



**Exploring Grade 12 Learners' Understandings of, and  
Problem-Solving Approaches to Work-Energy-Power in  
Physical Sciences in High Schools**

by

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## DECLARATION

The work presented in this thesis was undertaken at the School of Education, Science and Technology Education Cluster, at the University of KwaZulu-Natal under the supervision of Professor Govender Nadaraj. Ethical Clearance was granted for this study by the Research Office of the University of KwaZulu-Natal. This study represents original work by the author, except where otherwise stated and has not otherwise been submitted in any form for any other degree or diploma to any tertiary institution. Where use has been made of the work of others, it is duly acknowledged in the text.

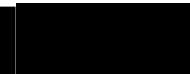
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## **DEDICATION**

*To Physical Sciences learners everywhere.*

## ABSTRACT

Learners in high schools are performing poorly on the topic Work Energy Power as is evident in the National Senior Certificate Examinations (NSC) since 2008. The purpose of this study was to explore Grade 12 learners' understandings of, and problem-solving approaches to Work-Energy-Power in Physical Sciences in high schools. The combination of Phenomenography and Variation Theory (VT) have been found to be best suited as an approach with which to tackle the research questions in this study as it enabled the researcher to probe into learners' understandings and problem-solving approaches through their (the learners') eyes which was the purpose of this study.

This research employed a mixed methods approach as it used both quantitative and qualitative methods underpinned by pragmatism and interpretivism. The mixed methods approach was heavily weighted on the qualitative aspect with the quantitative aspect focusing primarily on descriptive statistics that was used to inform the qualitative aspects. The sample comprised of 100 National Senior Certificate Physical Sciences Paper One examination scripts and eight Grade 12 Physical Sciences learners. This sample was selected from six schools in one province in South Africa. The sampling method involved convenience sampling and typical case sampling, which is a type of purposive sampling, at different stages of the sampling process. A semi-structured interview schedule, Think Aloud Questionnaire (TAQ) and the NSC examination scripts were used to collect raw data. The TAQ (Appendix 10) was the instrument that was used to gain insights into the "thinking" of learners using the Think Aloud Method. Both qualitative and quantitative data were collected via document analysis, thematic analysis and Think Aloud, all of which were underpinned by phenomenography and VT. The use of several data collection instruments and methods assisted with ensuring trustworthiness by triangulation.

It was found that learners display seven alternative conceptions (ACs) about work, four ACs about energy and three ACs about power. Seven problem-solving approaches (PSAs) among Grade 12 Physical Sciences learners were identified, and these were missed the point state (MPS), limited (L), plug-and-chug-trial (PACT), layman's approach (LAY), by elimination (BE), not shown (NS) and linked and integrated state (LIS). All the PSAs had problem-solving difficulties (PSDs) embedded in them except for the LIS approach.

It was also found that awareness, simultaneity, discernment, reason, logic and clarity are important conditions for learners to fully understand scientific phenomena and successfully solve problems in physics. The last three conditions in the previous sentence, namely reason, logic and clarity, are being proposed in this study as additions to the current discourse on learning proposed by VT. The four patterns of variation namely contrast, generalisation, separation and fusion have been employed in this study as a possible explanation for the prevalence of alternative conceptions and problem-solving difficulties among Grade 12 Physical Sciences learners.

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## LIST OF ACRONYMS

AC	Alternative Conceptions
ACP	Alternative Conceptions Power
BE	By Elimination
CAPS	Curriculum and Assessment Policy Statement
DBE	Department of Basic Education
DRS	Disjointed Relationships State
DCI	Dynamics Concept Inventory
ECA	Energy Concept Assessment
ECI	Energy Concept Inventory
EMCS	Energy and Momentum Concept Survey
FET	Further Education and Training
GDE	Gauteng Department of Education
GET	General Education and Training
L	Limited
LAY	Layman's Approach
LFS	Limited Factual State
LIS	Linked and Integrated State
LOA	Lack of Awareness
LOC	Lack of Clarity
LOD	Lack of Discernment
LOL	Lack of Logic
LOR	Lack of Reason
MPS	Missed the Point State
NCS	National Curriculum Statement
NS	Not Shown
NSC	National Senior Certificate
PACT	Plug And Chug Trial
PSA	Problem Solving Approach
PSAD	Problem Solving Approach and Difficulties
PSD	Problem Solving Difficulties
TA	Think Aloud
TAP	Think Aloud Protocol
TAQ	Think Aloud Questionnaire
VT	Variation Theory
WEP	Work Energy Power
WET	Work Energy Theorem

## KEY TERMS

<i>Term or phrase</i>	<b>Explanation</b>
<i>Object of learning</i>	The act and/or pursuit of learning implies that there is something to be learned. (Marton & Booth, 1997) describe this as the object of learning, that is, what is to be learned by the student. The object of learning in this study are the concepts of Work, Energy and Power in the Physics curriculum in schools.
<i>Object of learning: Intended</i>	The intended object of learning will consist of what the teacher, curriculum designers, textbooks, amongst others, intend for learners to learn (Bussey et al., 2013; Marton & Pang, 2006). The intended object of learning is bound by the teacher's sphere of knowledge and experience, textbooks and the curriculum. The intended object of learning is the Curriculum and Assessment Policy Statement (CAPS).
<i>Object of learning: Enacted</i>	The enacted object of learning is defined by the interactions that occur between teacher and learner, learner and learner and learner and learning materials. Several researchers refer to the enacted object of learning as opportunities to learn which is a broad view of the enacted object of learning (Euler et al., 2020; Ingerman et al., 2007; Sun, 2011). These possibilities or opportunities for learning are determined for example by the quality of the learning materials and classroom interactions that take place involving teachers and learners within and with the learning environment (Åkerlind, 2012; Akerlind et al., 2011; Lo, 2012; Marton & Booth, 1997). The possibility for learning is dictated by what is actually presented to learners and is co-constructed through the interactions that occur between teacher and learner and among learners within and with the learning environment (Akerlind et al.,

<b><i>Term or phrase</i></b>	<b>Explanation</b>
	2011; Lo, 2012; Marton & Booth, 1997). In this study, the responses of learners in the NSC examination scripts, focus group interviews and think-aloud sessions will provide data on the enacted object of learning by inference. This will inform the research on the learners' experience in the teaching and learning process. This study does not directly focus on the enacted object of learning.
<i>Object of learning: Lived</i>	The lived object of learning can be described as the way learners make meaning of the object of learning after the lesson ends and beyond (Marton & Ling, 2007; Tóth & Ludányi, 2007). This object of learning is often the focus of educational research, that is, what did students actually learn? In this study, the responses of learners in the NSC examination scripts, focus group interviews and think-aloud sessions will provide data on the lived object of learning. The lived object of learning is the focus of this study.
<i>Problem</i>	“A problem is a situation in which you are trying to reach some goal, and you must find a means of getting there” (Chi & Glaser, 1983).
<i>Problem-Solving</i>	Many researchers such as Chi et al. (1981); Holyoak (1995); Morrison and Holyoak (2003) have stated that problem-solving has four components, namely, a goal state, an initial state, a set of operators or operations to reach the goal state from the initial state and a set of constraints that impose additional conditions on a success path to the solution.

<b><i>Term or phrase</i></b>	<b>Explanation</b>
<i>Protocol</i>	In this study, learners were requested to Think Aloud as they solved problems in Physics. The Think Aloud spoken words of the learners were recorded on audio tape. According to (van Someren et al., 1994, pp. 1, 2) the spoken words were called spoken protocols and the transcribed spoken words were called written protocols. This study used this definition of protocol of (van Someren et al., 1994).
<i>Scientific Community</i>	By “scientific community” I refer to the widely accepted science textbooks, other science literature and scientists which include physicists who may also be teachers or lecturers.
<i>Think Aloud (TA)</i>	According to several researchers, TA is a research method where the participants in the research voice their thoughts pertaining to the task as they are performing that task (Charters, 2003; Docktor et al., 2016; Meijer et al., 2007; van Someren et al., 1994). TA is a very direct method to gain insight into the knowledge and problem-solving approaches of people (van Someren et al., 1994, p. 1). The TA method was used to gain insights into the “thinking” of learners as they solved problems.
<i>Think Aloud Protocol (TAP)</i>	The TAP is the transcript of the audio recordings that were done during the Think Aloud Session.
<i>Think Aloud Questionnaire (TAQ)</i>	The TAQ is the Think Aloud Questionnaire

<i>Term or phrase</i>	<b>Explanation</b>
<i>Understanding</i>	<p>Understanding ... does not refer to a mysterious empathy between human beings. Nor does it refer to an intuitive or rationalistic ascription of motivations. Instead, it is a social phenomenon - a phenomenon of shared meanings (Wax, 1971, pp. 10-11).</p> <p>Borrowing the meaning of the construct “understanding” as a “phenomenon of shared meanings” (Wax, 1971) this study approaches its purpose of exploring the Grade 12 learners’ understandings of Work Energy Power as the meanings that learners share with the scientific community (p. 11).</p>

# Chapter 1 - INTRODUCTION AND BACKGROUND TO THE STUDY

## 1.1 Introduction

The teaching and learning of the topic Work Energy Power in Physical Sciences is not that simple because the terms work, energy and power are used in casual conversations among all members of society, young and old. Prior to encountering this topic in the science classroom, many, if not all learners would have encountered these terms and possibly used them. Problems arise when these words do not carry the same meaning or rigor in casual conversations compared to the conversations in the science classroom. Furthermore, this topic is a core concept in Physical Sciences, and it is discussed in various knowledge areas including mechanics, electricity, electrodynamics and electrochemistry. In addition, it is incorporated into various other disciplines, for example, Biology, Physical Education and Dietetics resulting in an ongoing robust debate about the concept of energy itself (Dreyfus, 2011). Also, energy resources are now a scarce commodity in the global and Southern African states and knowledge about its constituents, production and application becomes far more relevant in our daily lives. Finally, there is ongoing competition regarding ownership of energy resources globally. This makes this topic an important topic in the school curriculum. All life need energy to exist. How well the learners understand and solve problems involving this topic must surely have a positive impact on the way the country competes on the international stage.

