recorded and a summary of responses that contained all the different explanations were made. The responses were videotaped, coded and analysed.

3.7 Data analysis

According to Maree *et al.* (2007:155) survey data is used to describe and explain the existence of phenomena and to draw comparisons. A number of statistical methods, commonly known as descriptive statistics, are used to organise and summarise data in a meaningful and simple way (Maree *et al.*, 2007:183). In the quantitative phase inferential statistics were used to compare results of isomorphic items and determine the significance of the comparisons. Figure 3-4 represents the procedure followed to analyse the quantitative data.

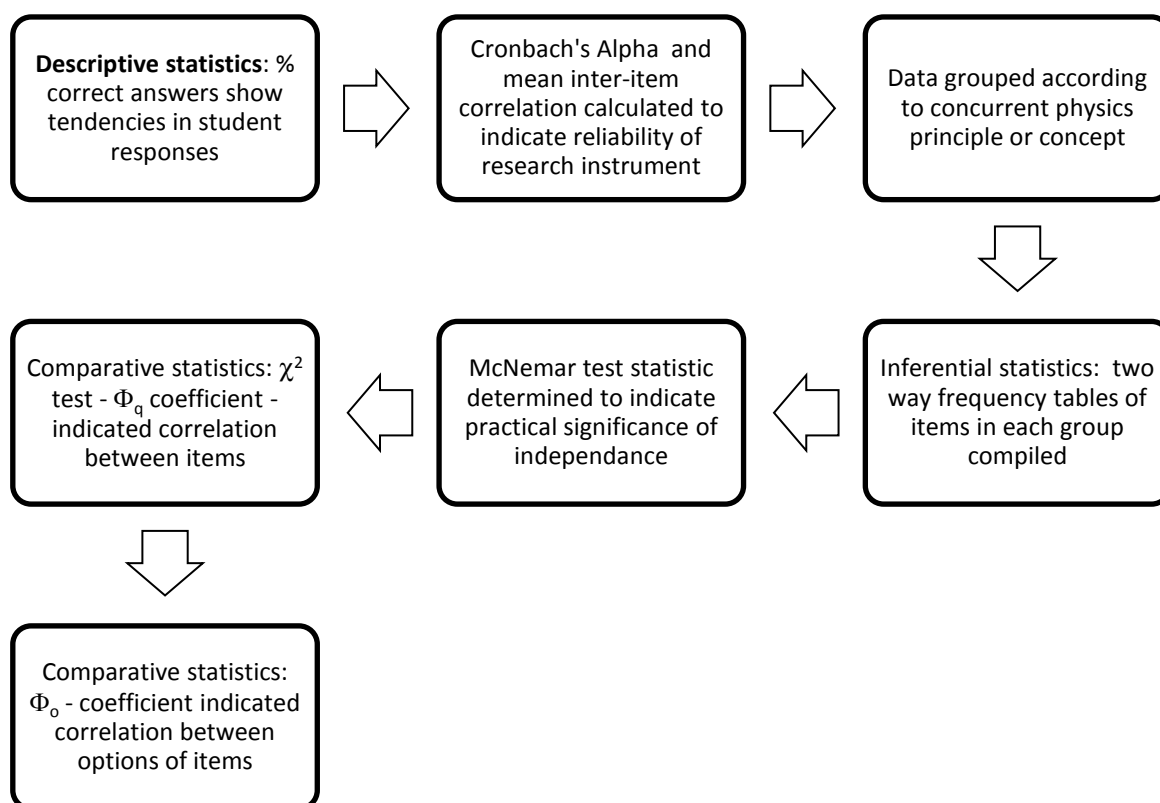


Figure 3-4: Procedure followed in analysis of data from the first phase

3.7.1 Descriptive statistics: Quantitative data

The options of the items on the questionnaire were numbered and the students had to indicate their choice of option by colouring the circle representing the corresponding number of the option on a data card. The quantitative data were analysed by Statistical Consultation Services at the North-West University, Potchefstroom campus and frequency tables were compiled in which the demographic data (in Table 3-1 and Table 3-2) as well as the responses on each item (attached as Table 7-5 in Appendix B) were presented. The data were then grouped according to the underlying principles and variables in the items, as described in the compilation of the questionnaire in section 3.6.1.1. The tables were analysed and obvious discrepancies were identified.

3.7.2 Inferential statistics data analysis of paired items

Where descriptive statistics merely describes the group they belong to, inferential statistics are used to draw conclusions about a larger group of people. The inferential statistics for the questionnaire were obtained by using SPSS Statistics Version 22, Release 22.0.0. The Cronbach's Alpha and the mean inter-item correlations were determined to indicate the

reliability and validity of the questionnaire, (attached as Table 7-1 paragraph 7.1.1 in Appendix B) as well as for the groups (Table 7-2, Table 7-3 and Table 7-4 in Appendix B). The motivation for using both Cronbach's Alpha and the mean inter-item correlation in this study is described in paragraph 3.8.

Cronbach's Alpha is a measure of internal consistency of a test or scale, expressed as a number between 0 and 1. Cronbach's Alpha is not a statistical test but rather a coefficient of reliability (or consistency). For average inter-item correlation Clark and Watson (1995:316) recommend the range of 0.15 to 0.50 as a guideline.

The discrepancies observed in the frequency tables required the compilation of two-way frequency tables of the grouped items. Because of the stochastic (a mathematical and scientific concept of uncertainty) component embedded in the raw data, statistical analysis was required to determine whether the differences in the frequencies had any practical significance. Practical significance of the difference between data was established by determining the effect size. The practical significance of the correlations between data was indicated by means of correlation coefficients. These statistically calculated ratios indicated how meaningful the relationships were and whether the effect was large enough to be important in practice (Ellis & Steyn, 2003:51-53). The McNemar test statistic was used in order to determine the effect size of the differences among the responses to the items observed in the frequency tables. The McNemar test considered sample size and other sample information like standard deviation to determine the practical significance of the difference in frequencies.

The McNemar test is applied to 2×2 contingency tables. A 2×2 contingency table is a two dimensional table containing frequencies by category that compared the outcomes of two items on the sample of n subjects, as follows:

Table 3-3: Example of a 2×2 contingency table

	Item 2 incorrect	Item 2 correct	Row total
Item 1 incorrect	a	b	a + b
Item 1 correct	c	d	c + d
Column total	a + c	b + d	n

The test statistic for the McNemar test was determined by applying the formula: $\chi^2 = \frac{(b-c)^2}{b+c}$

The test has an asymptotic “chi-square χ^2 ” distribution which means that there are critical values with which the test statistic can be compared to indicate the practical significance of the difference in the frequencies. The effect size ω was calculated using the test statistic by means of the formula: $w = \sqrt{\frac{s}{n}}$ where $s = \chi^2$; the test statistic from the McNemar test and n was the sample size. Cohen (as cited by Ellis & Steyn, 2003:52) provided guidelines for the interpretation of effect sizes: An effect size (ω) with a value of $\omega \leq 0.3$ is considered a small effect, $0.3 \leq \omega \leq 0.5$ of medium and $\omega \geq 0.5$ as a large effect. Any relationship larger than 0.5, is practically significant. The bigger the value of the effect size, the higher the certainty that

- i) the value would not be included in the distribution descriptive of the test and
- ii) the difference in the frequencies was meaningful.

Values between 0.0 and 0.5 mean that the number falls within the range that would be included in the usual distribution described by the test and values larger than 0.5 implies that there is 95% certainty that those values indicate results that are not expected and it may be worthwhile to investigate the discrepancy.

After analysis of the results of the McNemar test statistics regarding the differences between the paired items, a chi-square test was executed to test for independence between the paired items. The test is used to determine whether there is a significant association between two categorical variables from a single population i.e. if one knew the level of item 1 one could predict the level of item 2. The correlation coefficient ranges from -1 to $+1$, where ± 1 indicates perfect agreement or disagreement, and 0 indicates no linear relationship. Contingency tables as described in Table 3-3 are used to determine values for the phi coefficient (Φ). With coding similar to that in Table 3-3 the phi coefficient between the items is determined by the formula:

$$\Phi = \frac{(bc - ad)}{\sqrt{(a+b)(c+d)(a+c)(b+d)}}$$

The phi-coefficient (Φ_p) for each pair of item indicates the degree of correlation between the contexts in which the items were set. The correlation between options in the respective items that might indicate some misconceptions were compared by means of 2×2 contingency tables as well. The correlation between the options was calculated and is indicated by Φ_o .

3.7.3 Analysis of qualitative data

Analysis of the qualitative data acquired during interviews was based on an interpretative philosophy; a methodology required to reach an interpretative understanding and to appreciate the subjective explanation provided by the participants (De Vos *et al.*, 2011:309). Analysis of

the reasons given by the participants explained the nature of problems that manifested. During the analysis of the reasons the researcher tried to interpret and determine which concepts proved to be most difficult to apply, and to determine why the same physics principles were not applied regardless of the context. The interpretative approach was aimed at identifying and understanding any deficits in students' conceptual knowledge and application thereof in the different contexts. This was aimed to add to the existing body of knowledge and understanding by providing a basis for choosing teaching strategies regarding the effect that different contexts have on the knowledge that students use when solving mechanics problems.

3.8 Reliability and validity

The extent to which a concept is well founded and corresponds to the real world is described as its validity. The content validity of the research was ensured by having the questionnaire checked by experts currently teaching in the field of Physics. The questionnaire was completed under supervision and the researcher was present when the questionnaire was completed. The results of this study cannot be generalised because the research group may not be representative of the general population of first year physics students. Validity and reliability of the qualitative research was ensured by peer evaluation where another researcher evaluated the inferences based on the responses on the items used in the interviews.

The reliability of an instrument is closely associated with its validity. An instrument cannot be valid unless it is reliable although the reliability of a test does not depend on its validity. A test can be reliable and not valid at the same time (Tavakol & Dennick, 2011:53).

Cronbach's Alpha is the most widely used measure of reliability in statistical analysis (Tavakol & Dennick, 2011:53). Reliability is concerned with the ability of an instrument to measure consistently. Tavakol and Dennick (2011:54) stated that Cronbach's Alpha is an important concept in the evaluation of questionnaires and that internal consistency should be determined to ensure validity. They further described internal consistency as the extent to which all the items in a test measure the same concept or construct. It is therefore connected to the inter-relatedness of the items within the test. It can be viewed as a measure of how well the sum score on the selected items reflects the expected score in the entire test and is expressed as a number between 0 and 1. According to Nunnally (1978:245) one saves time and energy by working with instruments that have modest reliability, for which purpose reliabilities of 0.70 or higher will suffice. While Tavakol and Dennick (2011:54) maintained that values between 0.7 and 0.95 are regarded as acceptable values, they warned that values higher than 0.9 may indicate that some items may be testing the same concept but in a different guise and could therefore be redundant.

According to Clark and Watson (1995:309), a measure of internal consistency is a more useful index to indicate reliability and coherence than the Alpha coefficient. *Internal consistency* refers to the overall degree to which the items are inter-correlated. Clark and Watson (1995:309) suggest all inter-item correlations should be moderate in magnitude. As a more specific guideline, they recommend that the average inter-item correlation fall in the range of 0.15 - 0.50 (Clark and Watson, 1995:316)

3.9 Ethical issues

The researcher adhered to ethical requirements. Application for ethical clearance was made and the ethical clearance number received is NWU-00053 – 14 - A3. Documentation confirming ethical clearance is included as Appendix C, paragraph 8.2. No personal or embarrassing questions were asked and all participants were older than 18. The purpose and aim of the questionnaire explained in the consent form were read out to the participants. Participants completed the questionnaire voluntarily and understood that as they were not being assessed the result of the questionnaire would not affect them in any way. Each participant was requested to sign a consent form, see Appendix C paragraph 8.1. Students also had to indicate whether they were willing to participate in interviews.

The interviews were videotaped and to combine the students' vocal responses to their written explanations, the camera was focused on the table where the writing was done. The students participating in the interviews were not identified by name, or photograph.

3.10 Summary

In this chapter the motivation for the choice of the research design and methodology was explained and procedure for the execution of the empirical study was described.

In the following chapter the results of the study are presented and discussed. The results of the two parts of the study are integrated and discussed simultaneously.

Chapter 4

RESULTS AND DISCUSSION OF RESEARCH RESULTS

4.1 Introduction

In this chapter the results from the empirical study are presented and discussed. The aim of the study was to investigate the extent to which students applied their physics knowledge in various contexts and to determine from the results whether the direction of movement was regarded as a separate context where the physics principles were applied differently.

The reliability of the questionnaire and the different groups is presented and interpreted first (paragraph 4.2). The results of the quantitative part of the study are presented next followed by the qualitative results from the interviews (paragraphs 4.3-4.4). When reporting the quantitative results the information gathered during the interviews was incorporated to interpret and argue the inferences made from the results. The trends observed in the empirical study are discussed in paragraph 4.5 and in the summary (paragraph 4.6) possible implications for teaching are suggested. Since the interview questions specifically addressed students' reasoning on items of the questionnaire, the qualitative results are discussed together with the quantitative results.

4.2 Reliability

The need and use of obtaining a value for Cronbach's Alpha is discussed in paragraph 3.8. For the questionnaire (Appendix A) consisting of 14 items Cronbach's Alpha was calculated as 0.726 (Table 7-1). The mean inter-item correlation was 0.16 which according to Clark and Watson (1995:316) indicated sufficient correlation between the items. The correlation between the items also indicated that the items were well chosen and the questionnaire well-constructed. The results showed that the items in the questionnaire were internally consistent and reliable and that similar results should be obtained if the questionnaire was repeated.

4.3 Qualitative results of interviews

The results of the quantitative study illuminated some discrepancies in the students' responses to a number of items in the questionnaire, which were further investigated during the interviews with the randomly selected students. The explanations for some of the discrepancies were very interesting but other disturbing deficits were also discovered. It was interesting that the common misconception that heavier objects fall faster also existed among the students in the research group. However, this was not unexpected, as various researchers reported the remarkable persistence of such misconception (Halloun & Hestenes, 1985b:1056). The extent

to which this misconception influenced students' application of physics principles regarding the relationships between force and acceleration and the effect of these two concepts on the objects' motion raised reason for concern. This research presented evidence that students regard formal physics principles to be unrelated to everyday reality and showed that students are of the opinion that testing their ability to apply physics principles in everyday contexts does not test their physics knowledge, confirming the gulf between the two contexts (Sanborn *et al.*, 2013:411).

Inconsistencies in students' responses revealed their lack of conceptual understanding (Stewart *et al.*, 2007:2). Although the majority of the students stated the physics principles applicable in the formal context correctly, they became confused about the relationship between the concepts of force and acceleration when they were asked to reflect on the forces acting on or the acceleration of the objects. Various terms for concepts were used inappropriately (Minstrell, 1982:11) and it seemed that students' knowledge of physics concepts were superficial and typically based on textbook content without comprehension or insight. The majority of the students were unable to use a relevant physics relation to assist their reasoning.

4.4 Quantitative results of questionnaire

The frequency table containing the percentages of the students' responses to the questionnaire items is presented as Table 7-5 in Appendix B. The percentages of students' responses of the items that were grouped together were summarized per group and presented in Table 4-1, Table 4-3 and Table 4-5.

4.4.1 Results of items in group A

For the items in group A, the Cronbach's Alpha of 0.687 and the mean inter-item correlation of 0.27 (refer to Table 7-2) indicated high internal consistency. By Clark and Watson's (1995:316) account this indicated that the items as a group were closely related and reliable. The frequency of students' responses to the items in group A is presented in Table 4-1. In every combination of paired isomorphic items the context, direction and the variable that had to be compared were indicated by using the abbreviations given below. The results of the students' responses on the items are discussed in terms of the percentage of the students who answered the items correctly as well as in terms of the test statistics obtained from the difference or correlation between the paired items. The combination of items in group A was numbered and the heading of the combination consisting of the number, as well as the context of each item-pair, is followed by results of the paired items. For differentiating between the contexts; F = formal conceptual; C = contextual; N = numeric were used. The direction of motion was

indicated by: $\uparrow$ = upward or $\downarrow$ = downward. The physics quantity that had to be compared was indicated by; t = time; v = velocity; d = distance.

Table 4-1: Frequency table of students' responses to items in group A

	Frequency of answers to items: %					
Item	Item 6	Item 7	Item 16	Item 17	Item 20	Item 22
Context	F $\downarrow$ t	F $\downarrow$ v	C $\downarrow$ v	C N $\downarrow$ t	F $\uparrow$ v	F N $\uparrow$ d
% correct	83.99	69.02	29.11	63.62	34.93	43.87
Heavy object moves faster	14.76	24.53	48.44	34.59	51.98	32.56

The physics principle in all these items was: objects in *free fall* have equal acceleration regardless of their mass; $a = \frac{F_w}{m} = \frac{mg}{m} = g$; i.e. gravity exerts a force on any object with such magnitude that it results in all objects having equal acceleration (refer to paragraph 3.6.1.1.1). In each item the movement of two balls of unequal mass had to be compared. Free fall meant that the force of gravity was the only force acting on the object, thus no friction or air resistance. As is described in chapter 3 (paragraph 3.6.1.1.1), with no opposing force acting on the objects their motion was not influenced by their mass. When the objects were released from or projected to the same height, the time needed to cover the distance would be the same and they would travel at the same speed at any given time. In each item in group A, two balls with unequal mass covered the same distance in free fall. Either the initial or the final speed was given or could be deduced. All the items were verbal representations of the settings i.e. in none of the items diagrams were given to assist the students' reasoning.