The purpose of this study was to explore Grade 12 learners' understandings of, and problem-solving approaches to work-energy-power in Physical Sciences in high schools. The concept of energy can be used to solve many problems given to learners in the Physical Sciences classroom, however most learners do not use this concept unless prompted to do so. According to Swackhamer (2005) learners graduating from school generally cannot use energy to describe or explain basic phenomena that occur in everyday life like the burning candle for example. Many other researchers say that confusion can be caused by careless use of language in energy discussions (Jewett, 2008c). Statements such as "work was done during the process" can cause confusion as it does not state "on" or "by" what work was done. According to Knight (2013)

“mechanical transfer of energy to or from the system is called work” (p. 279). It is equally important that learners understand this about work and that they also understand the concept of a system. In the natural world there are many objects and interactions that take place in seemingly organised and chaotic ways. It is important that learners are able to isolate the components of an interaction in order to explain or calculate energy or other physical quantities. It is for this reason that they need to understand and apply the concept of a “system” and the “environment” (Knight, 2013, p. 279).

In South Africa, most of the learners are not English first language speakers. It is not only scientific language that can pose a challenge to learners, but also that most learners are not learning science in their mother-tongue. Although, mother-tongue instruction was not a focus of this research, it was factored-in during the data recording and analysis phases. The focus on language here was the rigorous scientific language that pertains to work, energy and power and how it impacted on learners’ understandings and problem-solving approaches.

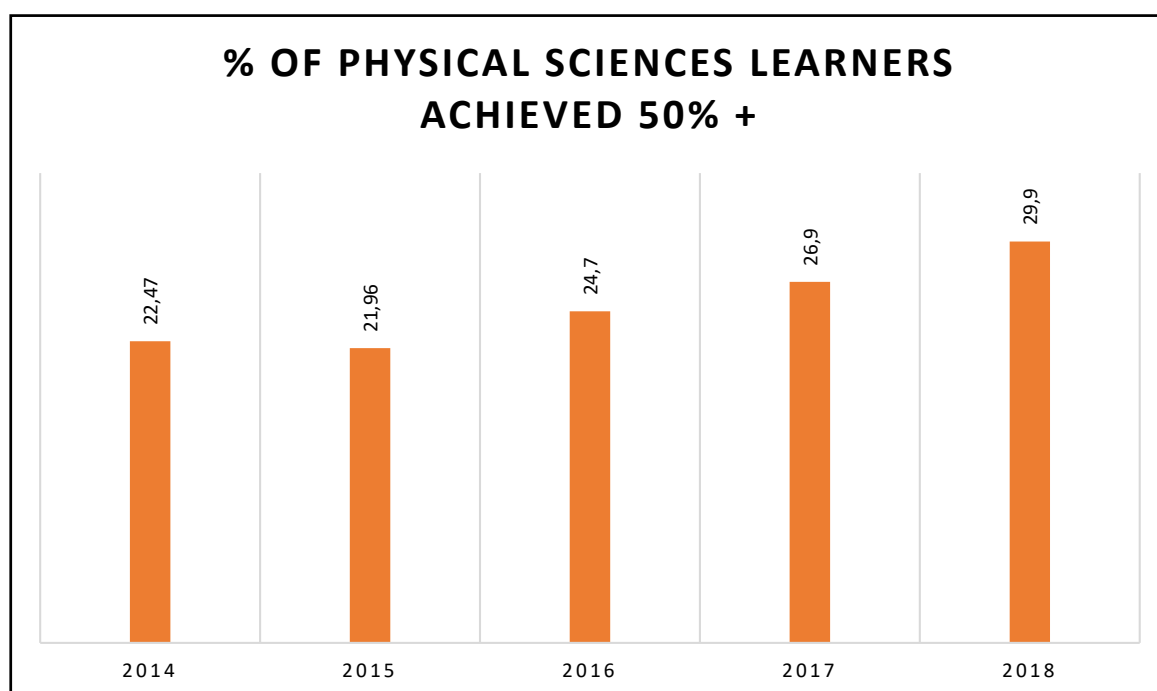
The problem that had prompted this study is poor understanding of concepts and problem-solving ability involving Work Energy Power (WEP) among many Grade 12 Physical Sciences learners in South Africa. During the period 2014 to 2018 the average mark expressed as a percentage that learners obtained on the topic WEP in the National Senior Certificate (NSC) examinations ranged from a minimum of 40% in 2014 to a maximum of 57% in 2015 (DBE, 2014, 2015a, 2016, 2017a, 2018a, 2019). This is a dismal picture that calls for informed solutions. This poor performance led to the purpose of this study which was to explore Grade 12 learners’ understandings of, and problem-solving approaches to work-energy-power in Physical Sciences in high schools.

## **1.2 Background to the study**

Physical Sciences has been identified as a key subject by the Department of Basic Education (DBE) in South Africa for the advancement of scientific knowledge and skills (DBE, 2018b). This highlights the importance of Physical Sciences as a school subject in the education sector.

The Gauteng Department of Education (GDE) in collaboration with the University of Johannesburg ran a Script Analysis Project which was aimed at analysing “samples of the GDE NSC examination papers of 2008 in order to make recommendations for the improvements of learner performance in various subjects” (Maseko et al., 2010, p. 4). Physical Sciences was one of the subjects that formed part of the project. After conducting the script analysis of the Physics paper the study revealed that students have “a naïve, superficial and fragmentary understanding of scientific phenomena that is based upon their experiential knowledge” (Maseko et al., 2010, p. 31). “These conceptions were not theoretically grounded as students appeared to string together pieces of knowledge in response to contextual feature of the problem situation” (Maseko et al., 2010, p. 31). Several other studies found that many learners hold alternative conceptions in Physics (DBE, 2017a; Mchunu & Imenda, 2013; Singh & Rosengrant, 2016; Wijayanti et al., 2018). An analysis of the achievement data of learners in Physical Sciences from 2014 to 2018 reveals that less than 30% of these learners obtain an achievement of 50% and above and for most of this period this achievement rate was under 25% of learners. The data for this analysis was sourced from the National Senior Certificate examination reports (DBE, 2018b, p. 76). This analysis is presented in Graph 4-1.

**Graph 1-1: % Physical Sciences learners achieving 50% and over**

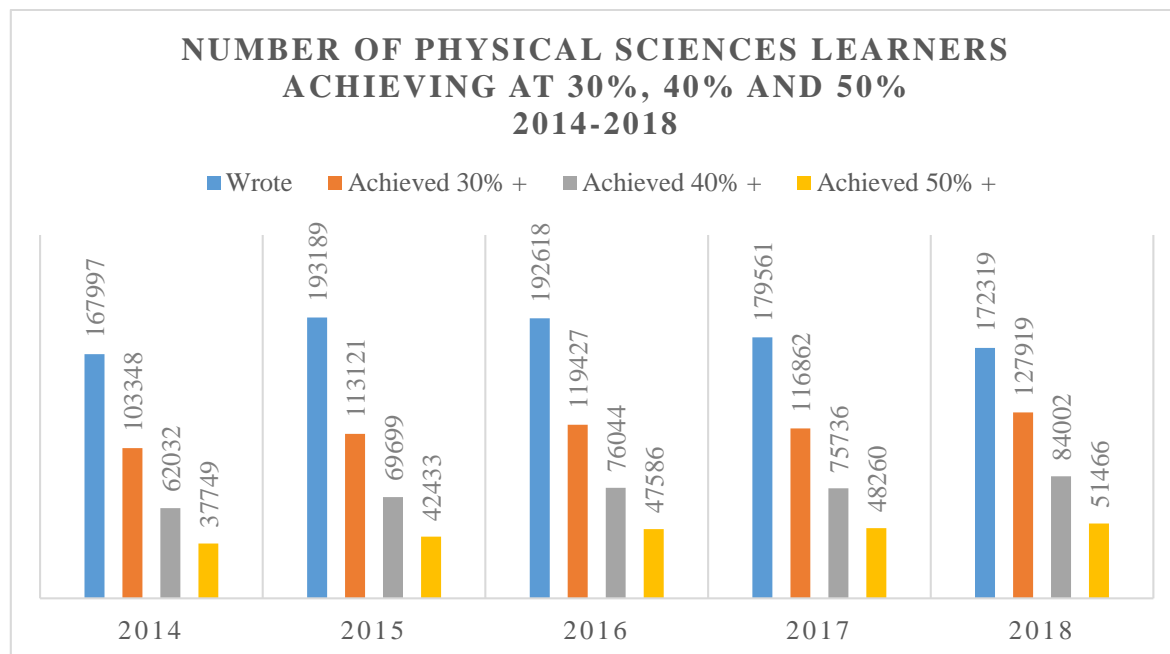


The analysis in Graph 1-1 shows that many learners perform poorly in Physical Sciences in the NSC. Energy as presented in school science is not taught as a single coherent concept. Energy is not taught in a consistent way from one grade to the next and from one subject to the next in schools (Swackhamer, 2005, p. 1). In most problem-solving activities in the NSC papers, energy is often presented as a quantity that can be calculated and that always remains the same when calculated for a closed system. “Being only a number that curiously turns out to be conserved, energy, then, is just a useful contrivance, a fiction” (Swackhamer, 2005, p. 2). Many learners then simply look for ways of manipulating the equation for the work-energy theorem to arrive at an answer, without thinking about the concept itself and any energy transformations that may be taking place. The absence or the lack of emphasis of energy as a thermodynamic quantity in the Physical Sciences Curriculum in South Africa further contributes to lack of understanding of problems that include non-conservative forces. The term “system” is also not well understood or presented in classroom discussions of energy and many learners fail to identify the isolated system in which to apply the work-energy theorem as is also reported in the Diagnostic Report on Learner Performance in the NSC (DBE, 2014).

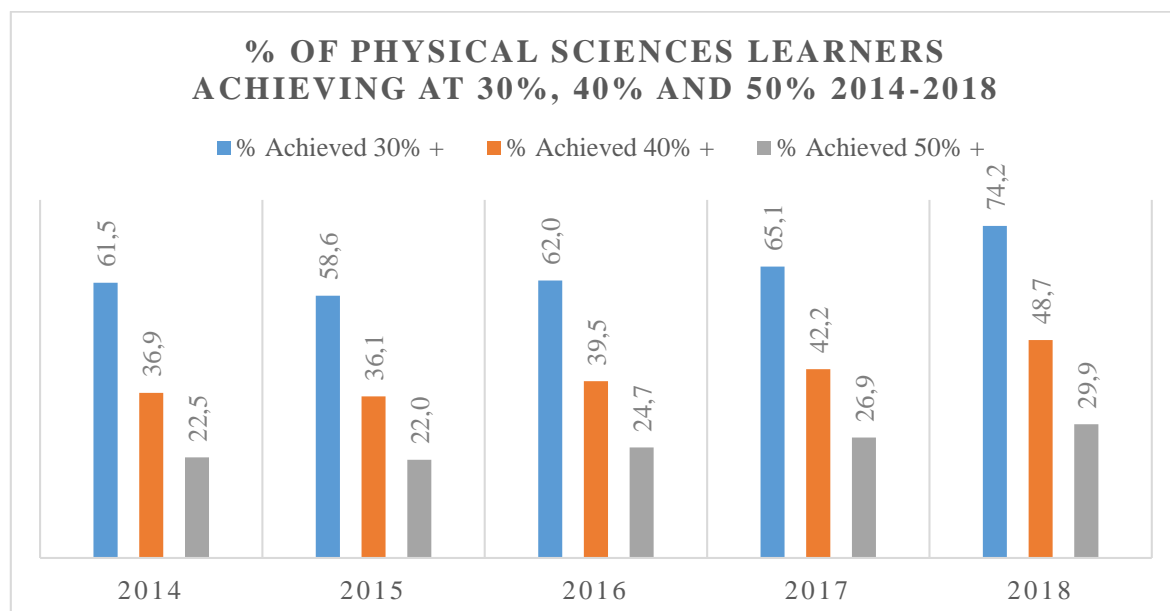
### **1.3 Rationale to the study**

The achievement of learners in Physical Sciences was not good at 30% and over, 40% and over and 50% and over during 2014-2018. The number and percentage of learners achieving at each of these three levels are presented in Graphs 1-2 and 1-3 respectively. The data for Graphs 1.2 and 1.3 have been sourced from the NSC Examination reports and Diagnostic reports (DBE, 2014, 2015a, 2016, 2017a, 2018a, 2019). It can be seen from this analysis that as the achievement bar is raised from 30% to 50% the success rate drops by more than 50%. In 2018 for example, 74.2% of the learners achieved when the bar was at 30%. This dropped to 48.7% of the learners succeeding when the bar was raised to 40% and this fell further to 29.9% when the bar was raised to 50%.

**Graph 1-2: Number of learners achieving at 30%+, 40%+ and 50%+ in Physical Sciences 2014-2018**



**Graph 1-3: Achievement Rate in Physical Sciences 2014-2018**



According to Graphs 1-2 and 1-3, the majority of learners cannot answer at least 60% of the paper correctly. This shows that most of the learners in South Africa are experiencing

difficulties in Physical Sciences. Since understanding and problem-solving are key skills in Physical Sciences, this study explored them in order to contribute to the knowledge base to highlight challenges experienced by learners. For this exploration, one Physics topic namely Work Energy Power in the Grade 12 Physical Sciences curriculum in South Africa had been selected.

These ideas led to the purpose of this study:

*The purpose of this study was to explore Grade 12 learners' understandings of, and problem-solving approaches to work-energy-power in Physical Sciences in high schools.*

## **1.4 Context**

The study was located in a province in South Africa. The Curriculum and Assessment Policy Statement (CAPS) is one of the policy statements of the NCS in the Basic Education Sector in South Africa (DBE, 2011). This CAPS provides details of the curriculum to be taught in schools.

CAPS was introduced to Grades R, 1, 2, 3 and 10 in 2012; in Grades 4, 5, 6 and 11 in 2013 and Grades 7, 8, 9 and 12 in 2014. According to the foreword in CAPS, this curriculum is the product of concerted efforts over a period of seventeen years to transform the curriculum that was handed down to South Africa after the advent of democracy that followed the demise of the apartheid regime (DBE, 2011).

This study was conducted in six schools from two districts belonging to one province in South Africa. The six schools were not similar in terms of physical infrastructure and resources. They were selected deliberately to represent a typical case sample of the schools in the selected districts of the province. The sampling method is discussed in detail in Chapter 4. All six schools in the sample offered Physical Sciences from Grades 10 to 12. Each of the schools had qualified Physical Sciences teachers.

## **1.5 Aim and Objectives**

The overall aim of this study was to gain insight into grade 12 learners' understandings of and problem solving approaches on Work Energy Power in the selected districts in a province in South Africa.

The objectives of the study were:

- 1.5.1 To explore how Grade 12 Physical Sciences learners perform on the questions on work, energy and power in the National Senior Certificate (NSC) examinations.
- 1.5.2 To explore Grade 12 Physical Sciences learners' alternative conceptions and problem-solving difficulties on work, energy and power.
- 1.5.3 To explain why Grade 12 Physical Sciences learners, hold certain alternative conceptions and problem-solving difficulties in work, energy and power.
- 1.5.4 To account for Grade 12 Physical Sciences learners' alternative conceptions and problem-solving difficulties using the variation theory of learning.

## **1.6 Research questions**

The purpose of this study was to explore Grade 12 learners' understandings of, and problem-solving approaches to Work-Energy-Power in Physical Sciences in high schools. Four research questions were developed to frame this exploratory study and to attempt to achieve its purpose.

The research questions that framed the study were:

- 1.6.1 How do Grade 12 Physical Sciences learners perform on the questions on work, energy and power in the National Senior Certificate (NSC) examinations?
- 1.6.2 What are the alternative conceptions, problem-solving approaches and problem-solving difficulties of Grade 12 Physical Sciences learners on work, energy and power?

- 1.6.3 Why do Grade 12 Physical Sciences learners hold certain alternative conceptions and problem-solving difficulties on work, energy and power?
- 1.6.4 How can the Grade 12 Physical Sciences learners' alternative conceptions and problem-solving difficulties on work energy and power be explained, using variation theory of learning?

## **1.7 Methodology**

The research was underpinned by pragmatism and interpretivism as research paradigms. This study adopted a subjectivist epistemology at times as the data was interpreted through the researcher's own understandings, experiences and interactions with the participants. It also adopted an objectivist epistemology at other times when making meaning of the science concepts that are included in the study. This research followed a non-dualist ontology as it made the assumption that reality is a relationship between the knower and that which is to be known. Paradigms are not unique as they may be certain overlaps among them (Cohen et al., 2018). Pragmatism draws on the epistemology associated with interpretivism based on what works to answer the research questions, and making the assumption that reality can be regarded as both objectively and socially constructed (Cohen et al., 2018; Johnson & Onwuegbuzie, 2004). This study is based on the pragmatic paradigm as well as on interpretivism. These paradigms best suit the purpose of this research which is to explore Grade 12 learners' understandings of, and problem-solving approaches to work-energy-power in Physical Sciences in high schools, since this would require an understanding of the subjective world of the learners and an assumption that the science concepts involved in this study stem from an objective world of science. Pragmatism and interpretivism were found to be most suitable to analyse and interpret the data and arrive at conclusions and recommendations.