In items 6 and 17 the students had to compare the travelling time of two falling objects, in items 7, 16 and 20 either the initial or the final speed had to be compared, and in item 22 the height that the objects reached had to be compared. To investigate the effect of direction of motion on students' responses, two items, 20 and 22, were set in vertical upward and four, items 6, 7, 16 and 17 in vertical downward direction. Items 7 and 20 were identical except that the balls were projected upward to reach a certain height in item 20 whereas in item 7 they were dropped from the same height.

Three of the items, 6, 7 20 and 22, were presented in a formal physics setting while the others were set in everyday context (referred to as contextual questions). In two of the contextual items numerical values were given which the students could use to help them solve the problem.

4.4.1.1 Descriptive statistics results of group A

From the high percentage of correct answers for item 6 (83.99%), one would assume that students knew the principle of objects in free fall having the same acceleration and hitting the ground at the same time. The setup for items 6 and 7 were the same, both were formal conceptual items in the vertical downward direction. The only difference between the two items was the physical quantity (time, speed or distance) that had to be compared. Although the correct percentage for item 7 was still high, (69.02%) it was ~15% lower than that of item 6. The low percentage of correct answers for item 16 (29.11%) was most surprising, meaning that more than 70% of the students answered item 16 incorrectly. Although items 16 and 17 were both set as contextual items the percentage correct answers for item 17 was more than 30% higher than that of item 16. Items 20 and 22 were formal conceptual items in an upward direction but were answered much poorer than in corresponding items 6 and 7 for downward motion.

From the incorrect options that were chosen, students mostly chose one that implied that the heavier object would fall faster, either implying that the travelling time would be less or the speed would be more. Approximately half of the students (~50%) revealed this misconception in items 16 and 20 (refer to Chapter 2 paragraph 2.2.2).

4.4.1.2 Inferential statistics results for group A

To determine whether the difference in the percentages of correct answers were significant, all the items were compared by means of contingency tables and the McNemar test statistic was used to determine the effect size (ω) for the paired items. Once the significance of the difference between the items was determined, the correlation between the item-pairs (indicated by ϕ_q) was also calculated. All the items had at least one option indicating that the heavier object would fall faster or have a higher velocity than the lighter object. To determine if and how these options correlated, the correlation between them were calculated also by means of a chi-squared test. The correlation coefficient between the options is represented as ϕ_o . The two-way contingency tables from which the test statistics were calculated are presented in Appendix B; Table 7-6 to Table 7-7. A summary of the test statistics is presented in Table 4-2. As explained in paragraph 3.7.2, the guidelines for interpretation of effect size (ω) or correlation with a value of $\omega < 0.3$ is considered to be a small effect, $0.3 \leq \omega \leq 0.5$ of medium and $\omega \geq 0.5$ a large effect.

Table 4-2: Summary of test statistics of paired items in group A

Combination Nr	Construct	Paired items a:b	ω (effect size)	Φ_q correlation items	Φ_o correlation options
A1	F ↓ t vs F ↓ v	6; 7	0.35	0.517	0.457
A2	F ↓ t vs C ↓ v	6; 16	0.72	0.192	0.089
A3	F ↓ t vs C N ↓ t	6; 17	0.41	0.471	0.450
A4	F ↓ t vs F ↑ v	6; 20	0.65	0.118	0.072
A5	F ↓ t vs F N ↑ v	6; 22	0.58	0.192	0.135
A6	F ↓ v vs C ↓ v	7; 16	0.58	0.261	0.172
A7	F ↓ v vs C N ↓ t	7; 17	0.01	0.391	0.383
A8	F ↓ v vs F ↑ v	7; 20	0.48	0.132	0.045
A9	F ↓ v vs F N ↑ d	7; 22	0.38	0.203	0.135
A10	C ↓ v vs C N ↓ t	16; 17	0.52	0.266	0.138
A11	C ↓ v vs F ↑ v	16; 20	0.10	0.222	0.132
A12	C ↓ v vs F N ↑ d	16; 22	0.24	0.236	0.085
A13	C N ↓ t vs F ↑ v	17; 20	0.43	0.210	0.148
A14	C N ↓ t vs F N ↑ d	17; 22	0.31	0.233	0.172
A15	F ↑ v vs F N ↑ d	20; 22	0.17	0.442	0.300

The statistical values and frequencies reported in the combinations are presented in Table 4-1 and Table 4-2. A discussion of these results follows below. The words “the heavier mass option” is used to describe the option containing the misconception that the heavier mass object will fall faster.

4.4.1.2.1 Combination A1: (Item 6 F ↓ t : item 7 F ↓ v)

In combination A1 item 6 was compared to item 7 (refer to Table 4-2). The difference between the settings was the physical quantity of the objects that had to be compared. In item 6 the falling time and in item 7 the final velocity of the objects had to be compared.

Items 6 and 7 were both posed in a formal conceptual setting. 83.99% - refer to Table 4-1- of the students answered item 6 correctly namely that, balls with unequal mass will hit the ground at the same time when released from the same height. It could be deduced that the students knew the principle that mass does not influence the acceleration of a free falling object. The setting posed in item 6 is often used in textbooks to introduce the principle of free falling objects

having the same acceleration. Similar settings are also used in test and exams to test students' knowledge of this principle and this specific item may have been familiar to most students (Klopfer *et al.*, 1983:181; Elby, 1999:S52). 14.76% said that the heavier ball would take less time to fall. The McNemar test statistic ($\omega = 0.35$, Table 4-2), indicated a moderate difference in the way the research group answered these two items. The percentage of students that answered item 7 correctly was 14.97% less than that of item 6. In item 7 the maximum speed of the objects in item 6 had to be compared. 69.02% said correctly that the balls will reach the same speed and 24.53% said the heavier ball will reach a higher speed, an increase of more than 9%.

The Phi coefficient indicated high correlation between these two items ($\phi_q = 0.517$, Table 4-2). 85.7% of the students who answered item 6 wrong also had item 7 wrong and 79% of the students who had item 6 correct also had item 7 correct - refer to Table 7-7. Further analysis of the options that were chosen indicated that 71.8% of students that chose the option of the heavier object falling fastest at item 6 -also chose the same option at item 7 – refer to Table 7-8. The Phi-coefficient for the options confirmed this correlation ($\phi_o = 0.457$ Table 4-2).

Although from the percentage of correct answers for item 6 it seemed that students knew the principle, one could deduce from the results of item 7 that they did not understand the principle well enough to infer its implications to less familiar applications. When the students were asked to explain their answers to item 6 the majority said that it was a principle that one just had to know or that it was common sense. It seemed that they did not realize that it also meant that the objects would reach the same final velocity. Only one stated that the answer to item 7 was also common sense and explained the answer logically.

4.4.1.2.2 Combination A2: (item 6: F ↓ t : item 16: C ↓ v)

In combination A2 students' responses to item 6 was compared to those of item 16. The items were set in different contexts and different physical quantities had to be compared. Item 16 was a contextual item where the final velocity of two objects moving down identical frictionless slides had to be compared. As friction had to be ignored the objects would have equal acceleration because the inclines of the slides were identical.

The McNemar test statistic for item 6 and item 16 indicated a very large, practically significant difference in the answers, $\omega = 0.72$ - Table 4-2. The correct response on item 16 was 54.88% less than that of item 6. This large difference was not expected. 90% of the students that answered item 6 wrong also had item 16 wrong but more than 67% of the students that had item 6 correct had item 16 wrong - Table 7-7. It seemed that if students answered item 6 wrong item 16 would probably also be wrong but the opposite did not apply. The Phi coefficient for the

items, $\phi_q = 0.192$, as well as for the options $\phi_o = 0.089$ showed that the correlation between the items and options could be neglected.

The high percentage of correct answers in item 6 indicated that students knew the principle of objects in free fall having the same acceleration, however from the results of item 16 one could argue that they did not know what the principle implicated thus they did not understand the principle. It seemed that the majority of students failed to recognise the similarity between item 6, formal conceptual setting and item 16, set in an everyday context. The majority of the students chose an option that implied that the heavier object would reach a larger speed. During the interviews all but one student, including some who stated the principle in item 6 with conviction, answered without hesitation that the mass of an object would influence its vertical movement and that the heavy object would fall faster thereby reaching a larger final velocity.

The students were not clear on the effect of friction on movement (Minstrell, 1982:11). One participant stated outright that it was difficult to adjust everyday context to a physics thinking framework. Two students stated that an everyday context differed from the physics one because “the everyday context is reality”, clearly illuminating that they regarded physics principles as being unrelated from real life situations.

4.4.1.2.3 Combinations A3 and A10: (item 6: F $\downarrow$ t : item 17: C N $\downarrow$ t) and
(item 16: C $\downarrow$ v: item 17: C N $\downarrow$ t)

Two sets of paired items were compared to evaluate the effect of the contextual settings of items 16 and 17 in comparison to the formal setting of item 6 as items 6 and 17 might have been familiar to some students as is reported in the paragraph below. Only 28.6% of the students that answered item 6 correctly also answered both items 16 and 17 correctly– refer to Table 7-7; combination 16 - and 79.22% of students that had item 6 wrong also chose the wrong options in items 16 and 17.

The difference between item 6 and item 17 was moderate to high; $\omega = 0.41$ but it was less than the difference between items 6 and 16. It was interesting that the test statistic for items 16 and 17 was also high - $\omega = 0.52$. Given the difference between item 6 and items 16 and 17 respectively, one would not expect such a large difference between items 16 and 17. The large difference between items 16 and 17 may be due to the numerical values in item 17 that allowed for a calculation to get to the correct answer. 39.3% of students that had item 17 correct had item 16 wrong and 4.8% who had item 16 correct had item 17 wrong. Both items were set in an everyday context and the large difference confirmed research indicating that problems with numeric values are answered more correctly than those without. It seemed that in both the contextual contexts however, the students did not link the settings to the physics principle

applicable in the formal physics context, as is suggested by the moderate correlation, $\phi_q = 0.266$. The differences between items 16 and 17 and item 6 may be due to the everyday contexts of items 16 and 17 that caused students fell back on their intuitive knowledge instead of applying their physics knowledge to the everyday contexts.

The high correlation between items 6 and 17, $\phi_q = 0.471$, indicated a significant correlation which meant that the students answered the items in the same way. Settings similar to that of item 17 are also often used in exams and might have been familiar to those students who were able to recall well-drilled items without understanding the underlying principle. The $\phi_o = 0.450$ indicated a fairly high correlation between the options i.e. students who chose the heavy object option in one item also chose the corresponding option in the other item. The difference between the items was noted in the 26.5% students who answered item 6 correct but item 17 wrong (Table 7-7). It seemed that although sufficient information was available to do a calculation, 36% of students relied on their intuitive knowledge to choose an option, rather than switching to a physics thinking framework. The observation that students did not use the numerical values to check their intuitive reasoning was also made in combination C4 (p.88).

4.4.1.2.4 Combination A4: (Item 6 F ↓ t : item 20 F ↑v)

The setting in item 20 was identical to item 6 but instead of falling, the balls were projected upwards. The test statistic $\omega = 0.65$ indicated a large difference in student responses. It seemed that the change in direction of the movement confused a larger percentage of students. Only 34.93% of respondents gave the correct answer to item 20 and 51.98% (Table 4-1) did not recognise the similarities between the items and that the same principle and variables in item 6 also applied to item 20. While the results of item 6 could indicate that students have conceptual knowledge, it was clear from this comparison that the majority of the students did not understand the principle and could not apply it in other than the familiar (formal) context. The insignificant correlation of the choice of options, $\phi_o = 0.072$ served as confirmation of this observation. Only 37.4% of the students who chose the correct options in item 6 also chose the correct option in item 20 while 51.0% students that chose the correct option in item 6, chose the heavy option in item 20 (Table 7-8).

The information obtained in the interviews confirmed that the students regarded upward and downward movement as unrelated. The results from the quantitative data lead to the conclusion that students applied physics principles differently to motion in different directions and the interviews presented evidence that the students were convinced that different principles applied to the different directions. This phenomenon could be the subject of further research.

4.4.1.2.5 Combination A5: (Item 6 F ↓ v : item 22 F N ↑ d)

The difference between item 6 and item 22 was slightly less ($\omega = 0.58$) than that of item 6 and item 20 - refer to combination A4 above. Of the students only 29% who answered items 6 correctly also had both items 20 and 22 correct (refer to Table 7-7 correlation A 17). The difference between items 20 and 22 was that numerical values were given in item 22 and the variables that had to be compared also differed. In item 20 the initial speed had to be compared whereas in item 22 the heights of the objects had to be compared. Again it seemed that comparing the speed of free falling objects (applying conceptual knowledge and proof of conceptual understanding) proved harder than comparing the falling time or the distance (demonstrating acquisition of knowledge) - combination A1, A3 and A10. 32% of students who had item 6 correct chose the heavier mass option in item 22, a decrease of almost 20% compared to those in item 20. This difference in the percentages of items 20 and 22 served as indication that numeric items were answered better than nonnumeric items. This observation agreed with research previously reported (Leonard *et al.*, 1996:1496; McBride, 2012:275; De Cock, 2012:1; Hedge & Meera, 2012:2)

When interviewed the students were convinced that up- and downward movement were not related and that different physics principles were applicable. An interesting observation was that students took the direction in which the objects moved irrespective whether they were moving up- or downwards, as positive and said that the direction of the gravitational force and acceleration changed depending on whether the object was going up or coming down. Some students used terms for physics concepts incorrectly; some used the word “gravity” to describe the force of gravity and acceleration without discrimination. Only one student used the concepts of mass and weight correctly.

4.4.1.2.6 Combination A6: (Item 7: F ↓ v : item 16: C ↓ v)

In both items 7 and 16 the final speed of the objects had to be compared but the items differed in context. Item 7 was a formal conceptual item while item 16 was a contextual item. The difference between the way these items were answered is practically significant $\omega = 0.58$ and the difference were ascribed to the difference of context. Only 37% of the students who had item 7 correct also had item 16 correct. The result confirmed the observation that students found contextual items harder to answer.

The same misconception noticed in combinations A2 and A3, presented itself as 63.6 % of students chose the heavier mass option in both items (Table 4-2). The remarks about students' perceptions regarding friction and the application of conceptual knowledge in everyday contexts made in combination A2 (p. 69) also applied in this combination.

4.4.1.2.7 Combination A7: (Item 7: F ↓ v : item 17: C N ↓t)

These items were discussed in terms of their correlation to item 6. The difference between item 7 and 17 was practically zero $\omega = 0.01$, an indication that students who answered item 7 correct also answered item 17 correct and those who had item 7 wrong also had item 17 wrong. The responses on both items differed significantly from item 6. It appeared that the numerical values given in item 17 were sufficient to eliminate the possible negative effect of the everyday contextual setting noticed in combinations A2, A3 and A6. In this pairing of items 7 and 17 the comparison of the speed and time respectively did not appear to influence student responses.

76.2% of students that answered item 7 correctly also had item 17 correct while 64.4% of students that answered item 7 wrong also had item 17 wrong (Table 7-7), a relationship indicated by the Phi coefficient of $\Phi_q = 0.391$ (Table 4-2). The options that were chosen also correlated moderately as 66.7% of the students who chose the **heavy mass option** in item 7 also chose the heavy mass option in item 17. It should be kept in mind though, that the setting of item 17 could be familiar to many students as was mentioned in combination A3 (p. 70).

The small difference between items 7 and 17 was clarified during the interviews when the students immediately switched to their intuitive thinking framework when the familiar formal context where the time of the falling objects had to be compared, changed to where the velocity had to be compared. It is suspected that more students answered item 17 correctly because of the familiar setting found in many textbooks.

4.4.1.2.8 Combination A8: (Item 7: F ↓ v : item 20: F ↑v)

The direction of movement is the only variable that differed in these items' settings and according to these results the direction of motion had a much larger effect than was expected. The McNemar test statistic for these paired items is $\omega = 0.48$. Of the students that had item 7 wrong 74.5% also had item 20 wrong - refer to Table 7-7. There was no significant correlation in the choice of options of the two items, which may be ascribed to the students' perception that the different directions of motion were subjected to different physics principles.

4.4.1.2.9 Combination A9: (Item 7: F $\downarrow$ v : item 22: F N $\uparrow$ v)

The difference between item 7 and 22, $\omega = 0.38$, was smaller than between item 7 and 20 but still moderate to largely significant. Item 22 was a numerical contextual item compared to item 20, which was a formal conceptual item and again it seemed that the numerical values given eliminated the effect of the contextual setting and the difference in direction that might have influenced the students' thinking framework.

4.4.1.2.10 Combination A11: (Item 16: C $\downarrow$ v : item 20: F $\uparrow$ v)

The effect size, $\omega = 0.1$ indicate that the students answered these items in the same way. Both items were answered poorly and it seemed that students found it equally difficult to apply their conceptual knowledge to the contextual setting of item 16 and the unfamiliar upward direction of movement in item 20. 58.8% of students that chose the heavy option in item 16 also chose the heavy option in item 20 (Table 7-7) while 54.4% that chose another option in item 16 also chose a similar option in item 20 (Table 7-8).