In mixed methods research, both quantitative and qualitative methods are used to understand and approach the research purpose and questions (Cohen et al., 2018; Johnson & Onwuegbuzie, 2004). These methods are not utilised completely independently of each other as reality is not viewed as either quantitative or qualitative but rather as an integrated whole of both (Cohen et al., 2018). Hence, the quantitative aspects and qualitative aspects of the study are integrated in order to arrive at the findings.

This was a mixed methods study where both qualitative and quantitative methods were used concurrently to analyse data. The qualitative methods were of a higher priority than the quantitative methods. The qualitative analysis was informed by the phenomenographic approach and variation theory (VT). The phenomenographic approach in research involves the limited number of qualitatively different ways in which people could experience the same phenomenon (Bussey et al., 2013; Reed, 2006; Walsh et al., 2007). Phenomenography and VT were adopted as approaches for two reasons. Since this study required the researcher to explore both the understandings of learners and their problem-solving approaches and difficulties (PSADs) to Work Energy Power, there was a need to identify the understandings and PSADs and a need to explain and account for them. Phenomenography was adopted to identify the qualitatively different ways in which learners' understood concepts and solved problems. VT was employed to explain and account for these qualitatively different ways in which learners experienced the phenomenon called Work Energy Power. Phenomenography and VT were found to be most suitable to answer the research questions in this study as this study aimed to identify the range of understandings and PSADs of learners (as in phenomenography) and to explain why and account for these understandings and PSADs (as in VT) (Bussey et al., 2013).

The research was conducted using data from six schools from one province and one district. The province and district were selected using the convenience sampling method. The sources of data were NSC examination scripts of 100 learners and the TAPs of 8 learners. The 100 examination scripts and the sample of eight learners were selected using typical case sampling which is a type of purposive sampling method. This sampling method was selected as this study made no attempt to generalise its findings. The convenience sampling method was used to select the province and the district. This was done because of easy access to the province and the district. The schools and participants were selected using typical case sampling which is a type of purposive sampling. Typical case sampling is a non-probability sampling method that is used in research where no attempt is made to generalise the findings (Cohen et al., 2018). It is also a sampling method that allows the researcher to hand-pick the sample according to criteria that are relevant to the study. This sampling method to select the 6 schools was chosen so that it was representative of the schools in the selected districts of the province with respect to

size and number of learners. The criteria to select the participants were achievement level so that one could arrive at a sample that was representative of some of the achievement levels of learners in the districts of the province. The sampling method is discussed in detail in Chapter 4.

The study employed multiple data collection methods to ensure trustworthiness. Document analysis, think aloud method, and thematic analysis underpinned by VT and the phenomenographic approach provided rich data. The use of multiple sources of data assisted with triangulation and ensuring trustworthiness. Strategies like peer debriefing and coder reliability checks were undertaken to ensure credibility of the study.

## **1.8 Significance of the research study**

Studies that employ phenomenography, VT and TA together to explore learners' understandings and PSADs on WEP have not been undertaken in South Africa. A significant part of the data collection method is TA. The results of this study are informed by phenomenography and VT and it is intended to fill the gap in such studies in South Africa. It is anticipated that the results of this study will be beneficial, and it will add to the local research results on critical issues regarding the high school Physics curriculum policy and implementation and that it will inform future education curriculum reforms in South Africa. It is also envisaged that teachers could use the detailed ACs and PSADs in their lesson plans and classroom practice to improve learners' understandings and problem-solving skills. The use of VT in this study may also encourage teachers and teacher development organisations to employ VT in teacher development courses, lesson planning and classroom practice to improve teaching and learning in Physical Sciences.

## **1.9 Overview of the thesis**

This thesis consists of nine chapters.

Chapter 1 provides the introduction, background and rationale informing the study. It also provides a brief overview of the research design and a discussion on the significance of the study. Chapter 1 concludes with an overview of the thesis.

Chapter 2 presents a review of literature associated with this study. It includes a survey of literature that focus on understanding WEP, alternative conceptions, problem-solving, problem-solving strategies and the TA method.

Chapter 3 presents the theoretical framework that underpins this study. It provides a discussion on phenomenography and VT.

Chapter 4 presents the methodology of the study. It includes a discussion on the paradigms selected, context of the study, sampling, sources of data, data collection tools, data collection methods, ethics, trustworthiness and data analysis.

Chapter 5 to Chapter 8 report the results of the research questions. Chapter 5 reports the results of the first research question. The second research question is reported in Chapter 6. Chapter 7 reports the results of the third research question and Chapter 8 reports the results of the fourth research question.

Chapter 9 presents the conclusions, limitations and recommendations of the study.

## **1.10 Conclusion**

This chapter provided an introduction to this study. It dealt with the background, rationale, context, objectives, research questions, methodology, significance and overview of the study. The problem that had prompted this study was poor understanding of concepts and problem-solving ability involving WEP among many Grade 12 Physical Sciences learners in South Africa.

This chapter is introduced by discussing the importance and relevance of the topic WEP in the high school curriculum. Energy resources are now a scarce commodity in the global and Southern African states and knowledge about its constituents, production and application becomes far more relevant in our daily lives. There is also ongoing competition regarding ownership of energy resources globally. The topic Work Energy Power deals with energy and is therefore a significant topic in the school curriculum. In

the background to this study, the poor quality of passes of learners in Physical Sciences is discussed.

This study was conducted in one province in South Africa. It was a mixed methods study where both qualitative and quantitative methods were used concurrently to analyse data. The qualitative methods were of a higher priority than the quantitative methods. These methods were not utilised completely independently of each other as reality is not viewed as either quantitative or qualitative, but rather as an integrated whole of both (Cohen et al., 2018). Hence, the quantitative aspects and qualitative aspects of the study were integrated in order to arrive at the findings.

The significance of this study was that it employed phenomenography, VT and TA together to explore learners' understandings and problem-solving approaches on WEP and that such a combined approach has not been undertaken in South Africa. It is anticipated that this study will fill this missing gap in such studies in South Africa.

## Chapter 2 - LITERATURE STUDY

### 2.1 Introduction

The previous chapter provided the background and rationale of this study. This chapter reviews literature that pertains to key ideas that are crucial to the purpose of this study. The purpose of this study is to explore Grade 12 Learners' understandings of, and problem-solving approaches to work-energy-power in Physical Sciences in high schools. It was therefore important to conduct a review of literature dealing with understanding Work Energy Power, alternative conceptions, problem-solving, problem-solving difficulties on Work Energy Power, problem-solving strategies and approaches, problem-solving taxonomies and think aloud method. These are the areas for which a literature review was conducted and presented in this chapter. Dated literature has also been used to show that the challenges experienced by Physical Sciences learners on Work Energy Power are not new and that research has grappled with these challenges for decades. Most of these studies have not been conducted among South African participants and it is envisaged that this current study will contribute in filling this gap and also in pointing towards future research that may use these results to find solutions. The theoretical framework underpinning this study will be presented in Chapter 4.

### 2.2 Understanding of Work Energy Power

According to the Physical Sciences Subject Statement in the National Curriculum Statement (DBE, 2011) the net work done on an object causes a change in the object's kinetic energy and the work-energy theorem is stated as  $W_{\text{net}} = E_{\text{kf}} - E_{\text{ki}}$ . In the Grade 12 curriculum for South African Schools, the study of the concept of work is confined to mechanical work (DBE, 2011). The concept of work as a thermodynamic quantity is not part of the Grade 12 curriculum (DBE, 2011). Learners are also expected to apply the work-energy theorem to objects on horizontal and inclined planes including surfaces that have friction and those that are frictionless. Arons (1999) argues that since work is a physical quantity that satisfies the First Law of Thermodynamics, it "cannot be calculated in general as an applied force times the displacement of the center of mass" and therefore the work-energy theorem cannot be applied to determine energy transformations when

work is done against friction (p. 1063). Arons (1999) adds that often in first year physics courses, the work energy theorem (WET) is applied to the rectilinear motion of particles having a mass  $x$ . This approach is used to introduce the concept of energy in the first year of physics courses. Newton's Second Law is employed as the starting point of this development of an understanding of energy concepts (Arons, 1999). This concept is extended further and includes the following: work done by or against forces, the work done by forces perpendicular to the direction of motion is zero (these are called zero-work forces) and the work done against the gravitational force is stored in the object as potential energy which can later be transformed into kinetic energy or using it to lift another object (Arons, 1999; Dreyfus, 2011; Lehrman, 1973). This paper notes that this manner of introduction of the work-energy theorem does not give the learner an opportunity to develop a good understanding of work as a thermodynamic quantity and it further allows for serious misconceptions about work done in the presence of friction, running and jumping (Arons, 1999). Other research also argue that the study of energy only from a kinematics and dynamics perspective negatively impacts on understanding and appreciating the concept (Domènech et al., 2001).