Any one of items 16 and 20 would be a more reliable indicator of conceptual knowledge and understanding than item 6 as the correct option of both items 16 and 20 was not as obvious as that of item 6 and had to be inferred instead of merely stating a memorized principle. From these results it also seemed that if students applied their intuitive knowledge – misconception – to a problem, the unfamiliar context of that item did not influence their response. In some cases the opportunity of doing a calculation were not taken apparently because they were convinced that their intuitive knowledge was correct - see combination C4 (p. 88).

4.4.1.2.11 Combination A13: (Item 17 C N $\downarrow$ t : item 20 F $\uparrow$ v) and

The significant effect size of these two items, $\omega = 0.43$ was a further indication that item 17 was either familiar to the students, or the numerical values given enabled them to solve the problem more successfully. 78.3% of the students who had item 17 wrong also had item 20 wrong whereas only 42.5% of students who had item 17 correct also had item 20 correct (Table 7-7), and it can be inferred that students who failed to answer item 17 correct would also not be able to answer item 20.

The response from the interview with student 2 (refer to Appendix B paragraph 7.2.2) that the objects in item 17 will have the same velocity because they fell from the same height was interesting because the same inference was not made in item 16 but it resurfaced in the answers to group C. No interviewed student was able to use an equation effectively to help them solve item 20.

4.4.1.2.12 Combination A14: (item 17 C N ↓ t : item 22 F N ↑ d)

The same inference about items 17 and 22 could be made as to items 17 and 20 - combination A13. The slight decrease in difference $\omega = 0.31$ as compared to combination A13 could be due to item 22 posed with numerical values that provided the opportunity for doing a calculation to assist students in making the correct choice.

It was noticed during the interviews that none of the students used equations to assist their reasoning even though numerical values were supplied in both items suggesting that the students' misconception was so deeply rooted that they did not even consider evaluating their answers with calculations - refer to combination A13.

4.4.1.2.13 Combination A15: (Item 20 F ↑ v : item 22 F N ↑ d)

The direction of motion in both items was upward, which might have resulted in the very low test statistic, indicating no difference between the ways the items were answered. Items 20 and 22 were more than moderately correlated in terms of students who had item 20 wrong also had item 22 wrong and students who answered item 20 correctly also answered item 22 correctly as was indicated by the Phi coefficient; $\Phi_q = 0.442$. 72.2% of the students who had item 20 wrong also had item 22 wrong and 73.4% of those that had item 20 correct also had item 22 correct (Table 7-7). There was a moderate correlation in terms of the options chosen; $\Phi_o = 0.300$. 82.0% of the students who did not choose the heavy option in item 20 also did not choose that option in item 22 where 46% chose the heavy option in both items (Table 7-8).

Trends noticed in the students' responses to group A items:

- A large percentage of students have the misconception that heavy objects fall faster.
- $\approx 70\%$ of students do not understand the Newtonian concept of free fall.
- The direction of movement is perceived as a context on its own.
- Students find numerical items easier to answer.
- Students think that physics principles do not apply to everyday contexts.
- Students think that the physics world and reality are unrelated.

4.4.2 Results of items in group B

The rationale for this grouping was to illuminate the effect that the plane in which movement occurred might have on students' interpretation of the force, mass, acceleration relationship as described by Newton's second law, therefore all items were set in a formal conceptual context.

The Cronbach's Alpha for this group of items was lower than for the other groups with the value of 0.420 (Table 7-3) but the grouping was valuable to compare isomorphic movement in different planes. The mean inter-item correlation for this group was 0.153, which meant that the items in group B were not as coherent and internally consistent as those in group A. The compilation of group B is explained in paragraph 3.6.1.1.2.

Group B consisted of two sets of items in formal conceptual context, both supported with diagrams. In one set (items 8 and 9), the balls moved vertically downwards and in the other set (items 11 and 12) the blocks were moved along a horizontal plane. In items 8 and 11 the students had to determine which of the two objects would cover a certain distance first i.e. the time had to be compared, and in items 9 and 12 the objects' final velocity had to be compared. In both sets of items the two objects of unequal mass were moved simultaneously from rest with equal constant acceleration but over different distances. Both sets were represented verbally as well as pictorial with labelled diagrams representing the settings. These sets of items were included to determine whether students' comprehension of the relationship between mechanics concepts was influenced by the plane in which the objects moved. Students often ascribe free falling objects' motion to a common misconception - the "fact that the gravitational force on all objects are the same" because they do not understand the physics principle involved in free fall namely that all objects in free fall experience equal gravitational acceleration at the same place. We wanted to determine if a similar misunderstanding regarding the force and acceleration relationship applied to movement in a horizontal plane. The movement of objects of unequal mass along vertical and horizontal planes differ in the respect that no equal acceleration is implied in horizontal movement when friction and air resistance are ignored.

4.4.2.1 Results of quantitative and qualitative study

The frequencies of students' responses to the items in group B are presented in Table 4-3. The context, direction and the variable that had to be compared were indicated by using the following abbreviations: The context; F = formal conceptual, the direction of motion was indicated by $\downarrow$ = downward; or $\rightarrow$ = horizontal. The physics quantity that had to be compared was indicated by; t = time; v = velocity

Table 4-3: Frequency of students' responses to items in Group B

	Frequency of answers to items: %			
Items	Item 8	Item 9	Item 11	Item 12
Context	$F \downarrow t$	$F \downarrow v$	$F \rightarrow t$	$F \rightarrow v$
% correct	86.07	65.90	40.96	71.73
Object have same speed /time	10.60	19.75	44.68	17.46

In constructing items 8 and 9 the heavier object covered the shortest distance resulting in the heavy object reaching the ground first. This setup was unfortunate because it was unclear whether the correct choice was made due to the misconception that heavy objects fall faster, or due to students' application of conceptual knowledge. Due to the results of the data on group A, it is argued that the high percentage of correct answers to item 8 (86% refer to Table 4-3) could be ascribed to the misconception. If the research should be repeated it is suggested that the objects should be switched in order to eliminate the possible confusion. The results from the interviews provided further evidence that the high percentage was due to the misconception. When the interviewer asked how switching the objects would influence the outcome, the students replied that the heavier object would fall faster resulting in both objects reaching the destination simultaneously.

When dealing with problems regarding horizontal movement students are often required to determine the final velocity of objects accelerated by an applied force. To determine the time that such an object will take to cover a certain distance is seldom asked. The percentage of correct answers to item 12 is more than 30% more than that of item 11 suggesting that students relied on their memory to answer the items instead of applying their conceptual knowledge to the new context. It seemed that the students once again did not use physics equations as thinking tools but relied on their intuitive knowledge to choose the correct answer. Contrary to what was expected, the absence of friction did not simplify the movement of the objects. The results from the interviews indicated that the students actually found it more difficult to incorporate the absence of friction and air resistance in their intuitive reasoning, providing evidence that the students had difficulty in adjusting to a physics thinking framework.

4.4.2.2 Descriptive statistics results of group B

In all the items of group B two objects of unequal mass moved from rest at the same time with equal accelerations but over different distances. It seemed obvious that the object covering the shorter distance would reach the ground/wall first and that the object travelling **the longer**

distance would have the larger speed when it eventually reached the ground/wall since the acceleration was the same.

At least 65.9% of the students answered items 8, 9 and 12 correctly (Table 4-3). The big difference between the percentages of items 8 and 11, (45.11%) was unexpected. 86% of the students chose the correct option that the object travelling the shorter distance would reach the ground first but only 40.96% chose that option in item 11 although the items were supported with diagrams. The percentage of students who said that the objects would reach the wall at the same time in item 11 was more than the percentage that chose the correct option.

Although most students answered items 9 and 12 correctly more than 30% of the students said that the objects would reach the ground/wall with the same velocity. The difference in responses between items 11 and 12, both in the horizontal plane, was 30.77% compared to the difference of 20% between items 8 and 9, which were set in the vertical plane. The percentage of correct answers on items 8 and 11 differed with more than 46% where the correct answers of items 9 and 12 differed with only 6%. From these results one could argue that the students were more comfortable in solving a horizontal motion problem regarding velocity than time. This is further evidence of students' inability to apply their physics conceptual knowledge to unfamiliar contexts and that students did not develop deep understanding of the physics concepts.

The students indicated during the interviews that they found supporting diagrams helpful in solving problems but the misconception that heavy objects fell faster prevailed in spite of the accompanying diagrams.

4.4.2.3 Inferential statistics results for group B

To determine whether the difference in the frequencies of responses (Table 4-3) were significant, all the items of group B were compared by means of contingency tables and the McNemar test statistic (ω) was used to determine the effect size for the paired items. Once the significance of the difference between the items was determined, the correlation between the item-pairs (indicated by ϕ_q) was also calculated. To determine if and how the options correlated, the correlation between them were calculated also by means of a chi-squared test. The correlation coefficient between the options is represented as ϕ_o . Two contingency tables were compiled to determine the correlation of the options in group B. One was a 4x4 contingency table where all options in the items were compared, and the other a 2x2 contingency table comparing the options of the objects reaching the same velocity of travelling the same time. A summary of the contingency tables from which the test statistics were calculated is presented in Appendix B; Table 7-9 and Table 7-10. The test statistics were

summarized and are presented in Table 4-4. It should be noted again as explained in paragraph 3.7.2 according to the guidelines for interpretation of effect size (ω) or correlation with a value of $\omega < 0.3$ is considered to be a small effect, $0.3 \leq \omega \leq 0.5$ of medium and $\omega \geq 0.5$ a large effect.

The context, direction and the variable that had to be compared were indicated by using the following abbreviations: The context; F = formal conceptual, the direction of motion was indicated by $\downarrow$ = downward; or $\rightarrow$ = horizontal. The physics quantity that had to be compared was indicated by; t = time; v = velocity. The results of the students' responses on the items are discussed in terms of the percentage of the students who answered the items correctly as well as in terms of the test statistics obtained from the difference or correlation between the paired items. The combination of items in group B was numbered (B1, B2 etc.) and the heading of the combination consisting of the number and the context of each item-pair is followed by results of the paired items.

Table 4-4: Summary of test statistics of paired items in group B

Combination Nr	Construct	Paired items a : b	effect size ω	<i>phi-coefficient</i> items Φ_q	<i>phi-coefficient</i> options Φ_o
B1	F $\downarrow$ t : F $\downarrow$ v	8:9	0.35	0.167	0.117
B2	F $\downarrow$ t : F $\rightarrow$ t	8:11	0.64	0.189	0.194
B3	F $\downarrow$ t : F $\rightarrow$ v	8:12	0.25	0.054	0.019
B4	F $\downarrow$ v : F $\rightarrow$ t	9:11	0.38	0.216	0.228
B5	F $\downarrow$ v : F $\rightarrow$ v	9:12	0.10	0.181	0.198
B6	F $\rightarrow$ t : F $\rightarrow$ v	11:12	0.44	0.110	0.117

4.4.2.3.1 Combination B1: (Item 8 F $\downarrow$ t : item 9 F $\downarrow$ v)

In items 8 and 9 two objects with unequal mass were released at the same time from different heights. Because air resistance was ignored both objects would fall at gravitational acceleration and therefore the object covering the shortest distance would hit the ground first while the other object would accelerate over a longer distance thereby obtaining a larger final velocity.

The difference between these items was not practically significant with a small effect size of $\omega = 0.35$ and the correlation between the items was also small with $\Phi_q = 0.167$. It can therefore not be assumed that all students who could answer item 8 would also be able to answer item 9

as was indicated by the difference in the frequencies of ~15%. The correlation between the options was also very small $\Phi_o = 0.117$ which meant that students did not choose corresponding options in the two items.

The same constructs were compared in combination A1 (paragraph 4.4.1.2.1) and interestingly enough the effect sizes were identical $\omega = 0.35$ (Table 4-2). The correlation between the items in combination A1 was much higher than those in combination B1, although more students chose wrong options in combination A1 than in combination B1. In combination B1 a small percentage of the students indicated that the two objects would hit the ground with the same speed. From the explanations obtained during the interviews it seemed that those students did not take into account that the objects travelled different distances and applied what they thought was a principle that objects travelling together would reach the same velocity. It seemed that the wording “released at the same time” invoked the application of the concept that “objects released at the same time from the same height would fall together” without realizing that the condition of the same height was not met. This was contrary to their explanation of combination A1 and suggested severe inconsistencies in the students’ reasoning.

4.4.2.3.2 Combination B 2: (item 8 $F \downarrow t$: item 11 $F \rightarrow t$)

In this combination the effect of directions/plane of motion as a different context could be determined because the items were identical in all aspects but for the plane of movement. In both items the objects were moved simultaneously from different distances at equal accelerations. The objects falling vertically downwards in item 8, experienced gravitational acceleration because of the absence of air resistance and the acceleration for the objects moving along a frictionless horizontal plane in item 11 were given as equal for both objects.

The difference between items 8 and 11 was practically significant, as was indicated by the large effect size $\omega = 0.64$. It seemed that the students did not regard motion in the vertical direction in the same way as in the horizontal direction and applied the physics principles differently. The difference between the responses to these two items was very intriguing and explanations for the phenomena were sought in the interviews. From the results from the interviews confirmed that the students think that different principles applied to motion in different planes. Due to the large effect size it was expected that the correlation between the items would be low, $\Phi_q = 0.189$. The low correlation indicated that students were not consistent in their application of physics concepts by choosing corresponding options.

4.4.2.3.3 Combination B3 and B4: (Item 8 $F \downarrow t$: item 12 $F \rightarrow v$

and Item 9 $F \downarrow v$: item 11 $F \rightarrow t$)

In this paired items not only the direction of movement but also the physical quantity to be compared differed. The effect size of combination B3 was low to moderate, $\omega = 0.25$, showing that the percentages of correct answers to items 8 and 12 did not differ much and the effect size of combination B4 was moderate to high, $\omega = 0.38$. The higher effect size of combination B4 supported the remark made in paragraph 4.4.2.1 suggesting that students relied on their memory of previously done problems instead of applying the little knowledge they had to unfamiliar contexts. There was no significant correlation between the items or the options of the items due to the low percentage of students who chose the option of objects having the same time or velocity in items 8, 9 and 12 (Table 4-3 and Table 4-4). $\phi_q = 0.22$

4.4.2.3.4 Combination B5: (item 9 $F \downarrow v$: item 12 : $F \rightarrow v$)

As in combination B2 the effect of direction/plane of motion as a different context could be determined in combination B5 because the items were identical in most aspects but for the plane of movement. In both items the objects were moved simultaneously from different distances and the equal accelerations of the two objects had to be inferred. The objects falling vertically downwards in item 9, experienced gravitational acceleration because of the absence of air resistance while the acceleration for the objects moving along a frictionless horizontal plane in item 12 had to be deduced. The ratio of the forces on the objects was the same as the ratio of their masses; therefore they would experience equal accelerations in both items.

77.6% of students that chose the correct option for item 9 also chose the correct option for item 12 (Table 7-10). Again the only difference between the two items was the plane in which the objects were moving. The effect size, $\omega = 0.10$, indicated no difference between the response to this combination. This may be attributed to the familiarity of the problem setting as described in paragraph 4.4.2.3.3.

4.4.2.3.5 Combination B6: (item 11 $F \rightarrow t$: item 12 $F \rightarrow v$)

In this combination the time and velocity respectively of the objects moving along a frictionless horizontal plane had to be compared. 71.73% of the students answered correctly that object B, travelling the longer distance, will have the larger speed, item 12, but only 40.96% said that object A, who covered a shorter distance, would reach the wall first even though the objects started from rest at the same time, item 11. The effect size of $\omega = 0.44$ showed that the difference was practically significant and we argue that the difference could be due to the

unfamiliar nature of the variable that had to be compared in item 11. Settings like that of item 12 are often used in mechanics practice problems regarding Newton's second law.

Trends noticed in the students' responses to group B items:

- Physics principles applicable to vertical and horizontal motion differ.
- Students rely on their memory of familiar problems instead of applying their physics knowledge to solve problems.
- Students do not use equations in symbolic form to help them solve either numerical or non-numerical problems.

4.4.3 Results of items in group C

The rationale for including this group was to investigate the effect of multivariate physics quantities on students' application of physics concepts. The number of physical variables that had to be taken into consideration in items 11 and 13 seemed more than those in the remainder of the group as well as in groups A and B. With the distance and the masses being different it looked as if in item 11 four and in item 13 five variables had to be considered. Contrary to how it seemed the object's initial velocity for the distance they travelled together was the only variable to determine which object would reach the wall first, as their accelerations were equal. In items 10, 13, 18 and 24 the objects' masses were kept the same to eliminate the effect of the misconception that heavier objects fall faster. With this compilation we attempted to illuminate students' perception of the relationship between acceleration, velocity time and distance.

To ensure coherence with the other groups in the questionnaire, two items, items 11 and 13, were set in horizontal motion and all other items in group C were set in vertical motion.