In the curriculum in South African schools, work is not discussed as a thermodynamic quantity in Grades 10-12. The treatment of work and energy in Physics is purely from a kinematics and dynamics perspective and this could probably be impacting on learner's poor understanding of work and energy. Energy is studied in the Chemistry part of the curriculum as Chemical energy and as electrical energy on the topic Electricity in the Physics part of the curriculum but no holistic links between the different knowledge areas are made regarding the concept energy. The concept energy is studied in the different knowledge areas in exclusive compartments. The emphasis seems to lean heavily on calculations and formulae. This study intends to investigate how learners understand the concept, given the way in which the curriculum is structured.

### **2.3 Alternative Conceptions**

What is meant by the construct "understanding"? The following excerpt taken from an anthropologist provides a deep meaning of the construct "understanding":

Understanding ... does not refer to a mysterious empathy between human beings. Nor does it refer to an intuitive or rationalistic ascription of motivations. Instead, it is a social phenomenon – a phenomenon of shared meanings. Thus, a fieldworker who approaches a strange people soon perceives that these people are saying and doing things which they understand but he does not understand. One of the strangers may make a particular gesture, whereupon all the other strangers laugh. They share in the understanding of what the gesture means, but the fieldworker does not. When he does share it he begins to “understand”. He possesses a part of the “insiders” view (Wax, 1971, pp. 10-11).

Borrowing the meaning of the construct “understanding” as a “phenomenon of shared meanings” this study approaches its purpose of exploring the Grade 12 learners’ understandings of Work Energy Power as the meanings that learners share with the scientific community (Wax, 1971, p. 11; Wax & Wax, 1974). By “scientific community” I refer to the widely accepted science textbooks, other science literature and scientists which include physicists who may also be teachers or lecturers. The learner’s understanding of the concept work was explored from the context of whether the learner shares the same meaning of this concept with the scientific community. Where there was a disjuncture between the learners’ understandings and that of the scientific community then this was flagged as an alternative conception (AC), in other words that the learner harbours a different meaning to that which is generally accepted by the scientific community.

The terms misconceptions, pre-conceptions, alternative conceptions and pre-existing knowledge abound in research (Bransford et al., 2000; Dega & Govender, 2016; diSessa, 2014; Maseko et al., 2010; Singh & Rosengrant, 2003) . Researchers are still talking of this today and are still searching for effective solutions to the challenge that it presents to learner understanding. The terms misconceptions and alternative conceptions have been used interchangeably in this study. In this study, I will be exploring the alternative conceptions about Work Energy and Power that learners hold at the end of their secondary schooling. I will be using the terms misconception and alternative conception interchangeably.

The idea of pre-conceptions have been discussed as impediments to learning (Arons, 1999; Champagne et al., 1983; Leonard et al., 1999) and as early as 1983. This study will not necessarily explore the pre-conceptions with which learners entered the classroom,

but rather will be exploring the conceptions that learners still hold about Work Energy and Power after having completed their secondary schooling. Some of these conceptions can be as the result of pre-conceptions that learners hold and that did not change during instruction. Alternatively, some of these conceptions could be a result of classroom interaction or even the absence of it. In this study the researcher refers to “classroom interaction” to denote “instruction” as this places the responsibility of learners having misconceptions or not on the teacher, learners and classroom materials like textbooks, etc. This terminology “classroom interaction” is more suitable when exploring learner misconceptions from a Variation Theory perspective. According to VT the enacted object of learning is the act of learning, and it is defined by the interactions that occur between teacher and learner, learner and learner and learner and learning materials. The possibility for learning is dictated by what is presented to learners and is co-constructed through the interactions that occur between teacher and learner and among learners within and with the learning environment (Akerlind et al., 2011; Lo, 2012; Marton & Booth, 1997).

“Misconceptions are faulty conceptions that produce systematic patterns of error and can be the result of instruction or originate prior to learning” (Ioannides & Vosniadou, 2002, p. 4). By “systematic patterns of error” it is understood that there is some reasoning (although scientifically flawed) that the learner engages with and that underlies this error. In other words, the learners’ naïve ideas (misconceptions/alternative conceptions) are coherent (Ioannides & Vosniadou, 2002; Stathopoulou & Vosniadou, 2007). This is similar to the position on misconceptions expressed by Selden and Selden (1987) which is discussed in the next paragraph. diSessa (2014) however suggests an opposing view as he says “rather than a coherent whole, students’ ideas consist of many quasi-independent elements” (p. 3). This model suggests a “fragmented”, “knowledge in pieces” framework as opposed to the misconception framework for learners’ naïve ideas (diSessa, 1993, p. 174). Ioannides and Vosniadou (2002) argue that learners’ naïve ideas/misconceptions/alternative conceptions are coherent and are not in agreement with the phenomenological-primitives (p-prims) explanation of learners’ views as argued by diSessa (1993) and diSessa (2014). “Unlike diSessa (1993) we think that children organize at least some of these experiences in narrow but relatively coherent framework and specific theories in their attempt to make sense of the physical world” (Ioannides & Vosniadou, 2002, p. 6). There is an ongoing “coherence debate” (Leonard et al., 2014, p.

181). Brown (2010) argues that although there are differences between the coherence and knowledge in pieces frameworks “the views overlap significantly, and that both articulate a dynamic and multidimensional view of students’ conceptions” (p. 2). It is argued that the coherence framework and knowledge in pieces framework are complementary views and that both look at different aspects of the learners’ knowledge structures (Brown, 2010; Leonard et al., 2014). Both the coherence framework and the knowledge in pieces framework “view students’ conceptions as arising from dynamically interacting knowledge elements with some level of coherence” (Brown, 2010, p. 5). There are other researchers who argue that it is not necessary to choose one or other of the two knowledge construction frameworks, namely coherent and fragmented frameworks (Wells et al., 2020). The study of Wells et al. (2020) involved the identification of incorrect responses to MCQs in Physics. These incorrect responses were then explored further to determine whether they were better described by the misconception or knowledge in pieces view (Wells et al., 2020). Leonard et al. (2014) presented the view that “both conceptual framework and knowledge in pieces views have value in explaining student conceptions” (p. 182). The researcher in this study adopts the perspective that both the coherence framework and knowledge in pieces framework can be used to explain learners’ understandings as both have elements of coherent thinking and both have value in explaining learner conceptions (Brown, 2010; Leonard et al., 2014; Wells et al., 2020)

Selden and Selden (1987) have stated that students make different types of errors and they classified these errors into two categories, misconceptions and other errors. Where the error was analysed as having an underlying faulty conception (or misconception), it was classified as a misconception. Where the error was seen as being of a technical nature, it was classified as other (Selden & Selden, 1987). The following is an example of an error that was classified as a misconception: “Conservation of relationships” (Selden & Selden, 1987, p. 9). Selden and Selden (1987) had argued that this type of error happened when students “act as if doing the same thing to both sides of any relationship preserves the relationship” (Selden & Selden, 1987, p. 9). For example,  $2 > 1$  but  $(-1)(2) < (-1)(1)$ . This is an example of a faulty conception and was therefore classified as a misconception (Selden & Selden, 1987). An example of an error that was classified as “other” is: “Overextended symbols” (Selden & Selden, 1987, p. 10). It was argued that this error

occurred when learners used one symbol for two distinct concepts/ideas/things and that this happened usually when learners did not discern the distinction between the two.

MCQs are a key tool in researching learners' understandings as indicated by several studies (Hestenes & Wells, 1992; Hestenes et al., 1992; Luangrath et al., 2011; Neidorf et al., 2020; Wells et al., 2020). Some of the studies adopt the view that learners' incorrect answers to the MCQs indicate misconceptions/alternative conceptions (Hestenes & Wells, 1992; Hestenes et al., 1992; Neidorf et al., 2020). However, there are other studies that argue that learners' incorrect answers to MCQs do not necessarily indicate misconceptions/alternative conceptions and that they may sometimes indicate other reasons like guessing, misunderstanding the question or be of a technical nature (Crogman et al., 2018; Luangrath et al., 2011; Wells et al., 2020). Neidorf et al. (2020) conducted a study of learner misconceptions that surfaced in the Trends in International Mathematics and Science Study (TIMSS). According to Neidorf et al. (2020) misconceptions are ideas that are not aligned to the scientific explanations of the concepts/ideas/laws. This particular study on TIMSS analysed student responses to MCQs and to questions that required a longer written response, which they termed constructed-response (CR) items. These two types of questions, MCQs and CR, that were studied for evidence of misconceptions have also been used in my study. The CR questions have been referred to as structured questions in my study. In their study Neidorf et al. (2020) identified a misconception as those demonstrated by particular types of student responses such as specific incorrect response options for multiple-choice items or specific incorrect answers to the constructed-response questions. Luangrath et al. (2011) argued that incorrect answers to MCQs may not always be due to misconceptions/alternative conceptions as these can sometimes be due to learners guessing or misunderstanding the question. They argued on the one hand, that if the answers to an MCQ "are evenly spread" on the alternatives then the researcher could interpret this as "guessing" (Luangrath et al., 2011, p. 112). On the other hand, they argued that if a large percentage of students choose particular incorrect answers, then the researcher may interpret this as an alternative conception.

There are different views that are expressed in the previous paragraphs on why learners give wrong answers to questions. One of these views is the coherent framework expressed

by Ioannides and Vosniadou (2002) and the other is the knowledge in pieces view expressed by diSessa (1993). Other researchers have added to these two views by arguing that learners perhaps have simply not understood the question or may have guessed (Luangrath et al., 2011). Another reason for learners getting incorrect answers may be of a technical error like making an incorrect substitution (Selden & Selden, 1987). Some research has argued that one does not have to choose a framework but rather look for evidence in the learners answers that is best explained by the coherent framework, knowledge in pieces framework or any other reason (Leonard et al., 2014; Luangrath et al., 2011; Wells et al., 2020). The researcher in this study explored learners' understandings by adopting this view.

There are also different views that are expressed in the previous paragraphs on whether learners' incorrect answers to MCQs can be due to misconceptions/alternative conceptions or other reasons like guessing and not understanding the question. In this study the researcher had interpreted learner responses to MCQs in two sets of data. The first set of data had been sourced from NSC scripts of 100 learners and the second set of data had been sourced from 8 Think Aloud Protocols. The analysis of the learner responses to the MCQ in the NSC examination required the researcher to draw inferences about the learners' understandings from their choice of option in the MCQ. In the analysis of the MCQ in the NSC scripts of the 100 learners the approach of Luangrath et al. (2011) was adopted. This approach stated that if the percentage of learners choosing a particular incorrect option was high then this could be interpreted as a possible alternative conception but if the percentage was almost evenly distributed for all alternatives then this could be interpreted as guessing (Luangrath et al., 2011). However, this was not taken as conclusive evidence for an alternative conception. In order to obtain more conclusive evidence of learners holding alternative conceptions Think Aloud Protocols of eight learners were obtained as they had answered MCQs and structured questions in the Think Aloud Questionnaire. These Think Aloud Protocols provided insights into learners' thinking as they answered the MCQs and structured questions. The analysis of the learners' answers and their TAPs as they answered the MCQs in the TAQ did not require the researcher to make inferences about the learners' thinking as the TAPs provided verbalisations of their thinking. More details on the TAPs and TAQ are given in Chapter 4.

“It is well established that students frequently answer conceptual questions incorrectly, often in predictable ways” (Brown, 2010, p. 1). A review of literature that documented research on alternative conceptions was undertaken and presented in this chapter. Singh and Rosengrant (2003) conducted research to study the understanding of energy and momentum by students doing introductory physics. In this literature review, I will concentrate only on their research that pertained to the understanding of work and energy. Their methodology included the development of a 25-question multiple-choice test called the Energy and Momentum Concept Survey (EMCS) (Singh & Rosengrant, 2003, pp. 612-617). Of these 25 test items, 14 focused on work and energy concepts. The test included both work and energy concepts. These concepts were the work-energy theorem, conservation of mechanical energy, work done by gravitational and frictional forces. The methodology comprised of both quantitative and qualitative analysis with the qualitative part involving the think-aloud protocol. This test was administered to over three thousand students from various universities and colleges. Seven students who had taken the test had volunteered to be interviewed using the think-aloud protocol. This study found that “students’ knowledge is fragmented” and dependent on the context of the question (Singh & Rosengrant, 2003, p. 610). One of the findings was that learners believed that the work done by the gravitational force on a falling ball is negative because the gravitational force is negative (Singh & Rosengrant, 2003, p. 611). I found these findings to be very informative, but I wanted to extend this to probing the alternative conceptions that learners hold regarding work, energy and power. One of the two questionnaires that was developed in this study was called a Think Aloud Questionnaire (TAQ) (Appendix 10) because it was used during implementation of the Think Aloud (TA) method. The TA method will be discussed later in this chapter. The TAQ that was used in this study also probed for the prevalence of alternative conceptions and other problem-solving difficulties that learners experienced regarding work and energy, as did the studies by Singh and Rosengrant (2003) and Singh and Rosengrant (2016). This probing into learners’ understandings of work and energy was extended in the TAQ that was developed in my study to include power as these three broad concepts are closely related. Further details on the development of the TAQ and the TA method is provided in Chapter 4.

The EMCS developed by Singh and Rosengrant (2003) was also used by Dega and Govender (2016) to compare the “scientific and alternative conceptions” about “energy

and momentum” among Ethiopian and American students (p. 1). The participants in this study were 72 university science students in Ethiopia. The study also included the data from 352 American students obtained in the Singh and Rosengrant (2003) study. The methodology used in this study was quantitative and the data was analysed using the Concentration Analysis statistical method. The findings of this study showed that both groups of students hold certain alternative conceptions about energy. A dominant AC among both Ethiopian and American students was that the “acceleration of a falling object depends on its weight” (Dega & Govender, 2016, p. 5). A less dominant AC that was found among the Ethiopian students was that the speed of a falling object depended on its mass. The study also found that the analysis of the data showed that Ethiopian students in the sample held fragmented ideas about conservation of mechanical energy (Dega & Govender, 2016). These results are very valuable as they also resonate with some of the findings in my current study regarding the understandings of learners about energy.

Dalaklioglu et al. (2015) conducted a quantitative study to determine 11<sup>th</sup> Grade students’ difficulties and misconceptions about energy concepts. They had administered 21 multiple-choice questions based on work, energy and conservation of energy to 284 high school learners doing Grade 11. The 21 multiple-choice questions that Dalaklioglu et al. (2015) had administered were selected from the 25 questions that comprised the Energy and Momentum Conceptual Survey (EMCS) (Dalaklioglu et al., 2015). The Energy and Momentum Conceptual Survey (EMCS) was designed by Singh and Rosengrant (2003, p. 607). The test results in this study showed that the students did not have a “coherent understanding of energy concepts” and that they experience difficulties when applying these concepts to different contexts (Dalaklioglu et al., 2015, p. 16). They found that high school students have many misconceptions related to energy concepts. In this study, one alternative conception about energy was mentioned “the longer moving path, the more kinetic energy of the system” (Dalaklioglu et al., 2015, p. 17). While the study by Dalaklioglu et al. (2015) is a quantitative study with a relatively large sample that mentioned one misconception about energy, I wanted to conduct a qualitative study with a small sample of learners to investigate further into alternative conceptions at a deeper level. My exploration about ACs was underpinned by the phenomenographic approach and VT as theoretical frameworks.

Alternative conceptions that learners hold regarding force and motion also affect learners in their understanding of work energy and power. Since work is defined as the dot product of force and displacement, learners' understanding of force, velocity, acceleration and mass is required for a deep understanding of work. Mchunu and Imenda (2013) conducted a study to identify the alternative conceptions held by learners in Mechanics. The participants of the study were 140 Grade 12 learners from four schools in Empangeni Education District in KwaZulu-Natal in South Africa. An instrument comprising of structured and open-ended items was designed and named "Test in Basic Mechanics (TBM)" (Mchunu & Imenda, 2013, p. 30). This TBM was administered to the 140 Grade 12 learners and the data that was collected from the responses of learners was analysed qualitatively. The finding of the study included eight alternative conceptions (ACs) held by this sample of learners in mechanics, of which three ACs are pertinent to my research. These three ACs found in this study are: the velocity and acceleration of a projectile increases as it goes up, the weight or mass of an object has an effect on the magnitude of the force it exerts and force is needed to keep an object moving at all times (Mchunu & Imenda, 2013).

Liu and Fang (2017) conducted a comprehensive literature review of alternative conceptions about work and energy. The literature review used the keywords "misconception, conceptual misunderstanding, alternative conception, preconception, naïve conception, immature conception, work, energy, mechanical energy, energy conservation, principle of work and energy, engineering mechanics, engineering dynamics, and physics" (Liu & Fang, 2017, p. 4). The literature review covered several web-based databases including Web of Science and Google Scholar. The keywords were used to target journals and conference papers that focused on either Physics Education or Engineering Education or both. The study found four concept inventories that studied alternative conceptions about work and energy amongst learners. These four concept inventories are Energy and Momentum Concept Survey (EMCS), Energy Concept Assessment (ECA), Energy Concept Inventory (ECI) and The Dynamics Concept Inventory (DCI). This study was a literature review that also included the classroom and outside-the-classroom observations of the authors of this paper. It included the findings that were made by Singh and Rosengrant (2003) when they administered their EMCS. This review identified 23 alternative conceptions about work and energy that had been

found by other researchers in this field. This review is of particular interest to my current study because I have included five questions from the EMCS in the TAQ.

## 2.4 Problem-Solving

Diverse cognitive abilities for example language, perception, memory, categorisation, ordering, decision-making distinguishing, synthesising and creating play an important role in problem-solving. The ability to integrate knowledge and find relationships between concepts/variables/physical quantities plays a critical role in problem-solving. This is the ability to connect the dots in order to arrive at the solution. There are many researchers who have found that the integration of knowledge is an important process in the learning of science since it provides learners with opportunities to actively engage, reflect, evaluate, modify and monitor their existing knowledge (Bell et al., 1995; Chen & Bradshaw, 2007).