Cronbach's Alpha for this group of items was high with the value of 0.692 –Table 7-4 – and the mean inter-item correlation value was 0.31, which according to Clarke and Watson showed that the items were internally consistent with more than sufficient correlation between the items. From the statistical analysis it seemed that although item 11's corrected inter-item correlation was moderate, Cronbach's Alpha for the group would be 0.72 if the item was deleted suggesting that the item could be eliminated from this group if the research was repeated.

As was explained in paragraph 3.6.1.1.3 in each item in this group two objects were dropped or moved from different distances, released at different times. Group C consisted of items 10, 11, 13, 18 and 24. In items 10, 18 and 24 the masses of the objects were equal where in items 11 and 13 the objects had different masses. In items 10, 18 and 24 the settings were identical; two objects fell from rest from different heights in the absence of air resistance with the lowest object only started moving when the other object passed it on its way down. Because air resistance

had to be ignored all the objects experienced gravitational acceleration. In item 13, two objects at unequal distances from a wall, moved from rest along the frictionless horizontal plane. The nearest object only started moving when the other object passed it on its way and students had to deduce that they would have the same acceleration. The underlying principle in all the items was that the objects had the same acceleration but different initial velocities for the distance they travelled together. Students had to determine which object would reach the ground first. Item 10 was a formal conceptual question, while items 18 and 24 were set in everyday contexts with item 24 containing numerical values. Settings similar to item 24 are often found in exam questions and exercise books for grade 12 learners.

Items 11 and 13 were both set in a horizontal plane. In both cases friction had to be ignored so the applied force was the only force acting on the objects. In item 11 the acceleration was given as identical where in item 13 the students had to deduce that the accelerations would be the same. One object's motion was initiated before the other one and the time taken to cover the same final distance had to be compared. In items 10, 13 and 18 the option of the objects reaching the ground/wall first were given twice but with different explanations why that would be the case. All items were supported with labelled diagrams. The context, direction and the variable that had to be compared were indicated by using the following abbreviations: For differentiating between the contexts; F = formal conceptual; C = contextual; N = numeric was used. The direction of motion was indicated by: $\downarrow$ = downward or $\rightarrow$ horizontal. The physics quantity that had to be compared was indicated by; t = time.

The frequencies of students' responses are presented in Table 4-5.

Table 4-5: Frequencies of student responses for group C

	Frequency of answers to items: %				
Options	Item 10	Item 11	Item 13	Item 18	Item 24
Construct	F $\downarrow$ t	F $\rightarrow$ t	F $\rightarrow$ t	C $\downarrow$ t	C N $\downarrow$ t
% correct	55.53	41.13	43.72	58.63	51.06
Objects same time/speed	38.2	44.68	46.44	37.84	36.44

4.4.3.1 Descriptive statistics results for group C

In items 11 and 13 the objects moving along a horizontal plane had unequal mass but in the other items the objects, moving vertically downwards, were of equal mass. The percentage of students choosing the correct answers on the vertical items varied between 58.63% and

51.06% and on the horizontal items the frequencies ranged from 41.13% to 43.72% i.e. ~10% less (Table 4-5).

The misconception that heavy objects fell faster could not and did not present itself as the two objects whose movement had to be compared had the same mass but another interesting phenomenon regarding the options was observed when analysing the data. All the items except item 11 had one or more options that said both objects would reach the ground/wall simultaneously. Where more than one such option was given the explanations as to why the objects would reach the end simultaneously were different. The large number of students (between 36% and 46%) who chose an option that the two objects would either travel the same time or reach the same final velocity was an unexpected result. For the items set in vertical motion the sum of the “same” options for each item totalled between 38.20% and 36.44% but the percentage of students who chose the “same” options in horizontal motion were slightly more than the percentage that chose the correct option - see Table 4-5.

The percentages of students’ responses to items 10, 18 and 24 corresponded although the contexts of the items differed. Item 10 was set in formal conceptual context where items 18 and 24 were set in everyday contexts. The percentage of correct answers for item 24 was less than that of item 18 in spite of item 24 containing values that allowed for calculations to obtain the correct answer.

4.4.3.2 Qualitative results from the interviews

Analysis of the quantitative results (Table 4-5) showed that a large percentage of students were unable to choose the correct options to the items in this group. The percentage of students who chose an option that said that the objects would reach the destination together was more than the percentage that made the correct choice in items 11 and 13 (Table 4-5) while for the other items the percentages that made a similar incorrect choice were substantial. The masses of all the objects were equal thereby eliminating the possible influence of the misconception of heavier objects falling faster.

When analysing the quantitative results no possible explanations for the students’ incorrect choices could be suggested. It made no sense for students to argue that objects which had the same acceleration but different initial velocities for the distance they both travelled would reach the destination at the same time. This discrepancy presented itself in all the items in group C. The reasons provided for this discrepancy were incomprehensible. It seemed that the reasons provided for why the objects would reach the ground at the same time led the students to accept the option that corresponded with what they initially read in the problem. Some of the interviewed students argued that because the one object, already in motion, did reach a higher

velocity the option giving that reason would be correct: “but because the one has an initial velocity it means that his final velocity will be bigger and that option makes more sense”. Students who chose the other option that the objects would reach the wall/ground at the same time did so because the objects did cover the same distance, which was the reason provided in that option: “If A is directly opposite B then they fall the same distance therefore they will reach the ground at the same time. A will not be faster than B because they cover the same distance”.

When the use of equations of motion was suggested during the interviews, the students were unable to compare the variables in the equation qualitatively and use the equations as thinking guides. It was very disturbing that almost 50% of the students were not able to apply common sense let alone elementary physics conceptual knowledge to solve simple physics problems.

4.4.3.3 Inferential statistics results for group C

To determine whether the difference in the percentages of correct responses were significant, all the group C items were compared by means of contingency tables and the McNemar test statistic (ω) was used to determine the effect size for the paired items. Once the significance of the difference between the items was determined, the correlation between the item-pairs (indicated by ϕ_q) was also calculated. All the items but item 11 had two options indicating that the objects would reach the same velocity or travel the same time with different reasons why the option would be true. The corrected inter-item correlation for item 11 - Table 7-4 – indicated that item 11 should rather have been excluded from this group and should be eliminated from this group if the research was repeated. To determine if and how the options of the items correlated, the Phi coefficient were calculated also by means of a chi-squared test. The correlation coefficient between the options is represented as ϕ_o . The two-way contingency tables from which the test statistics were calculated are presented in Appendix B; Table 7-12 to Table 7-14. It should be noted again as explained in paragraph 3.7.2 according to the guidelines for interpretation of effect size (ω) or correlation with a value of $\omega < 0.3$ is considered to be a small effect, $0.3 \leq \omega \leq 0.5$ of medium and $\omega \geq 0.5$ a large effect.

The results of the students' responses on the items were discussed in terms of the percentage of the students who answered the items correctly as well as in terms of the test statistics obtained from the difference or correlation between the paired items. The combination of items in group C was numbered and the heading of the combination, consisting of the number as well as the context of each item-pair, is followed by results of the paired items. A summary of the test statistics is presented in Table 4-6.

Table 4-6: Summary of test statistics of paired items in group C

Combination nr	Construct	Paired items a:b	ω (effect size)	Φ_q items	Φ_o options
C1	$F \downarrow t : F \rightarrow t$	10:11	0.22	0.198	0.134
C2	$F \downarrow t : F \rightarrow t$	10:13	0.24	0.341	0.271
C3	$F \downarrow t : C \downarrow t$	10:18	0.07	0.535	0.545
C4	$F \downarrow t : C N \downarrow t$	10:24	0.09	0.382	0.345
C5	$F \rightarrow t : F \rightarrow t$	11:13	0.04	0.225	0.119
C6	$F \rightarrow t : C \downarrow t$	11:18	0.27	0.176	0.095
C7	$F \downarrow t : C N \downarrow t$	11:24	0.14	0.214	0.153
C8	$F \rightarrow t : C \downarrow t$	13:18	0.26	0.362	0.275
C9	$F \rightarrow t : C N \downarrow t$	13:24	0.11	0.262	0.240
C10	$C \downarrow t : C N \downarrow t$	18:24	0.16	0.403	0.384

4.4.3.4 Combination C1: (item 10 $F \downarrow t$: item 11 $F \rightarrow t$)

No significant correlation or difference was found between these two items. The two items in combination C1 differed in terms of the direction of motion and the reasons provided for the options. The options from which the correct answer had to be chosen were also in the same sequence. Item 10's options were supported with reasons where no reasons were provided for the options in item 11, which might explain why no significant correlation or difference was found between these two items.

4.4.3.4.1 Combination C2: (item 10 $F \downarrow t$: item 13 $F \rightarrow t$)

In combination C2 motion along the vertical and horizontal planes were compared and both items were put in formal physics context. Item 13 was compiled to appear more difficult than item 10 with more physical quantities to be considered but the effect size for these two items was small to moderate, $\omega = 0.24$ (Table 4-6). 58.6% of the students who answered item 10 correctly also answered item 13 correctly – refer to Table 7-13. The correlation between the items $\Phi_q = 0.341$ as well as the options $\Phi_o = 0.271$ (Table 4-6) indicated that students who chose one option in item 10 chose a corresponding option in item 13.

These correlations were confirmed in the results from the interviews that students chose an option because the reason for the option corresponded with the physics quantity they noticed in

the description of the problem. In both items similar reasons were given for the options, which might have contributed to the higher correlation between the items and the options. The number of physics quantities that had to be considered in item 13 had no effect on students' reasoning. A possible reason for this may be due to students' application of superficial intuitive reasoning and not noticing that a higher level of reasoning was required to solve this problem. The effect of multivariate physics quantities on students' application of conceptual knowledge may be investigated in further study.

4.4.3.4.2 Combination C3: (item 10 F $\downarrow$ t : item 18 C $\downarrow$ t)

In both items in combination C3 the movement of two objects falling from different heights but not released at the same time, had to be compared. In item 10 two balls were released (formal physics setting) and in item 18 two boys fell out of a tree – contextual setting. The effect size for the items was insignificant, $\omega = 0.07$ because the percentage of students who made the correct choice were similar- 55.53% and 58.69%. The correlation for both the items and the options were high, both more than 0.534 indicating that the students answered the items in the same way. This result contradicted those obtained from group A where the items set in everyday context were answered poorer than those in formal conceptual setting. Judging by the percentages of correct answers one would infer that more than 40% of the students found it equally hard to apply conceptual knowledge in a formal conceptual setting as in item 10 as they did in a contextual setting as in item 18.

It seemed that the fact that the two objects in the items in group C did not have the same initial velocity did not trigger formal physics reasoning in those students that answered the items wrong. This implies that the students who chose an option stating that the objects would reach the destination at the same time did so because the explanation of that option contained a clue that was picked up in the verbal statement of the problem. The inference is based on the responses of the students during the interviews (see Appendix B paragraph 7.2). With reference to the point where object A reaches object B, student 1 realized that "A has already a velocity and B = 0". Unfortunately she neglected this realisation and only focused on the equal distances that the objects travelled further: "but because they cover the same distance they travel the same time as measured from when B starts to move". Student 4 argued that: "Two similar options with different reasons were given but because A has an initial velocity it means that his final velocity will be bigger and that option makes more sense" thereby ignoring the fact that A would cover the same distance faster because of its higher velocity. One possible reason is that the existence of such explanations impose cues on the student, rather than drawing out the conceptual knowledge that the student has unprompted access to. Another is that the student may be able to appreciate that the reason is valid, but not related to the given situation.

4.4.3.4.3 Combination C4: (item 10 F ↓ t : item 24 C N ↓ t)

The lower correlation coefficients between the items in combination C4 ($\phi_q = 0.382$ and $\phi_o = 0.345$) and those in combination C3 between items 10 and 18 ($\phi_q = 0.535$ and $\phi_o = 0.545$) were confusing. One would expect that numerical items would be answered more correctly than non-numerical ones but this result contradicted that expectation. An explanation for this observation was found in the interviews when the interviewer deduced from the students' answers that the students chose an option that contained a physics attribute stated in the description of the problem. No physics reasoning was applied to obtain the correct answers because the "correct answer" seemed obvious to them.

When the interviewer suggested the use of an equation to assist his reasoning, student 1 wrote down an appropriate equation ($y = v_i t + \frac{1}{2} a t^2$) and although the variables were compared verbally — "y and g are the same, v_i is not the same but t is going to be equal" the student was unable to provide the correct answer (S1:133).

4.4.3.4.4 Combination C6 and C8: (Item 11 F → t : item 18 C ↓ t

and item 13 F → t : item 18 C ↓ t)

The items in these two combinations were set in different directions of motion. Item 18, vertical downwards, was compared to items 11 and 13 respectively where motion was in the horizontal plane. In both combinations the effect sizes indicated moderate differences (0.27 for combination C6 and 0.26 for combination C8 -Table 4-6) confirming that the direction or plane of motion influenced the way students answered for they answered these items differently. The higher correlation between items 13 and 18 ($\phi_q = 0.362$) than that between items 11 and 18 ($\phi_q = 0.176$) indicated that the reasons given with each option in items 13 and 18 influenced the students' choices - refer to combinations C3 and C4.

4.4.3.4.5 Combination C10: (item 18 C ↓ t : item 24 C N ↓ t)

According to the small effect size ($\omega = 0.16$), items 18 and 24 were answered in the same way. This was confirmed by the significant correlations coefficients between the items as well as the options ($\phi_q = 0.403$ and $\phi_o = 0.384$). It was noticed that although no reasons were provided for the options in items 11 and 24, the effect of the absence of reasons was less in the case of item 24 than item 11 in comparison with item 18.

Trends noticed in the students' responses to group C items:

- Students do not use equations to solve problems or to help them think when their intuitive knowledge is triggered.
- Students disregard formal reasoning when problems seemed to contain a common misconception that they agree with.
- Item wording seemed to be confusing.

4.5 Discussion of results

Analysis of the quantitative data from the questionnaire directed the information gathered during the interviews. The results of the empirical study regarding misconceptions and other tendencies observed in the questionnaire and interviews were summarized and presented in Table 4-7.

Table 4-7: Observed misconceptions and other ambiguities

Misconceptions
Heavy objects fall faster
Two objects of different mass and released from different heights will reach the ground simultaneously because the heavy one falls faster
Light objects are easier to accelerate but heavy objects fall faster
Inconsistency in student reasoning
Two objects with different initial velocities but equal acceleration travelling the same distance together, will hit the ground/wall at the same time because they cover the same distance
Up- and downward movement
Different principles apply to up- and downward movement
An object needs a force moving upward but not when moving downward
The direction of gravitational acceleration and force on an object change as the object is projected into the air and falling down again
Formal and everyday context
In formal physics contexts everything is in a box but everyday context is in reality
It is confusing if friction and air resistance have to be ignored
Confusion of terminology
The word "gravity" is used to describe the force of gravity as well as gravitational acceleration

4.5.1 Misconception: Heavy objects fall faster.

The low percentage of students who were able to answer items 16 and 20 correctly directed investigation into this misconception. Research on this Aristotelian idea had been widely reported (Kavanaugh & Sneider, 2007:21; Minstrell, 1982:11). Students' responses in this study confirmed that many of them still believe that heavy objects fall faster than lighter objects. The following answers were given during the interviews: If the balls moved downwards the heavy ball would hit the ground first;

- Because you are heavier you must fall faster than your niece.
- In theory class we learnt that heavier things fall faster I think that larger weight causes larger acceleration So I think I made a wrong choice in item 6 because the heavier object will fall faster.
- If friction can be ignored then your (heavy object) velocity will be larger than that of your niece (lighter object).
- A heavy person always goes faster than a lighter one.
- The heavier one will accelerate faster. The larger the mass the larger the acceleration.

4.5.2 Students think that the force of gravity is equal on all falling objects

Students seem to be uncertain whether all falling objects experience the same magnitude of force or the same acceleration. From the answers and explanations given during the interviews, it was clear that many students believe that the force of gravity exerted by the earth is equal on all objects. They were not clear on the difference between the effect of the force of gravity, which results in all objects having the same acceleration, and the magnitude of the force. In some of the answers the students referred to the mass and the weight of the objects indiscriminately. The inference is based on the following answers:

- Gravity has a larger effect on the heavy ball because of its larger weight.
- Then the only force acting on the object is the force of gravity and the larger the mass the larger the acceleration.

Your greater weight causes a larger acceleration.

- Lighter objects are easier to accelerate with the same force. ...
- Because you weigh more therefore your acceleration will be more ...

- I think that larger weight causes larger acceleration.
- The force on the heavy ball will be twice that of the lighter ball, which is why its velocity will decrease faster.
- The heavier ball, 2m, will have a larger acceleration equal to 2a.
- Gravity has a larger effect on the heavy ball because of its larger weight.
- The heavier one will accelerate faster.
- The force on the large ball is the same as on the lighter ball, it is 9.8.
- The force is the same; -9.8 m/s the force of gravity-,

4.5.3 Students' lack of conceptual understanding

Muis and Gierus (2014:409) presented evidence that high school students reveal different beliefs about knowledge in physics when the focus was on the procedural aspects compared to when the focus was on conceptual knowledge.

- There is a difference between knowing something and understanding it. If you understand something it is easier to remember.

The results of this study indicate that students rely on their memory of familiar problems instead of applying their physics knowledge to solve problems. Kavanaugh and Sneider (2007:23) reported on students' abilities to solve quantitative problems of the type typically encountered in textbooks and tested through problem sets and exams and similar results were found in this study. The quantitative results of group A and group B (refer to paragraphs 4.4.1 and 4.4.2) indicated that the typical physics textbooks items were answered noticeably better than others were. Research by Halloun and Hestenes (1985b:1057) and Klopfer *et al.*, (1983:174) revealed students' tendency to support their explanations with vague, unsubstantiated and meaningless "facts" and the same was observed in this study. Students based their explanations on reasons such as:

- The heavy ball would hit the ground first, because it is gravity.
- Gravity has a larger effect on the heavy ball because of its larger weight.
- The lighter one will go higher if they were thrown with the same force because of the force of gravity.

Some students were even convinced that although a heavier object was released from a greater height than a lighter one:

- The “weight” of the heavier one would cause it to land at the same time because it fell faster than the lighter one because: “the height and the mass cancel each other”.

The quantitative results indicate that most students answered more of the formal conceptual items, especially those of a familiar nature often found in textbooks, correct than items set against every day- or unfamiliar context. It seemed that students relied largely on their memory of previous applications or demonstrations of the underlying concepts of problems. The answers given on items regarding the different knowledge required to answer formal and contextual items unmistakably revealed a large void in their conceptual understanding:

- In formal context you just have to know the principle; I see the item and I know what logic and common sense says to me.
- I saw a video of a hammer and a feather falling at the same rate therefore the objects will land at the same time because gravitational acceleration is the same for the two and mass has no influence (on the acceleration).
- In formal context you just have to think which option is most suitable but in everyday context more factors must be considered and it is easier to come to a reasonable conclusion.

It seemed as if the students themselves were not aware of the conflicting nature of their reasoning. One student was initially very confident about the principle regarding free fall giving answers like

- I know what logic and common-sense says to me,
- Common-sense tells you what the answer is,
- It is a commonly known physics fact

but, after he was asked to compare the forces and acceleration of free falling bodies qualitatively, his answer was incompatible with those he gave before:

- It is confusing that they fall at the same rate because the larger object is supposed to fall faster.

Another student who indicated that she found formal items easier to solve also said:

- In everyday context more factors must be considered and it is easier to come to a reasonable conclusion.

4.5.4 Confusion about the meaning and/or implication of physics concepts

Klopfer *et al.* (1983:180) report that students' concept structures and the meaning they attach to terms differ from the physicist's point of view. Finegold and Gorsky (1991:97) document the

lack of shared understanding of scientific words that are integral to the concepts under consideration. Students' responses in this research confirmed the existence of such incorrect concepts as well. Alonzo and Steedle (2009:417), Finegold and Gorsky (1991:97) and Redish *et al.* (1998:212) are some of the researchers that expressed their concern about students misunderstanding of the meaning of physics concepts. If students do not understand the meaning of the terms used, the probability of obtaining conceptual understanding is very slim at most.

Students seem uncertain about the difference between the meanings of the terms **force** and net force and as a result encounter difficulties in applying Newton's second laws.

- So the **nett** force is normal force + / – the gravitational acceleration.
- If you drop the balls there is immediately a normal force and the gravitational acceleration that act on the ball.

Some students regard acceleration only as increase in velocity;

- Acceleration is when they move faster.

The results of the interviews showed the level of confusion that students have in respect to the use of physics terminology, confirming the results of multiple research studies (Bozdogan & Demirba, 2009:146; Klopfer *et al.*, 1983:180). Confusion regarding the terms gravitational force and gravitational acceleration is clearly illustrated by the answers: The terms gravitational **acceleration** and gravitational force are used as if they have equal implications which probably contribute to the confusion on gravitational force and gravitational acceleration.

- So the **nett** force is normal force + / – the gravitational acceleration.
- Thus gravitational acceleration is part of the force of gravity”.
- The force (of gravity) is the same;-9.8 m/s - but the acceleration is 9.8 x the weight that the person falls”.
- The force on the large ball.... is 9.8.
- The acceleration of gravity is 9.8.

4.5.5 Confusion regarding upward and downward movement

Students use the direction in which an object is moving as their frame of reference which results in the belief that the directions of the force of gravity and gravitational acceleration change depending on the direction in which the falling object is moving:

- In high school we learnt that gravity is negative when the object moves upward and positive when the object moves downward.

The unexpected responses on the items in the questionnaire regarding movement in opposite directions were explored during the interviews to reveal whether students applied the physics principles differently. From the quantitative results, it seemed that the students perceived the direction of movement as a context on its own and the results of the interviews confirmed that the students were convinced that different principles applied to upward and downward movement. The direction of movement is perceived as a context on its own. The students clearly stated that up- and downward movement were not the same: (I= interviewer)

I: Is up and downward motion the same?

- No it is not, they are not subjected to the same principles.
- No, because the force of gravity is downwards. If a ball is released it will fall but to go upward it has to be thrown.
- If you throw a ball into the air then you throw it (have to exert a force), but if you let it fall then you do not have a force.
- the force of gravity and acceleration acted differently on objects moving upward and downwards.
- No, I regarded the items as totally different items.

4.5.6 Physics principles applicable to vertical and horizontal motion differ

The results from group B also indicated that students thought that different physics principles applied to vertical and horizontal motion in problem settings where they had to consider other variables from which they were used to.

4.5.7 Physics and everyday context

Students disregard formal reasoning when problems seemed to contain a common misconception that they agree with. The remarkable observation that students were unable to transfer and apply physics principles from formal contexts to everyday contexts were investigated in the interviews and the responses indicated that students think that formal physics principles did not apply to everyday contexts, a perception parallel to what Ogilvie, (2009:2) reported: Ogilvie (2009:2) states that students think that the physics world and reality are unrelated, have different spheres of applicability. The confusion regarding the perceived discrepancy between every day and formal contexts was revealed by answers such as:

- In a formal physics context everything is in a box, you do not have to consider anything else but (in an everyday context) you have to read the questions carefully because they like to hide what you have to do."
- Everyday context is not as simple because other factors play a role. In formal context you just have to think which option is most suitable".

- You can imagine yourself in the situation and then compare it with reality but sometimes what you think is going to happen is not as simple.
- You have to know the principle; the balls will reach the ground at the same time even though the one is lighter.
- In practice the handbag will hit the ground first because of its larger weight but if air friction is to be ignored then it is like two round balls and they will hit the ground at the same time as they did in item 6”.
- It is difficult to convert everyday situations to a physics context because everyday context is the reality.
- I would like to test this in practice because you learn that they fall at the same rate but in practice it does not work like that”

4.5.8 Students’ use of equations

In conceptual problems the majority of students did not use equations in symbolic form to help them solve problems or to help them think. Students said that they preferred numerical problems because they find them easier to answer. Students do not use equations in symbolic form to help them solve either numerical or non-numerical problems. Although it is documented (Van Heuvelen, 1991:892; Leonard *et al.*, 1996:1496; Singh, 2007:196) that students find numerical items easier to answer the students in this research did not use equations to solve problems or to help them think when their intuitive knowledge was triggered.

- I use equations normally for numerical values and not to help me think.
- When I read an item which is logical then I do not find it necessary to use an equation. If the item consists of words only then I know you will probably not use an equation. If values are given, then you will have to use an equation.
- I prefer items with values because you can be surer that your answer is correct. If it is in everyday context then you just have to argue the point, otherwise you can use a formula.
- Item 17 is easier to solve because values were given and an equation can be used. In item 6 you have to know it (the principle) by heart, but in item 17 you can check your reasoning by doing a calculation.

The lack of mathematical manipulation skills in an unfamiliar context needed for understanding physics and problem solving reported by Hedge and Meera (2011:135) was also exhibited during these interviews. For some problems set in everyday context, numerical values for some of the variables were given to allow the students to solve the problem by doing calculations. Surprisingly, the students did not even consider using the given values in an equation to solve the problems numerically only one student was able to use an equation in symbolic form effectively after the interviewer suggested it. The inability to proceed even when a student has access to the relevant equations is an intriguing observation and is documented by Hedge and Meera (2011:135). The same deficit was observed during the interviews. With item 10 of the

questionnaire under discussion the following was reported: (S = student's responses; I = interviewer)

S1: If A is directly opposite B then they fall the same distance therefore they will reach the ground at the same time. A will not be faster than B because they cover the same distance.

I: How do the velocities (of the two objects) compare when B starts to move?

S1: A has already a velocity and $B = 0$ but because they cover the same distance they travel the same time as measured from when B starts to move.

I: Would using an equation help to figure out the answer?

S1: (writes down the equation $y = v_i t + \frac{1}{2} a t^2$ and compares the variables) ..y and g are the same, v_i is not the same but t is going to be equal. Because they fall from the same height and move the same (at the same acceleration) so the time must be equal.

S4 The objects move together but one has an initial velocity whereas the other one starts from rest. The one will fall faster but because there is no air resistance, they will land simultaneously depending on the weight.

4.5.9 Influence of friction

Another interesting observation made in this study was that many students are unclear about the influence of friction. Most students did not notice that disregarding concepts such as friction or air resistance, actually simplified the problems; consequently they did not benefit from the simplification. This observation corresponds with reports by researchers such as Halloun and Hestenes (1985a:1045) and Minstrell (1982:11) that students often do not see simplification of contexts as a general physical law hidden beneath distracting factors like friction, and they think that simplified problem contexts have no relevance whatsoever to everyday life. The difficulty that students experience in transferring their reasoning from their intuitive knowledge of situations involving friction to a problem without friction, an occurrence also reported by Singh (2007:196), is demonstrated by this response:

- You know what is going to happen if there is friction and then it is confusing if friction has to be left out."

4.5.10 Variation

Grouping isomorphic problems or examples of problems with the same underlying principle but with different contexts during instruction may force the students to consider the principle instead of just giving an intuitive answer (in accordance with the variation theory for teaching).

- Initially I said that mass would have an influence and that the heavier ball will have a larger velocity but now I realize that all the items in this group have the same underlying principle. but grouping the items together does not jumble your knowledge and it is easier now to recognise the same principle

- The friction prevents you from accelerating faster.
- I think it is better to draw diagrams as long as you understand the diagrams.

4.5.11 Students were inconsistent in their reasoning

As expected, students did not respond consistently to similar problems set in different contexts (Alonzo & Steedle, 2009:390) which may be indicative of compartmentalised learning (Hutchinson & Elby, 2013:196; Hedge & Meera, 2012:2). When students had to compare the movement of two objects of different mass sliding down an incline, they predicted that more massive object will reach the higher velocity a similar occurrence to that reported by Klopfer *et al.* (1983:178). Students' reasoning was not consistent as they either did not apply the same principles to equivalent situations or adjusted their thinking according to the familiarity of the problem setting. The different answers given on the isomorphic items in group B, founded on the same principle items indicated that students changed their reasoning because they answered, differently.

4.5.12 Qualitative reasoning

During the interviews the students were asked to think aloud which initiated qualitative reasoning. Consequently some students were able to recognise flaws in their reasoning and change their answers in agreement to the underlying principle of the problem.

- Because the one that moved first has a different speed when they start moving together, therefore it will reach the ground first. If they were at the same height and of equal mass then they would reach the ground at the same time but now I see they do not have the same initial speed and that I chose the wrong option.
- In practice the handbag will hit the ground first because of its larger weight but if air friction is to be ignored then it is like two round balls and they will hit the ground at the same time as they did in item 6".
- The one that moved first has a different speed when they start moving together; therefore it will reach the ground first. If they were at the same height and of equal mass then they would reach the ground at the same time but now I see they do not have the same initial speed and that I chose the wrong option".
- Force... is not the same. $F = ma$ so the larger mass will need a bigger force. F and g are both the same but $g = \frac{GM}{r^2}$ and also $F=mg$ so mass has influence". Oh! The force is not the same if the mass differs but the acceleration will be the same. I do not know why I said the larger ball will have the larger initial velocity".
- It helps if you do your reasoning aloud. We students usually do not read the item properly and answer without thinking, too fast.

4.5.13 The value of errors

The errors students make can tell us a lot about how students think as they tend to fall in patterns indicating common misconceptions. The cumulative percentage of students who chose the option of “at the same time” in items in group C revealed the importance of using correct wording in questions and it also revealed students resistance to using appropriate physics equations to help them in conceptual reasoning. In this case, instead of threatening validity, misinterpretations signal the phenomenon we are studying.

4.5.14 The usage of different representational formats

Bozdogan and Demirba (2009:146) found that the usage of different representational formats during instruction contribute to guiding student approach and ability in problem solving an opinion shared by Alonzo and Steedle (2009:390).

I: Does it make a difference if a problem is supported with a diagram?

S: Yes, a diagram makes it better; it makes more sense if one is provided. If I draw a diagram it may be wrong and then the whole item will be wrong.

4.6 Summary

Despite the fact that research had been pointing out the presence of misconceptions in students' intuitive reasoning since the 1980's, little had been done to address this problem at school- and first year physics level. Teachers lecture about how to use formulae as a result students learn to use physics without fully understanding the fundamental concepts (Concannon, 2012:22). In such cases, students' knowledge of physics concepts seems to be relative to how familiar they are to the problem they are trying to solve. Rather than creating the situated learning, physics teachers should facilitate students' fluent understanding of physics concepts. It is suggested that the concept of misconceptions is included in the curriculum of physics students as well as student teachers' training from the first year. This may be an opportunity to address the misconceptions early in the study course, which may result in improved understanding of physics concepts.

In this chapter the results of the empirical study were presented and discussed. In the final chapter the results are summarized and the research questions answered. The study concludes with highlighting the contribution of this research study to the existing body of knowledge.

Chapter 5

SUMMARY AND CONCLUSIONS

5.1 Overview of study

Contextual questions, i.e. questions set in everyday context, are better indicators of conceptual understanding than formal physics questions. One student comment was to the researcher's opinion sufficient motivation for the preceding statement: "People who compile questions can test your physics knowledge by using questions set in formal physics context but instead they are spiteful and set it in everyday context, which does not test your knowledge". The students also discriminated between conceptual knowledge and conceptual understanding: "There is a difference between knowing something and understanding it. If you understand something it is easier to remember".

In this dissertation an explanatory sequential mixed methods design was used to obtain information regarding student application of physics conceptual knowledge in solving kinematics problems in various contexts. To the authors knowledge this study is the first to investigate the influence of the direction of movement as a context in problem solving.

Chapter 1 presented the motivation for this study where a gap in the literature was identified in terms of the influence of the direction of movement as a context in problem solving. A brief overview of current literature relevant to this study was given and the aims, objectives and research questions were set out.

In Chapter 2 a comprehensive overview of existing literature in the body of knowledge regarding physics education and student knowledge was given. The study was set against epistemology as the theoretical framework and focused on literature on student perception of learning and knowledge in physics, the relationship between mathematics and physics; everyday life and physics.

Chapter 3 comprised of comprehensive explanations about the choice of methodology and application of the method used for the investigation. The various methods of data processing were also described in detail; statistical processes comprised of frequency tables and statistical test included the McNemar contingency test and determination of the Phi coefficient by means of a chi-squared test. To determine the validity and reliability of the questionnaire Cronbach' Alpha and mean inter item correlations were calculated. Analysis of the quantitative data from the questionnaire directed the information gathered during the interviews.

Next the results were presented, analysed and discussed in Chapter 4. The results of the research is summarized and presented in the following paragraph.

5.2 Summary of results

The misconceptions and other ambiguities that were revealed in the investigation are summarized in this paragraph.

Misconception: Heavy objects fall faster.

A large percentage of students still have the misconception that heavy objects fall faster and do not understand the concept of free fall.

Students think that the force of gravity is equal on all falling objects.

Students are uncertain whether the magnitude of the force of gravity or the gravitational acceleration is equal for all falling objects. Many students believe that the force of gravity exerted by the earth is equal on all objects.

Students' lack of conceptual understanding

The results of this study indicate that students rely on their memory of familiar problems instead of applying their physics knowledge to solve problems. Students solve formal conceptual questions, especially those of a familiar nature often found in textbooks, more correctly than questions set against every day- or unfamiliar context. It seemed that students relied largely on their memory of previous applications or demonstrations of the underlying concepts of problems. The answers given on questions regarding the different knowledge required to answer formal and contextual questions unmistakably revealed a large void in their conceptual understanding.

Confusion about the meaning and/or implication of physics concepts

Students are uncertain about the difference between the meanings of the terms force and net force. Some students regard acceleration only as increase in velocity. The lack of discrimination between the terms gravitational force and gravitational acceleration leads to the terms being used as if they have the same meaning. The difference between the effect of the force of gravity and the magnitude of the force is not clear. Students refer to the mass and the weight of the objects indiscriminately.

Confusion regarding up- and downward movement and vertical and horizontal planes

Students use the direction in which an object is moving as their frame of reference instead of using the direction of the net force as reference for indicating the vector nature of the physics quantities. Students perceived the direction of movement as a separate context and think that different principles apply to up- and downward movement. Students do not apply physics principles in vertical and horizontal motion, consistently.