Holyoak (1995) defines a problem as “In general, a problem arises when we have a goal – a state of affairs that we want to achieve – and it is not immediately apparent how the goal can be attained” (p. 269). According to van Someren et al. (1994), problem-solving can be regarded as a cognitive process that is “goal” oriented (p. 13).

Several researchers have stated that problem-solving has four components, namely, a goal state, an initial state, a set of operators or operations to reach the goal state from the initial state and a set of constraints that impose additional conditions on a success path to the solution (Chi & Glaser, 1983; Holyoak, 1995; Morrison & Holyoak, 2003). Some researchers speak of experts and novices when researching problem-solving. According to many researchers, experts perform an initial qualitative analysis before using appropriate equations when solving a problem (Champagne et al., 1983; Schultz & Lochhead, 1988). By contrast, novices will usually look for an equation and they do this by matching physical quantities given in a problem with variables in an equation. In this study, I did not look at problem-solving from the perspective of experts and novices since that would have required a deductive approach to the analysis of the data and having to place the learners into previously determined “categories of problem-solving approaches”. Instead, the data that provided information on the problem-solving approaches of learners in this study, was categorised and analysed using the phenomenographic and inductive approach. This will be discussed later in Chapter 4.

## 2.5 Problem-Solving difficulties on Work Energy Power

van Heuvelen and Zou (2001) stated that

students attempt to solve problems by matching quantities listed in the problem statement to special equations that have been used to solve similar problems. Students move between words and equations, which are abstract presentations of the world, with no attempt to connect either representation to more qualitative representations that improve understanding and intuition (p. 193).

In an alternative strategy, van Heuvelen and Zou (2001) viewed physics problems as descriptions of physical processes. They found that the introduction of qualitative representations of problems prior to the introduction of the relevant mathematical formulae resulted in improved understanding among students. They also found that this sequence of introducing qualitative representations followed by mathematical formulae resulted in students accepting qualitative reasoning more easily as well as improving their effectiveness in using them to solve problems. According to van Heuvelen and Zou (2001), an energy process can be represented by words, pictures, bar graphs, formulae, equations and other mathematical tools. They found that the qualitative work-energy bar charts, served as a useful visual tool to help students understand work-energy concepts and to solve related problems (van Heuvelen & Zou, 2001, p. 184).

From my experience as a teacher, I found that learners who usually solved the difficult problems started with the general principles relating to the knowledge domain in question, whereas learners who generally failed to solve challenging problems started with the surface features of a problem, like the value of a given variable. This problem solving difficulty that I observed in my experience is not new. It was also observed decades ago by Chi and Glaser (1983) who had shown that novices respond to the surface features of a problem, while experts respond to its deep structure. In most problem-solving activities given to learners in schools, that involve work, energy and power, problems are reduced to calculations that involve routine and slightly advanced mathematical manipulations. Learners are experiencing challenges in doing problem-solving activities in Grades 10-12 in Physical Sciences (DBE, 2014, 2015b, 2016). In general, learners succeed in solving the ‘plug and chug’ type questions.

There are fewer studies that have investigated learner difficulties regarding work, energy and power concepts compared to those that relate to force and motion (Singh & Schunn, 2009). Singh and Schunn (2009) have stated that learner difficulties involving energy have not been investigated as much as other concepts like force and motion. In this study, the researchers probed the nature of difficulties experienced by learners on the three topics, one of which was conservation of energy and drew on data that was obtained in another study that had developed and administered the 25-question Energy and Momentum Conceptual Survey (Singh & Rosengrant, 2003, pp. 612-617; Singh & Schunn, 2009, p. 27). They found the following three learner difficulties regarding energy: difficulty in recognising a problem as a conservation of energy problem, confusion about different forms of energy and difficulty with “parametric dependence of energy on variables” (Singh & Schunn, 2009, p. 35). The researchers reasoned that instead of using conservation of energy principles to solve problems that warrant this approach, learners are inclined to focus on “calculating forces along a path” since force concepts have been given more focus in the classroom (Singh & Schunn, 2009, p. 27). They also found that learners focused on the surface features of a problem instead of applying the principle of conservation of energy. The study also found that learners got confused between the “force” and the “work done by the force” (Singh & Schunn, 2009, p. 31). I have viewed these problem-solving difficulties that learners in my study have also experienced from a Variation Theory perspective. These are discussed in Chapters 6 and 7.

Some learners have difficulty in understanding mathematical concepts and this leads to them experiencing problem-solving difficulties in physics. Sign conventions for example are a critical mathematical concept that has application to both vector quantities like force, displacement, velocity and acceleration and to scalar quantities like work, energy, height and distance. Govender (2007) explored the understanding of positive and negative signs in vector-kinematics of student teachers. The study used the phenomenographic research perspective in this exploration. Students had been interviewed individually and the transcriptions of these interviews were analysed using the phenomenographic approach (Govender, 2007). One of the findings of this study was that students did not clearly differentiate “the concepts of scalars with vectors and their associated signs” (Govender, 2007, p. 70). The reasoning provided for this misunderstanding of students was that in

one-dimensional kinematics positive and negative signs are allocated to vectors and this confuses learners since “scalars” like energy “often have two signs” (Govender, 2007, p. 70). Another finding was that some students did not correctly interpret the positive and negative signs associated with given velocities. Some learners interpreted a positive velocity as “moving faster” and a negative velocity as “moving slower” (Govender, 2007, p. 71). One explanation for this misunderstanding given in the study is that this perception could have its roots in the number line system “where positive numbers to the right of zero are increasing in value while negative numbers to the left of zero are decreasing in value” as the numbers move away from zero in either direction (Govender, 2007, pp. 70-71). This finding, particularly about velocity resonates well with how some of the learners in my study answered question 10 (Q10) in the TAQ which I will explain further in Chapter 6.

Problem-solving strategies employed by learners to solve problems can have an impact on whether they arrive at acceptable solutions or not. Since this research explored learners' alternative conceptions, problem solving approaches and problem-solving difficulties on work, energy and power, it was necessary to conduct a review of literature regarding problem solving strategies which is discussed in the next section.

## **2.6 Problem-solving strategies and approaches**

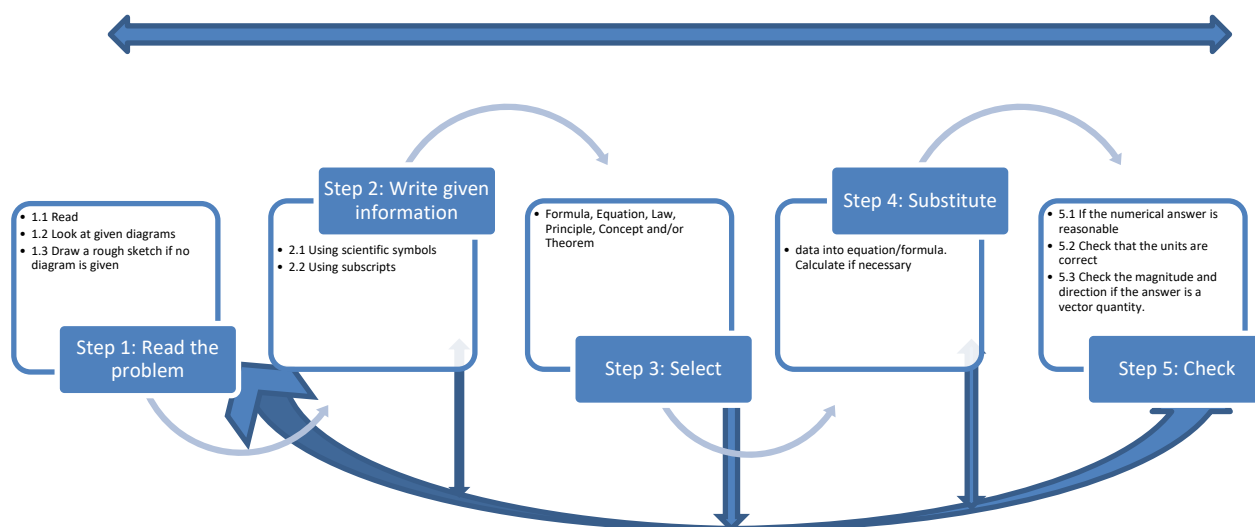
Several researchers have conducted research on problem-solving strategies or approaches and problem-solving difficulties (Modir et al., 2019; Nguyen et al., 2016; Nikat et al., 2018; Park, 2020; Schultz & Lochhead, 1988; Toh et al., 2009; Walsh et al., 2007). Firstly, a problem-solving strategy suggested by DBE will be discussed.

DBE provided a five-step general problem-solving strategy (DBE, 2017d, p. 6). The first step pertained to reading and was broken down into three sub-steps. I will refer to these three sub-steps as 1.1, 1.2 and 1.3. The first sub-step (1.1) guided learners to read the entire question as many times as necessary so that they could understand what information is given and what they are required to find out or calculate (DBE, 2017d, p. 6). The second sub-step (1.2) in this strategy guided learners to look at any given diagram/s while reading the question and to attempt to understand the diagram/s. Finally, the third sub-step (1.3)

advised learners to draw a rough sketch representing the problem and to depict all the given information for example  $v = 3 \text{ m}\cdot\text{s}^{-1}$  on the diagram. The second step in this problem-solving strategy advised learners to write down the given information using scientific symbols and subscripts, e.g.  $v_i$  for initial velocity and  $F_{\text{net}}$  for net force etcetera (DBE, 2017d, p. 6). The third step required learners to select or choose the correct formula, equation, law, principle, concept and/or theorem. The fourth step of this strategy required learners to substitute the given data into the selected equation and to perform the necessary calculations if these are required. The fifth and final step in this problem-solving strategy pertained to checking if the final answer to the question/problem made sense. The fifth step is broken down into three sub-steps, which I will denote as 5.1, 5.2 and 5.3.