Physics in everyday context

Students disregard formal reasoning when problems seemed to contain a common misconception that they agree with. Students have difficulty to transfer and apply physics principles from formal contexts to everyday contexts. Students think that formal physics principles do not apply to everyday contexts. Students think that the physics world and reality are unrelated and apply physics principles differently in different domains. Students look for feature attributes in problems on which they base their reasoning instead of evaluating the problem carefully

Students' use of equations

Students lack mathematical manipulation skills needed for understanding physics and for problem solving in altered and unfamiliar contexts. Most students are unable to use equations in symbolic form as tools to assist their thinking partly because they lack the skills to use the physics tool that are available. Students find numerical items easier to answer and do not use equations even when it was available, to solve problems or to help them think when their intuitive knowledge was triggered

Influence of friction

Many students are unclear about the influence of friction and did not notice that disregarding concepts such as friction or air resistance, actually simplified the problems. Students have difficulty in transferring their reasoning from their intuitive knowledge of situations involving friction to a problem without friction.

Variation in teaching

Grouping isomorphic problems or examples of problems with the same underlying principle but with different contexts during instruction clarifies the principle instead of invoking an intuitive answer. The use of different representational formats during instruction guides students' approach towards problem solving strengthens their ability to identify the underlying principles and enhances conceptual understanding.

Inconsistencies

Students do not answer similar problems set in different contexts consistently and struggle to solve problems when the variable they are required to solve, differs from one usually asked. They also do not apply the same physics principles consistently to different directions of motion.

Qualitative reasoning

Students are not used to implement qualitative reasoning. Some students are able to recognise flaws in their reasoning and change their answers in agreement to the underlying principle of the problem when they think aloud.

Value of errors

The errors students make reveal much about how students think, as trends indicating common misconceptions and cueing of students' answers were noticed.

5.3 Answers to research questions

The results of the empirical study enabled the researcher to address the research questions as follows:

Question 1: To what extent does students' naïve and conceptual knowledge influence their ability to recognise underlying physics concepts in isomorphic problems?

Students tend to apply naïve knowledge or misconceptions to physics problems set in everyday contexts because they do not understand the principles and the relevance of those principles to their daily life. Students' ability to solve formal contextual problems similar to those encountered in textbooks give a false indication that they understand and are able to apply physics principles. When students are presented with problems in unfamiliar context, they revert to naïve knowledge and do not recognise the physics principle underlying that problem. Students prefer numerical problems that can be solved by substituting numerical values into an equation but they have difficulty in transferring their reasoning from their intuitive knowledge of situations

involving friction to a problem without friction. Students find it hard to apply formal reasoning to unfamiliar situations and revert to naïve knowledge when presented with unfamiliar physics problems.

Question 2: What information regarding students' application of conceptual understanding is revealed by the context of physics problems?

Students often do not answer similar problems set in different contexts in the same way. This indicates that students' physics knowledge is much fragmented and their reasoning inconsistent as they do not view the body of knowledge as coherently founded on a few principles. When the variable to be solved is changed, or the context or a perceived feature of the context is changed, many students are unable to identify and apply the appropriate principles revealing their lack of conceptual understanding. Isomorphic problems containing unfamiliar contexts reveal whether students merely know a principle or whether they understand the principle and its implications in kinematics. Students tend to regard upward motion, downward movement and horizontal movement as separate contexts subject to different physics principles. By changing the direction of movement in a formal conceptual problem, the focus is still on the physics principle whereas setting the problem in everyday context triggers students' naïve knowledge, making the problem more complicated. Applying the principle in different directions of motion may enhance understanding of the principle, which may help transfer to other unfamiliar situations such as every day contexts.

Question 3: To what extent do students use physics principles to reason qualitatively to promote a stronger coherence of kinematics and connect appropriate equations to physics principles?

Students seem to rely on their memory of familiar problems instead of applying their physics knowledge to solve problems. Students do not use qualitative reasoning to promote a stronger coherence of kinematics or make appropriate connections between physics concepts and the mathematical equations that they are expected to use. The majority of students did not consider and/or were unable to use equations in symbolic form as tools to assist their thinking. The students struggled to adjust their thinking framework to a physics one, partly because their misconceptions were so deeply rooted and because they lack the skills to use the physics tool that are available.

Question 4: To what extent do students experience conceptual deficiencies and what is the nature and effect of such possible conceptual deficiencies?

A large percentage of students still have misconceptions about kinematics e.g. that heavy objects fall faster and the majority of students do not understand the concept of free fall. Students have difficulty in transferring their reasoning from their intuitive knowledge of situations involving friction to a problem without friction. These students do not know and are unaware of the importance of the precise meaning of physics concepts. They have poor understanding of physics concepts and their application of conceptual knowledge is influenced by the context of a problem. Students often have difficulty to transfer and apply physics principles from formal contexts to everyday contexts. They think that formal physics principles do not apply to everyday contexts. Students tend to think that the physics world and reality are unrelated and apply physics principles differently in different domains.

5.4 Conclusions

The main question this research attempted to answer was: To what extent do the first year university physics students use physics principles in solving physics kinematics problems? The conclusion of the study is that there is a remarkable deficit in the group of first year university physics students' ability to consistently use physics principles in solving kinematics problems. Students seem to regard formal conceptual problems as true physics problems while problems with numerical values are viewed as mere mathematical procedures and problems set in everyday contexts are solved by applying naïve knowledge.

5.5 Implications and value of this research study

Striving to change the way physics are taught nationwide is an idealistic but unrealistic aim. Teachers do not have access to the results of research and are mostly ignorant of findings that could be implemented to improve the level of teaching physics and enhance students' levels of conceptual understanding. The researcher suggests that environments that support student learning of concepts should be created, e.g. by rewriting physics questions. By changing the wording, the physical system, the variable to be solved for, or the direction of motion, a familiar item can be converted into an indicator of the level of conceptual understanding instead of just determining whether students are able to recite a principle. A result of aligning the context and the concept is that students realize what the concept really means and that they can use the concept as a tool to assist their reasoning. This may enable students to apply this concept to various other situations in a useful manner i.e. the ability to transfer such understanding to relevant new situations.

The results of this research have valuable contributions in various aspects. It showed that the questionnaire consisting of isomorphic problem paired questions can serve as indicator of whether students merely know or really understand a physics principle. Student response patterns on sets of questions can be analysed in greater detail, which is more valuable than the binary (correct or incorrect) analysis. Such an analysis has implications for instructors seeking to target instruction in their classroom to those areas where students have their greatest needs.

The different characteristics of the context of problems as the backdrop, against which physics problems are posed, influence the type and source of knowledge required in the certain conceptual framework to solve the problems. Where the context of physics problems previously referred to physics problems set in everyday, numerical or formal conceptual context, the direction of movement as an additional context can now be included.

Further research can be undertaken in a variety of ways. One of these is to investigate students' understanding of the meaning of definitions and their ability to relate definitions to mathematical equations and the use of equations as tools to develop conceptual understanding. Concentration analysis of erroneous answers can be executed to determine the type and range of cues in distracters and their influence on students answers. The study can be used to compare the responses of the male and the female students as well as the calculus- and non-calculus-based students. Furthermore; an important implication for physics instruction is to implement the direction of motion as a variation in physics instruction as well as assessment to develop students' perception of physics concepts as a coherent body of knowledge.

As a final conclusion, this study contributes to the field of Physics Education Research by implementing the direction of movement as a variation in teaching for and assessment of conceptual understanding of physics. This study also presents a self-complied questionnaire that allows investigation of various aspects and context of physics knowledge application.

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Appendix A

6.1 Questionnaire

6.1.1 Demographic questions

D1 What year did you pass grade 12?

(1) 2013

(2) 2012

(3) 2011

(4) 2010

(5) 2009

(6) 2008

(7) before 2008

D2. Please indicate your gender:

(1) Female

(2) Male

D3. Please indicate your Physics module and course you are enrolled:

(1) FSKS 111

(2) FSKS 113

D4. What study course are you enrolled for?

(1) BIng

(2) BSc

(3) Other

D5. Will you be willing to participate in an interview on your response to this questionnaire?

(1) Yes

(2) No

6.1.2 Physics questions

Q 6 Two metal balls are the same size but one weighs twice as much as the other. The balls are dropped from the roof of a single story building at the same instant of time. Air resistance can be neglected.

Which ball will reach the ground first?

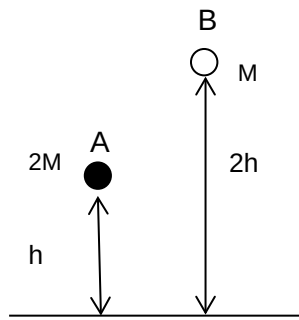
- (1) The heavier ball.
- (2) The lighter ball.
- (3) Both will reach the ground simultaneously.
- (4) Not enough information is provided.

Q 7 Which ball in Item 6 will reach the ground with the largest speed?

- (1) The heavier ball.
- (2) The lighter ball.
- (3) Both will reach the ground with the same speed.
- (4) Not enough information is provided

Q 8 Two metal balls are dropped simultaneously from different heights. Ball A has twice the mass of ball B but falls half the distance to the ground. Ignore the effect of air resistance. Which ball will reach the ground first?

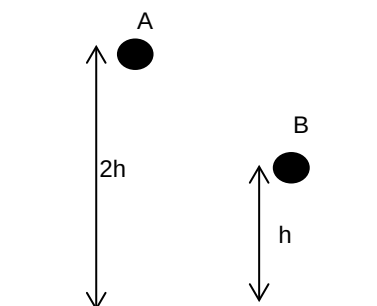
- (1) Ball A.
- (2) Ball B.
- (3) Both will reach the ground simultaneously.
- (4) Not enough information is provided.



Q9. Which ball in Item 8 will reach the ground with the largest speed?

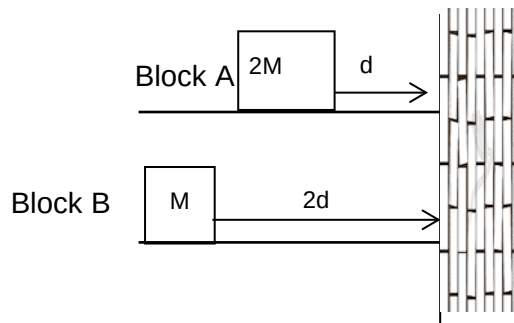
- (1) Ball A.
- (2) Ball B.
- (3) Both will reach the ground with the same speed.
- (4) Not enough information is provided.

Q10. Two balls A and B with the same mass are dropped from different heights and at different times. The initial height of ball A is twice that of ball B. Ball A is released first. Ball B is released at the exact moment that ball A passes ball B at height h . Ignore the effect of air resistance. Which ball will reach the ground first?



- (1) Ball A, because it reaches a larger speed.
- (2) Ball B, because it travels a shorter distance.
- (3) Both will reach the ground simultaneously because A travels a longer distance and reaches a larger speed.
- (4) Both will reach the ground simultaneously because they travel the distance h together.

Q11. Two blocks with different mass are simultaneously pulled from rest along a horizontal plane with identical constant accelerations. Block A has twice the mass of B but travels half the distance of block B. Which one will reach the wall first? Friction can be neglected.

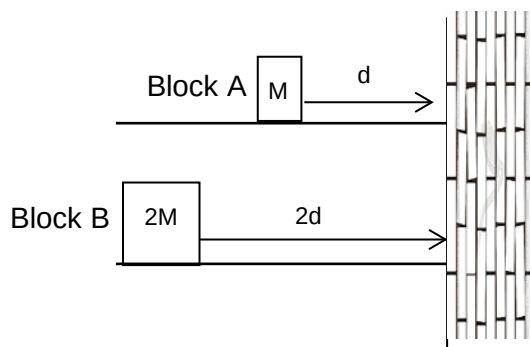


- (1) Block A.
- (2) Block B.
- (3) Both will reach the wall at the same time.
- (4) Not enough information is provided.

Q12. Which block in Item 11 will reach the wall with the larger speed?

- (1) Block A.
- (2) Block B.
- (3) Both will reach the wall with the same speed.
- (4) Not enough information is provided.

Q13. Two blocks, A (mass M) and B (mass $2M$), are accelerated over different distances. The force on block B is twice the force on block A and the distance over which B is accelerated is twice that of block A. Block B is moved first. Block A is moved at the exact moment that block B passes block A at distance d . Friction can be neglected



Which block will reach the wall first?

- (1) Both will reach the wall simultaneously because they travel the distance d together.
- (2) Both will reach the wall simultaneously because B travels a longer distance and reaches a larger speed.
- (3) Block A because it travels a shorter distance.
- (4) Block B because it reaches a larger speed.

Q16. While in a playground you and your 10 year old niece slide down two frictionless slides of similar height. Your mass is three times that of your niece. Assuming that both of you begin sliding from rest, which one of the following statements best describes who has a larger speed at the bottom of the slide?

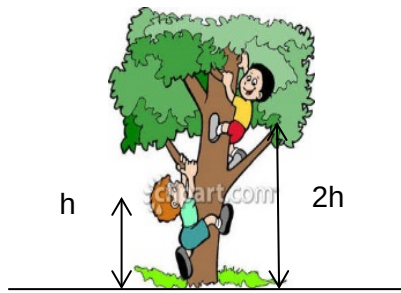
- (1) Your niece because she is not pressing down against the slide as strongly so her motion is closer to free fall than yours.
- (2) You because your larger weight causes a greater downward acceleration.
- (3) Your niece because lighter objects are easier to accelerate.
- (4) Both of you will have the same speed at the bottom.

Q17. During a family outing to an amusement park, a mother decides to take her young son on a Ferris wheel. At the highest point of the wheel, 30 m above the ground, the mother's overfull handbag (2 kg) and the little boy's small stuffed teddy bear (0.5 kg) accidentally fall out of the basket at the same time. The father, watching from the ground, acts immediately and tries to catch the two objects. Which statement is true for the time it takes for them to reach the ground? (Air resistance can be neglected).

- (1) The handbag will reach the ground first.
- (2) The teddy bear takes 4 times as long as the handbag.
- (3) Both will reach the ground simultaneously.
- (4) Not enough information is provided.

Q18. Bob and Martin, who weigh the same, climb up a tree. Bob reaches twice the height as Martin does above the ground when he loses his footing and falls. Martin is so concerned for

his friend that at the exact moment Bob passes him on his way down, he loosens his grip and falls down as well. Ignore the effect of air resistance. Which boy will reach the ground first?



- (1) Martin because he travels a shorter distance.
- (2) Bob because he reaches a larger speed.
- (3) Both will reach the ground simultaneously because Bob travels a longer distance and reaches a larger speed.
- (4) Both will reach the ground simultaneously because they travel the distance h together.

Q20. Consider two metal balls that are the same size, one weighing twice as much as the other. These balls are thrown upwards from the ground and reach the roof of a single story building at the same time. Air resistance can be neglected.

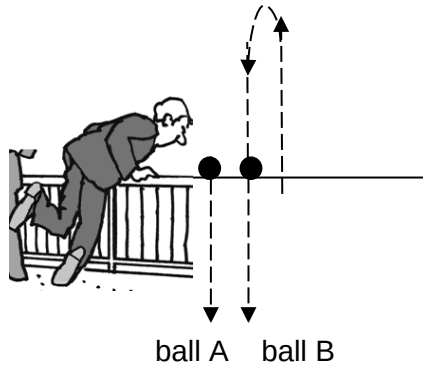
Which statement is true about their initial velocities?

- (1) The heavier ball must have the larger initial velocity.
- (2) The lighter ball must have the larger initial velocity.
- (3) Both are projected with the same initial velocity.
- (4) Not enough information is provided.

Q22. A 1-kg ball and a 5 kg ball are thrown into the air both with an initial vertical velocity of 30 m/s. Ignore the effect of air resistance. Which statement is true for the heights they reach?

- (1) the 1 kg ball reaches a height of 45 m.
- (2) the 5 kg ball reaches a height of 9 m.
- (3) they will reach the same height.
- (4) not enough information is provided.

Q24. Amlay Zee throws two cricket balls, one after the other, from the ground to his friend on the second floor of a building, 6 m above the ground. His friend catches the first ball (A) but misses the second ball (B) on its way up. He tries to catch ball B on its way down 1 s later, but accidentally lets go of ball A at the same moment, resulting in losing them both. The mass of a cricket ball is given as 150 g and air resistance can be ignored. Which ball will reach the ground first?



- (1) Ball A
- (2) Ball B
- (3) They will reach the ground at the same time
- (4) Not enough information is provided

Appendix B

RESULTS OF RESEARCH

7.1 Results of quantitative research

7.1.1 Reliability

Table 7-1: Cronbach's Alpha and inter-item statistics for all items in the questionnaire

Reliability Statistics Questionnaire							
Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items				N of Items		
0.726	0.724				14		

Summary Item Statistics							
	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Inter-Item Correlations	0.158	-0.035	0.535	0.570	-15.343	0.014	14

Item-Total Statistics					
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
qq6	7.13	8.536	0.303	0.364	0.715
qq7	7.28	7.909	0.460	0.394	0.696
qq8	7.11	8.632	0.278	0.128	0.717
qq9	7.31	8.118	0.361	0.165	0.708
qq10	7.41	7.943	0.402	0.363	0.702
qq11	7.56	7.976	0.396	0.174	0.703
qq12	7.25	8.696	0.158	0.071	0.730
qq13	7.53	8.095	0.346	0.212	0.709
qq16	7.68	8.370	0.283	0.146	0.717
qq17	7.33	8.193	0.325	0.297	0.712
qq18	7.38	8.020	0.379	0.366	0.705
qq20	7.62	8.320	0.280	0.246	0.717
qq22	7.53	8.079	0.352	0.254	0.709
qq24	7.47	7.991	0.381	0.254	0.705

Table 7-2: Cronbach's Alpha and inter item statistics for group A

Reliability Statistics Group A						
Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items				N of Items	
0.687	0.692				6	
Summary Item Statistics						
	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance
Inter-Item Correlations	0.272	0.118	0.517	0.399	4.392	0.015
Item-Total Statistics						
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted	
qq6	2.41	2.300	0.465	0.355	0.637	
qq7	2.56	2.127	0.453	0.316	0.634	
qq16	2.95	2.252	0.361	0.136	0.664	
qq17	2.61	2.055	0.482	0.290	0.623	
qq20	2.90	2.223	0.353	0.218	0.668	
qq22	2.81	2.115	0.409	0.237	0.650	

Table 7-3: Cronbach's Alpha and inter item statistics for group B

Reliability Statistics Group B

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.420	0.419	4

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance
Inter-Item Correlations	0.153	0.054	0.216	0.161	3.986	0.003

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
qq8	1.79	0.898	0.207	0.052	0.379
qq9	1.99	0.696	0.295	0.087	0.280
qq11	2.24	0.698	0.260	0.075	0.321
qq12	1.93	0.807	0.177	0.038	0.408

Table 7-4: Cronbach's Alpha and inter item statistics for Group C

Reliability Statistics Group C						
Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items				N of Items	
0.692	0.692				5	
Summary Item Statistics						
	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance
Inter-Item Correlations	0.310	0.176	0.535	0.359	3.042	0.012
Item-Total Statistics						
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted	
qq10	1.93	1.789	0.539	0.341	0.601	
qq11	2.07	2.115	0.277	0.083	0.711	
qq13	2.05	1.923	0.426	0.187	0.651	
qq18	1.90	1.788	0.549	0.358	0.597	
qq24	1.98	1.879	0.456	0.221	0.638	

7.1.2 Quantitative data of student responses

Table 7-5: Frequency table of student responses on questionnaire

Item	Option	Frequency	Percentage %
6	1	71	14.76
	2	5	1.04
	3	404	83.99
	4	1	0.21
7	1	118	24.53
	2	25	5.20
	3	332	69.02
	4	6	1.25
8	1	414	86.07
	2	14	2.91
	3	51	10.60
	4	2	0.42
9	1	61	12.68
	2	317	65.90
	3	95	19.75
	4	8	1.66
10	1	266	55.53
	2	30	6.26
	3	48	10.02
	4	135	28.18
11	1	197	41.13
	2	55	11.48
	3	214	44.68
	4	13	2.71
12	1	37	7.69
	2	345	71.73
	3	84	17.46
	4	15	3.12
13	1	108	22.59
	2	114	26.85
	3	47	9.83
	4	209	43.72
16	1	45	9.36
	2	233	48.44
	3	62	13.10
	4	140	29.11
17	1	105	21.88

	2	61	12.71
	3	306	63.75
	4	8	1.67
18	1	17	3.53
	2	282	58.63
	3	66	13.72
	4	116	24.12
20	1	250	51.98
	2	56	11.64
	3	168	34.93
	4	7	1.46
22	1	91	19.24
	2	63	13.32
	3	211	44.61
	4	108	22.83
24	1	49	10.38
	2	241	51.06
	3	172	36.44
	4	10	2.12

Table 7-6: Contingency tables of McNemar test statistic for group A

	Construct	Paired items a:b	Both x %	Both $\sqrt{}$ %	one $\sqrt{}$, one x %	ω (practical significance)
A1	F $\downarrow$ t vs F $\downarrow$ v	6: 7	13.72	66.7	19.5	0.35
A2	F $\downarrow$ t vs C $\downarrow$ v	6: 16	14.6	27.7	57.8	0.72
A3	F $\downarrow$ t vs C N $\downarrow$ t	6: 17	14.1	61.7	24.1	0.41
A4	F $\downarrow$ t vs F $\uparrow$ v	6: 20	12.5	31.3	56.1	0.65
A5	F $\downarrow$ v vs F N $\uparrow$ d	6: 22	12.5	40.3	47.2	0.58
A6	F $\downarrow$ v vs C $\downarrow$ v	7: 16	27.4	25.5	47.0	0.58
A7	F $\downarrow$ v vs C N $\downarrow$ t	7: 17	20.0	52.6	27.4	0.01
A8	F $\downarrow$ v vs F $\uparrow$ v	7: 20	23.1	27.0	50.0	0.48
A9	F $\downarrow$ v vs F N $\uparrow$ d	7: 22	22.0	34.9	43.0	0.38
A10	C $\downarrow$ v vs C N $\downarrow$ t	16: 17	31.6	24.3	44.1	0.52
A11	C $\downarrow$ v vs F $\uparrow$ v	16: 20	50.1	14.9	34.1	0.10
A12	C $\downarrow$ v vs F N $\uparrow$ d	16: 22	45.1	18.1	36.7	0.24
A13	C N $\downarrow$ t vs F $\uparrow$ v	17: 20	28.5	27.0	44.5	0.43
A14	C N $\downarrow$ t vs F N $\uparrow$ d	17: 22	26.0	33.5	40.5	0.31
A15	F $\uparrow$ v vs F N $\uparrow$ d	20: 22	47.0	25.8	27.2	0.17

Table 7-7: Correlation of paired items for group A

	Construct	Paired items a:b	%(bx/ax)	%(b√/a√)	%(bx/a√)	%(b√/ax)	Φ_q phi coefficient items
A1	F ↓ t vs F ↓ v	6: 7	85.7	79.5	20.5	14.3	0.517
A2	F ↓ t vs C ↓ v	6: 16	90.9	32.9	67.1	9.1	0.192
A3	F ↓ t vs C N ↓ t	6: 17	88.3	73.5	26.5	11.7	0.471
A4	F ↓ t vs F ↑ v	6: 20	77.9	37.4	62.6	22.1	0.118
A5	F ↓ v vs F N ↑ d	6: 22	77.9	48.0	52.0	22.1	0.192
A6	F ↓ v vs C ↓ v	7: 16	88.6	37.0	63.0	11.4	0.261
A7	F ↓ v vs C N ↓ t	7: 17	64.4	76.2	23.8	35.6	0.391
A8	F ↓ v vs F ↑ v	7: 20	74.5	39.2	60.8	25.5	0.132
A9	F ↓ v vs FN ↑ d	7: 22	71.1	50.6	49.4	28.9	0.203
A10	C ↓ vs C N ↓ t	16: 17	44.6	83.6	16.4	55.4	0.266
A11	C ↓ v vs F ↑ v	16: 20	71.8	51.4	48.6	28.2	0.222
A12	C ↓ v vs F ↑ d	16: 22	63.6	62.1	37.9	36.4	0.236
A13	C N ↓ t vs F ↑ v	17: 20	78.3	42.5	57.5	21.7	0.210
A14	CN ↓ t vs FN ↑ d	17: 22	71.4	52.6	47.4	28.6	0.233
A15	F ↑ v vs FN ↑ d	20: 22	72.2	73.8	26.2	18.1	0.442
A16		6,16,17	79.2	28.96			0.23
A17		6, 20, 22	12.99	28.96			0.456

Table 7-8: Correlation of options in paired items (Φ_o) for group A

	Construct	Paired items a:b	%(bx/ax)	%(b $\sqrt{a}$ /a $\sqrt{a}$)	%(bx/a $\sqrt{a}$)	%(b $\sqrt{a}$ /ax)	Φ_o coeffi- cient (options)
A1	F $\downarrow$ t vs F $\downarrow$ v	6: 7	83.7	71.8	28.2	16.3	0.457
A2	F $\downarrow$ t vs C $\downarrow$ v	6: 16	53.4	59.2	40.8	46.6	0.089
A3	F $\downarrow$ t vs C N $\downarrow$ t	6: 17	74.3	85.9	14.1	25.7	0.450
A4	F $\downarrow$ t vs F $\uparrow$ v	6: 20	49.5	60.6	39.4	50.5	0.072
A5	F $\downarrow$ v vs F N $\uparrow$ d	6: 22	70.0	47.8	52.2	30.0	0.135
A6	F $\downarrow$ v vs C $\downarrow$ v	7: 16	56.5	63.6	36.4	43.5	0.172
A7	F $\downarrow$ v vs C N $\downarrow$ t	7: 17	75.8	66.7	33.3	24.2	0.383
A8	F $\downarrow$ v vs F $\uparrow$ v	7: 20	49.3	55.9	44.1	50.7	0.045
A9	F $\downarrow$ v vs F N $\uparrow$ d	7: 22	71.1	43.6	56.4	28.9	0.135
A10	C $\downarrow$ v vs C N $\downarrow$ t	16: 17	71.8	41.4	58.6	28.2	0.138
A11	C $\downarrow$ v vs F $\uparrow$ v	16: 20	54.4	58.8	41.2	45.6	0.132
A12	C $\downarrow$ v vs F N $\uparrow$ d	16: 22	71.3	36.7	63.3	28.7	0.085
A13	C N $\downarrow$ t vs F $\uparrow$ v	17: 20	53.5	62.0	38.0	46.5	0.148
A14	C N $\downarrow$ t vs F N $\uparrow$ d	17: 22	73.3	43.6	56.4	26.7	0.172
A15	F $\uparrow$ v vs F N $\uparrow$ d	20: 22	82.0	46.1	53.9	18.0	0.300

Table 7-9: Contingency tables for McNemar test statistic for group B

	Construct	Paired items a:b	Both x nr students	Both $\sqrt{a}$ nr students	a $\sqrt{a}$; nr students	b $\sqrt{a}$ nr students	ϕ (practical significance)
B1	F $\downarrow$ t vs F $\downarrow$ v	8:9	36	286	128	31	0.35
B2	F $\downarrow$ t vs F $\rightarrow$ t	8:11	55	185	229	12	0.64
B3	F $\downarrow$ t vs F $\rightarrow$ v	8:12	23	301	113	44	0.25
B4	F $\downarrow$ v vs F $\rightarrow$ t	9:11	121	154	163	43	0.38
B5	F $\downarrow$ v vs F $\rightarrow$ v	9:12	65	246	71	99	0.10
B6	F $\rightarrow$ t vs F $\rightarrow$ v	11:12	92	153	44	192	0.44

Table 7-10: Correlation of paired items for group B

	Construct	Paired items a:b	%(bx/ax)	%(b $\sqrt{}$ /a $\sqrt{}$)	%(bx/a $\sqrt{}$)	%(b $\sqrt{}$ /ax)	Φ_q (correlation items)
B1	F $\downarrow$ t vs F $\downarrow$ v	8:9	53.7	69.1	30.9	46.3	0.167
B2	F $\downarrow$ t vs F $\rightarrow$ t	8:11	82.1	44.7	55.3	17.9	0.189
B3	F $\downarrow$ t vs F $\rightarrow$ v	8:12	34.3	72.7	27.3	65.7	0.054
B4	F $\downarrow$ v vs F $\rightarrow$ t	9:11	73.8	48.6	51.4	26.2	0.216
B5	F $\downarrow$ v vs F $\rightarrow$ v	9:12	39.6	77.6	22.4	60.4	0.181
B6	F $\rightarrow$ t vs F $\rightarrow$ v	11:12	32.4	77.7	22.3	67.6	0.110

Table 7-11: Correlation of options in paired items for group B

	Construct	Paired items a:b	%(bx/ax)	%(b $\sqrt{}$ /a $\sqrt{}$)	%(bx/a $\sqrt{}$)	%(b $\sqrt{}$ /ax)	Φ_o (correlation options)
B1	F $\downarrow$ t vs F $\downarrow$ v	8:9	81.9	33.3	66.7	18.1	0.117
B2	F $\downarrow$ t vs F $\rightarrow$ t	8:11	58.8	72.5	27.5	41.2	0.194
B3	F $\downarrow$ t vs F $\rightarrow$ v	8:12	82.8	19.6	80.4	17.2	0.019
B4	F $\downarrow$ v vs F $\rightarrow$ t	9:11	61.1	67.4	32.6	38.9	0.228
B5	F $\downarrow$ v vs F $\rightarrow$ v	9:12	86.3	32.6	67.4	13.7	0.198
B6	F $\rightarrow$ t vs F $\rightarrow$ v	11:12	86.5	22.4	77.6	13.5	0.117

Table 7-12: Contingency tables for McNemar statistic for group C

	Construct	Paired items a:b	Both x nr students	Both $\checkmark$ nr students	$a\checkmark$; nr students	$b\checkmark$ nr students	ϕ (practical significance)
C1	$F \downarrow t$ vs $F \rightarrow t$	10:11	150	132	134	65	0.22
C2	$F \downarrow t$ vs $F \rightarrow t$	10:13	162	156	110	53	0.24
C3	$F \downarrow t$ vs $C \downarrow t$	10:18	152	219	47	63	0.07
C4	$F \downarrow t$ vs $C N \downarrow t$	10:24	153	179	87	62	0.09
C5	$F \rightarrow t$ vs $F \rightarrow t$	11:13	187	112	85	97	0.04
C6	$F \rightarrow t$ vs $C \downarrow t$	11:18	138	136	61	146	0.27
C7	$F \downarrow t$ vs $C N \downarrow$	11:24	167	124	73	117	0.14
C8	$F \rightarrow t$ vs $C \downarrow t$	13:18	155	165	44	117	0.26
C9	$F \rightarrow t$ vs $C N \downarrow t$	13:24	167	136	73	105	0.11
C10	$C \downarrow t$ vs $C N \downarrow t$	18:24	147	189	93	52	0.16

Table 7-13: Correlation of paired items for group C

	Construct	Paired items a:b	$\%(bx/ax)$	$\%(b\checkmark/a\checkmark)$	$\%(bx/a\checkmark)$	$\%(b\checkmark/ax)$	Φ_q (correlation) items
C1	$F \downarrow t$ vs $F \rightarrow t$	10:11	69.8	49.6	50.4	30.2	0.198
C2	$F \downarrow t$ vs $F \rightarrow t$	10:13	75.3	58.6	41.4	24.7	0.341
C3	$F \downarrow t$ vs $C \downarrow t$	10:18	70.7	82.3	17.7	29.3	0.535
C4	$F \downarrow t$ vs $C N \downarrow t$	10:24	71.2	67.3	32.7	28.8	0.382
C5	$F \rightarrow t$ vs $F \rightarrow t$	11:13	65.8	56.9	43.1	34.2	0.225
C6	$F \rightarrow t$ vs $C \downarrow t$	11:18	48.6	69.0	31.0	51.4	0.176
C7	$F \downarrow t$ vs $C N \downarrow t$	11:24	58.8	62.9	37.1	41.2	0.214
C8	$F \rightarrow t$ vs $C \downarrow t$	13:18	57.0	78.9	21.1	43.0	0.362
C9	$F \rightarrow t$ vs $C N \downarrow t$	13:24	61.4	65.1	34.9	38.6	0.262
C10	$C \downarrow t$ vs $C N \downarrow t$	18:24	73.9	67.0	33.0	26.1	0.403

Table 7-14: Correlation of options for items in group C

	Construct	Paired items a:b	%(bx/ax)	%(b√/a√)	%(bx/a√)	%(b√/ax)	Φ_o coefficient (options)
C1	$F \downarrow t$ vs $F \rightarrow t$	10:11	60.7	53.0	47.0	39.3	0.134
C2	$F \downarrow t$ vs $F \rightarrow t$	10:13	64.4	63.4	36.6	35.6	0.271
C3	$F \downarrow t$ vs $C \downarrow t$	10:18	82.9	71.6	28.4	17.1	0.545
C4	$F \downarrow t$ vs $C N \downarrow t$	10:24	77.2	56.8	43.2	22.8	0.345
C5	$F \rightarrow t$ vs $F \rightarrow t$	11:13	59.2	52.8	53.8	40.8	0.119
C6	$F \rightarrow t$ vs $C \downarrow t$	11:18	66.3	43.0	57.0	33.7	0.095
C7	$F \downarrow t$ vs $C N \downarrow t$	11:24	70.8	43.9	56.1	29.2	0.153
C8	$F \rightarrow t$ vs $C \downarrow t$	13:18	74.5	52.3	47.7	25.5	0.275
C9	$F \rightarrow t$ vs $C N \downarrow t$	13:24	74.9	48.2	51.8	48.2	0.240
C10	$C \downarrow t$ vs $C N \downarrow t$	18:24	78.6	59.3	40.7	21.4	0.384

7.2 Qualitative results of research interviews

In reporting the students' responses during the interviews the questions or suggestions made by the interviewer is indicated by I. Abbreviations like S1 indicated the response of student 1 on that question. The words "Think-aloud" indicate just that. The parts in the students' responses where they were thinking aloud are indicated by inverted commas.

7.2.1 Student 1:

I: Please explain the reasons you chose the options.

Item 6

S1 (Recalls the principle). I saw a video of a hammer and a feather falling at the same rate therefore the objects will land at the same time because gravitational acceleration is the same for the two and mass has no influence (on the acceleration).

Item 16

S1: (Reads the question). They will have the same speed. Mass will have no influence, both objects are moving downwards and air resistance and friction can be ignored.

Item 17

S1: This item has the same principle as the previous ones, mass will have no influence and the objects will land simultaneously.

Item 20

S1: (Reads the question). Initially I said that mass would have an influence and that the heavier ball will have a larger velocity but now I realize that all the items in this group have the same underlying principle. I did not realize that when I completed the questionnaire but grouping the items together does not jumble your knowledge and it is easier now to recognise the same principle

I: Compare the force on and the acceleration of the balls in item 20.

S1: Think-aloud: "Acceleration is upwards so the larger ball has a larger v_i ... but upwards? The larger ball has larger initial velocity but if they are thrown at the same time it must be the same. I think...the acceleration is the same, the heavier one must be slower because gravity pulls it down... gravitational acceleration is downwards, if mass does not have an influence then they will have the same acceleration then they are going to fall down again. Acceleration is downwards for the upwards motion because they are going to come down again". Acceleration is when they move faster

I: Does acceleration mean an increase in velocity?

S1: No, velocity can decrease as well so acceleration can be negative or positive. So here it is negative acceleration because they are going to stop at the top, yes, the acceleration is the same.

I: How does the force on the objects compare?

S1: Thinks aloud: "Force:... is not the same. $F = ma$ so the larger mass will need a bigger force. F and g are both the same but $g = \frac{GM}{r^2}$ and also $F=mg$ so mass has influence". Oh! The force is not the same if the mass differs but the acceleration will be the same. I do not know why I said the larger ball will have the larger initial velocity, on your hand both balls has the initial velocity = 0.

I: Are items 6 and 20 related?

S1: No, I regarded the items as totally different questions.

I: Please give reasons why you chose the options in group C.

Item 10

S1: If A is directly opposite B then they fall the same distance therefore they will reach the ground at the same time. A will not be faster than B because they cover the same distance.

I: How do the velocities compare when B starts?

S1: A has already a velocity and $B = 0$ but because they cover the same distance they travel the same time as measured from when B starts to move.

I: Would using an equation help to figure out the answer?

S1: (writes down the equation $y = v_i t + \frac{1}{2} a t^2$ and compares the variables) y and g are the same, v_i is not the same but t is going to be equal. Because they fall from the same height and move the same (at the same acceleration) so the time must be equal.

I: Does it make a difference if a problem is supported with a diagram?

S1: Yes, a diagram makes it better; it makes more sense if one is provided. If I draw a diagram it may be wrong and then the whole item will be wrong.

Item 13

S1: (Reads the question again). Yes, the blocks will reach the wall at the same time. The force is doubled but so is the mass.

I: What can you say about the acceleration?

S1: It is constant acceleration, the same as the falling balls (in item 10). Think-aloud: "is it because the mass is twice as much or because the force is doubled"?.... Friction is ignored that is why they will reach the wall simultaneously.

Item 8

I: Which ball would reach the ground first if the balls were switched and the heavier ball fell the longer distance?

S1: If the objects were switched A would still reach the ground first because it travels a shorter distance.

7.2.2 Student 2

I: Please explain why you chose the options that you did.

Item 6

S2: You have to know the principle. The balls will reach the ground at the same time even though the one is lighter. But it depends on the density as well, whether air can move through the ball.

Item 16

S2: The heavier person has more friction that holds him back, if there is no friction the heavy person's weight still holds him back. The lighter person can slide easier. But in practice the heavier person slides slower.

Item 17

S2: Item 17 is easier to solve because values were given and an equation can be used. In item 6 you have to know it (the principle) by heart, but in item 17 you can check your reasoning by doing a calculation.

Item 18

S2: It is a contextual question; if the one boy jumps and reaches the other boy then the first one will already have an initial velocity so he will land first.

I: Would numerical values make a difference?

S2: The options do not have values and because if you consider the relationship (ratio) then it does not matter.

I: Does the context of questions make a difference to the way you perceive them?

S2: I prefer items with values because you can be surer that your answer is correct. If it is in everyday context then you just have to figure it out, otherwise you can use a formula.

Item 20

S2: If the balls moved downwards the heavy ball would hit the ground first, because it is gravity. But when they are thrown upwards the lighter ball will have the larger velocity because it is easier to throw and gravity has a larger effect on the heavy ball because of its larger weight.

I: How does the time that the objects are in the air compare?

S2: The time will be the same.

I: How does the force for up and downward motion compare?

S2: If you throw a ball into the air then you throw it (demonstrates), but if you let it fall then you do not have a force because its initial velocity is then $= 0$ and if you throw it upwards then it has an initial velocity.

Item 7

S2: The ball will have the same velocity because they fall from the same height.

I: Is up and downward motion the same? Why is there a difference?

S2: No, because the force of gravity is downwards. If a ball is released it will fall but to go upward it has to be thrown.

I: Considering the different settings of the items in the questionnaire, which kind of questions do you prefer?

S2: I prefer numeric questions because they are the easiest to calculate.

I: Which one of items 6 and item 16 seems easier to you?

S2: Item 6 seems easier than item 16, there are fewer words.

I; How do you regard questions in everyday context?

S2: You can imagine yourself in the situation and then compare it with reality but sometimes what you think is going to happen is not as simple because other factors play a role. What you think, is not necessarily what is going to happen. You know what is going to happen if there is friction and then it is confusing if friction has to be left out.

Item 8:

I: Which ball would reach the ground first if the balls were switched and the heavier ball fell the longer distance?

S2: If the masses were switched? Then the heavier ball will fall first or no, they will fall at the same time because the height and the mass cancel each other. The lighter one will then move slower.

Item 11:

S2: When the two blocks are pulled the one covering the shorter distance will reach the wall first.

I: How does the acceleration of the two objects compare?

S2: The heavier one will accelerate faster.

I: In all items of group C the simultaneous option was chosen. Can you explain your choice please?

S2: Because the one that moved first has a different speed when they start moving together, therefore it will reach the ground first. If they were at the same height and of equal mass then they would reach the ground at the same time but now I see they do not have the same initial speed and that I chose the wrong option.

I: What changed your reasoning?

S2: It helps if you do your reasoning aloud. We students usually do not read the item properly and answer without thinking, too fast.

I: How does your reasoning change according to the context of the question?

S2: In formal context you just have to think which option is most suitable but in everyday context more factors must be considered and it is easier to come to a reasonable conclusion.

7.2.3 Student 3:

I: To what extent do you prefer questions with numerical values?

S3: When I read an item which is logical then I do not find it necessary to use an equation. Especially in MCQ I see the item and I know what logic and common-sense says to me.

If the item consists of words only then I know you will probably not use an equation. If values are given, then you will have to use an equation.

I: Please explain why you chose the options that you did.

Item 6

S3: Common-sense tells you what the answer is. It is a commonly known physics fact.

Item 17

S3: This item looks much like the previous one. (Thinks aloud): "Air resistance can be ignored and the height is not that much". Although values were given you do not need to do a calculation, you can figure it out. In practice the handbag will hit the ground first because of its larger weight but if air friction is to be ignored then it is like two round balls and they will hit the ground at the same time as they did in item 6.

Item 20

S3: If you have two balls of unequal mass, the lighter one will go higher if they were thrown with the same force because of the force of gravity.

I: How does the acceleration of the two balls in the air compare?

S3: The heavier ball, $2m$, will have a larger acceleration $= 2a$. The rate at which velocity decreases will be twice that of the lighter ball. The force on the heavy ball will be twice that of the lighter ball, which is why its velocity will decrease faster. I would like to test this in practice because you learn that they fall at the same rate but in practice it does not work like that.

Item 16

S3: If friction can be ignored then your velocity will be larger than that of your niece. Your greater weight causes a larger acceleration. At a waterslide there is less friction and a heavy person always goes faster than a lighter one.

I: Compare the movement of the objects in items 6 and 16.

S3: The items look the same. The reason why they (the objects) reach the ground together in item 6 is because it is not a curved path. It is confusing that they fall at the same rate because the larger object is supposed to fall faster. I do not know why they fall at the same time.

i: Is up and downward motion the same?

S3: No it is not, they are not subjected to the same principles.

i: To what extent does the context of the question influence your thinking?

S3: In a formal physics context everything is in a box, you do not have to consider anything else. In everyday context you are immediately in reality and have to consider a lot of things. It is difficult to convert everyday situations to a physics context because everyday context is the reality. People who compile questions can test your physics knowledge by using questions set in formal physics context but instead they are spiteful and set it in everyday context, which does not test your knowledge.

I: Are you saying that there is a difference between having knowledge and being able to apply the knowledge?

S3: There is a difference between knowing something and understanding it. If you understand something it is easier to remember. You have to read the questions carefully because they like to hide what you have to do. I think it is better to draw diagrams as long as you understand the diagrams.

Item 8

I: Which ball would reach the ground first if the balls were switched and the heavier ball fell the longer distance?

S3: If the masses were switched then depending on the height, the objects will reach the ground at the same time. The heavier one would fall faster regardless of the height because gravity attracts it more. I do not know what will happen if the height is, let's say, 100 m.

7.2.4 Student 4

If I have to answer an item I try to apply the theory and afterwards evaluate my answer to see if it makes sense.

I: Please explain why you chose the options that you did.

Item 10

S4; (Reads the question). The objects fall in the same time.

- i: Do you use equations to assist your thinking?
- S4: I will use an equation with values like x and y and try to figure out what will happen.
- I: Please explain your reasoning in answering the items in group C.
- S4: You have a hunch and then look at the options to choose the appropriate one. You follow your intuition. The objects move together but one has an initial velocity whereas the other one starts from rest. The one will fall faster but because there is no air resistance, they will land simultaneously depending on the weight.
- I: What influence does weight have?
- S4: The larger the weight, the faster it will fall but if one has less resistance it will fall faster. Two similar options with different reasons were given but because the one has an initial velocity it means that his final velocity will be bigger and that option makes more sense. If friction is ignored then the $f = \mu mg$ factor does not apply and that makes the equation simpler.
- I: How does the force on the two balls compare?
- S4: The force is the same;-9.8 m/s the force of gravity-, but the acceleration is 9.8 x the weight that the person falls.
- I: How will the final velocity compare then?
- S4: Ball A and B..... one has initial velocity so it will fall faster but it can also be if their masses differ that they will fall the same time.

Item 16

- S4: Thinks aloud: "Because you are heavier you must fall faster than your niece so option 4 cannot be correct". Lighter objects are easier to accelerate with the same force. Option 2 can be true because you weigh more therefore your acceleration will be more ..." I do not know what the incline is". In theory class we learnt that heavier things fall faster I think that larger weight causes larger acceleration.

Item 20

The students had difficulty to express himself.

- I: Would it help if you drew a diagram?

S4: I do not usually draw diagrams because it takes less time to substitute the values into the equation.

S4: (Draws diagram) In high school we learnt that gravity is negative when the object moves upward and positive when the object moves downward. Therefore the velocity of an object will be the same when the object is at the same height whether it is going up or coming down. Because both objects reach the same height, their initial velocity will be the same.

I: How does the force in items 6 and 16 compare?

S4: The force on them both is the same because the only force acting on them is the force of gravity. The heavier ball experiences more friction.

I: To what extent do items 6 and 16 Items differ?

S4: Items 6 and 16 are similar so I think I made a wrong choice in item 6 because the heavier object will fall faster. Think-aloud: "..... the video of the feather and the brick but it is not applicable here".

I: Suggest the use of an equation of motion:

S4: I use equations normally for numerical values and not to help me think, I would like to try an equation to help me think.

The student writes down the equation $v_f = v_i + at$.

S4: Think-aloud: "The force on the large ball is the same as on the lighter ball, it is 9.8. The acceleration of gravity is 9.8. Thus gravitational acceleration is part of the force of gravity". If you drop the balls there is immediately a normal force and the gravitational acceleration that act on the ball. So the net force is normal force + / – the gravitational acceleration. "If there is no friction then the only force acting on the object is the force of gravity and the larger the mass the larger the acceleration. The earth attracts it with 9.8 m/s but that is not necessarily the acceleration. If something can only accelerate to 9.8 m/s what is terminal velocity then?" The friction prevents you from accelerating faster.

Appendix C

8.1 Consent form



NORTH-WEST UNIVERSITY

CONSENT TO PARTICIPATE IN RESEARCH

Researchers: **Dr M. Lemmer and Mrs A. Ferreira**

Study title: **Investigating students' solving of Physics kinematics problems in various contexts.**

You are requested to participate in a research study conducted by Annalize Ferreira from the School of Science, Mathematics and Technology Education, Faculty of Natural Sciences, North-West University (Potchefstroom Campus). The research results of this study will be made public in the form of scientific publications. You were selected as a possible participant in this study because you are a first year student in Physics.

PURPOSE OF THE STUDY

The purpose of this study is to investigate the knowledge that students use in solving kinematics problems in various contexts.

The main research question that will guide this study reads: *To what extend do students apply their Physics conceptual knowledge in solving kinematic problems in various contexts?*

PROCEDURES

If you volunteer to participate in this study, we will ask you to complete the questionnaire and indicate if you would be available for a follow-up interview regarding your responses to the questionnaire.

POTENTIAL RISKS AND DISCOMFORTS

The study to be undertaken will not provide any potential risks to the participant. The results of this study will not be included in the assessment of the student's Physics marks whatsoever.

POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY

This study is conducted specifically for the Faculty of Natural Sciences, North-West University (Potchefstroom Campus). Your participation may lead to revaluation and adjustments of current teaching strategies in Physical Science.

CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Information identifying any individual will not be released to any other party for any reason. Completion of the questionnaire is not anonymous because interviews are to be conducted with participants who agree to be interviewed. The final results of this study will be made available to participants on request.

PARTICIPATION AND WITHDRAWAL

You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may also refuse to answer any questions you don't want to answer and still remain in the study. The researcher may withdraw you from this research if circumstances arise which warrant doing so.

IDENTIFICATION OF RESEARCHERS

If you have any questions or concerns about the research, please feel free to contact Dr Miriam Lemmer (study leader) at 0182994270 or Mrs Annalize Ferreira (researcher) at 0182992167

RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research subject, please ask the researchers or promoter of the study.

SIGNATURES OF PARTICIPANT

The information above was described to me by Annalize Ferreira (researcher) in English and I am in command of this language.

I hereby consent voluntarily to participate in this study. I understand that this form will be stored by the researcher in case of any queries.

_____ *Name of Participant*

_____ *Signature of Participant*

_____/_____/2014 *Date*

Complete the questionnaire by marking the appropriate number on the multi-choice card. Should you have any comments you would like to share, please write them on the last page of this questionnaire. Thank you for participating in this survey.

8.2 Ethical clearance certificate



NORTH-WEST UNIVERSITY
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Ethics Committee

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ETHICS APPROVAL OF PROJECT

The North-West University Ethics Committee (NWU-EC) hereby approves your project as indicated below. This implies that the NWU-EC grants its permission that provided the special conditions specified below are met and pending any other authorisation that may be necessary, the project may be initiated, using the ethics number below.

Project title: Investigating conceptual knowledge of first year physics students in solving multivariate mechanics problems.																																												
Project Leader: Dr M Lemmer																																												
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Status: S = Submission; R = Re-Submission; P = Provisional Authorisation; A = Authorisation																																												
Approval date: 2014-06-06 Expiry date: 2019-06-05																																												

Special conditions of the approval (if any): None

General conditions:

While this ethics approval is subject to all declarations, undertakings and agreements incorporated and signed in the application form, please note the following:

- The project leader (principle investigator) must report in the prescribed format to the NWU-EC:
 - annually (or as otherwise requested) on the progress of the project,
 - without any delay in case of any adverse event (or any matter that interrupts sound ethical principles) during the course of the project.
- The approval applies strictly to the protocol as stipulated in the application form. Would any changes to the protocol be deemed necessary during the course of the project, the project leader must apply for approval of these changes at the NWU-EC. Would there be deviation from the project protocol without the necessary approval of such changes, the ethics approval is immediately and automatically forfeited.
- The date of approval indicates the first date that the project may be started. Would the project have to continue after the expiry date, a new application must be made to the NWU-EC and new approval received before or on the expiry date.
- In the interest of ethical responsibility the NWU-EC retains the right to:
 - request access to any information or data at any time during the course or after completion of the project;
 - withdraw or postpone approval if:
 - any unethical principles or practices of the project are revealed or suspected,
 - it becomes apparent that any relevant information was withheld from the NWU-EC or that information has been false or misrepresented,
 - the required annual report and reporting of adverse events was not done timely and accurately,
 - new institutional rules, national legislation or international conventions deem it necessary.

The Ethics Committee would like to remain at your service as scientist and researcher, and wishes you well with your project. Please do not hesitate to contact the Ethics Committee for any further enquiries or requests for assistance.

Yours sincerely

Prof Amanda Lourens
(chair NWU Ethics Committee)