In the first sub-step (5.1) learners were advised to check if the numerical answer that they obtained after solving the problem was reasonable. An example of this would be obtaining a walking speed of  $30 \text{ m}\cdot\text{s}^{-1}$  for a human being. This is certainly an unreasonable answer as it translates to  $108 \text{ km}\cdot\text{hr}^{-1}$  and no human being has set a record like this for walking. The second sub-step (5.2) advises the learner to check whether the correct units were used in the answer. The third and final sub-step (5.3) advises the learner to check the magnitude and direction if the answer is a vector quantity. The strategy is not provided in a diagram but stated in a paragraph with numbered steps and bulleted sub-steps. However, to make easier reading, Figure 2.1 presents the DBE General Problem-Solving Strategy in the form of a diagram. Figure 2.1 presents the General Problem-Solving Strategy of DBE.

**Figure 2.1: General Problem-Solving Strategy: DBE**



DBE further provides a three-step problem-solving strategy specific to Work Energy Power (DBE, 2017d, p. 29). The first step in this strategy is “Read and model the situation” (DBE, 2017d, p. 29). This step is similar to step one of the General Problem Solving Strategy but with two additional features, namely, identify which objects are part of the system and sub-divide the problem into two or more sub-problems if necessary. Step two of this problem solving strategy is “Visualise” (DBE, 2017d, p. 29). This problem-solving step is more content specific as it speaks to critical concepts related to Work Energy Power. Step 2 can be sub-divided into two sub-steps that I will denote as 2.1 and 2.2. Sub-step 2.1 requires the learner to draw free-body diagrams and to depict all the forces acting on the object/s. Sub-step 2.2 requires the learner to categorise the forces acting on the object/s as conservative or non-conservative. Step three of this problem-solving strategy is “Solve” (DBE, 2017d, p. 29). This step is specific to the topic Work Energy Power and it contains critical features like system, isolated, non-dissipative, dissipative, external, conservative and non-conservative (DBE, 2017d, p. 29). I will be exploring these critical features further in Chapter 6.

Step 3 is broken down into three sub-steps, which I will depict as sub-steps 3.1, 3.2 and 3.3. Sub-step 3.1 requires the learner to collect the data and to write it down using symbols. Sub-step 3.2 is similar to step 3 of the General Problem-Solving Strategy as it

speaks to “select formula” but it adds guidance pertaining to critical features of Work Energy Power to learners. Sub-step 3.3 is broken down into four sub-steps, which I will depict as sub-steps 3.3.1, 3.3.2, 3.3.3 and 3.3.4.

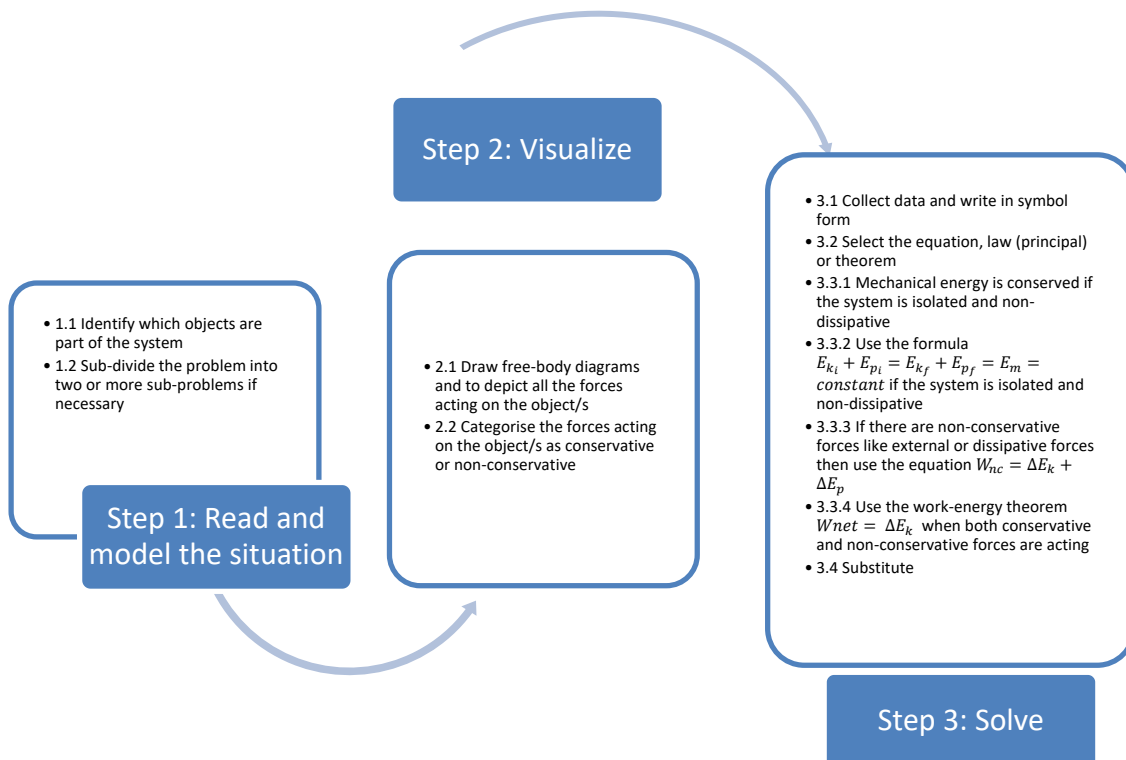
In sub-step 3.3.1, of the problem-solving strategy, learners are told that mechanical energy is conserved if the system is isolated and non-dissipative. Learners are guided to use the formula  $E_{k_i} + E_{p_i} = E_{k_f} + E_{p_f} = E_m = \text{constant}$  if the system is isolated and non-dissipative. In sub-step 3.3.2 learners are advised that if there are non-conservative forces like external or dissipative forces then they should use the equation:

$$W_{non-conservative} = \Delta E_k + \Delta E_p.$$

In sub-step 3.3.3 the strategy says that the work-energy theorem  $W_{net} = \Delta E_k$  can be used when both conservative and non-conservative forces are acting. Finally in sub-step 3.3.4 the strategy states that kinematic equations and some other laws must be used with some problems. Sub-step 3.4 is the same as the step 4 of the General Problem-Solving Strategy as it speaks to “substitute”. The strategy is not provided in a diagram but stated in a paragraph with numbered steps and bulleted sub-steps. However, in order to make easier

reading, Figure 2.2 presents the DBE Problem-Solving Strategy for Work Energy Power in the form of a diagram.

**Figure 2.2: Problem-Solving Strategy for Work Energy Power: DBE**



Park (2020) conducted a study on conceptual problem-solving in Physics. This study found that although students continued to use equations to solve qualitative problems, they did not do it in the same way. The study found that students who could see the relationships among variables used equations to explain problems. This finding was found to be of interest to my study as it could be used to support or deny two of the problem-solving categories, namely Plug-and-Chug Trial (PACT) and Linked and Integrated State (LIS) categories in the study.

A rubric to assess problem-solving by undergraduate physics students was designed, developed and tested in a study conducted by Docktor et al. (2016). Four general problem-solving steps were identified in this study and are provided below:

- Organising problem information (Useful Description)
- Selecting appropriate physics principles (Physics Approach)
- Applying those principles to the specific conditions in the problem (Specific Application of Physics)
- Using mathematical procedures appropriately (Logical Progression)

These four steps are similar to the problem-solving strategies provided by DBE that have been discussed in this section.

A phenomenographic study on problem-solving approaches to quantitative and qualitative physics problems was conducted by (Walsh et al., 2007). This study provided a hierarchical set of 5 categories of problem-solving approaches. These categories have been named scientific, plug-and-chug structured, plug-and-chug unstructured, memory based and no clear approach.

The categories provided by Walsh et al. (2007) are presented in Table 2.1 (Walsh et al., 2007, p. 4).

**Table 2.1: Students Approaches to Problem-Solving by Walsh et al. (2007, p. 4)**

CATEGORY	DESCRIPTION
Scientific	<ul style="list-style-type: none"> <li>• Qualitatively analyses the situation</li> <li>• Plans and carries out solution in a systematic manner based on that analysis</li> <li>• Refers to concepts to guide the solution</li> <li>• Evaluates the solution</li> </ul>
Plug-and-chug Structured manner	<ul style="list-style-type: none"> <li>• Qualitatively analyses the situation based on required formulas</li> <li>• Plans the solution based on the variables and proceeds systematically</li> <li>• Refers to concepts to guide the solution</li> <li>• Evaluates the solution</li> </ul>
Plug-and-chug Unstructured manner	<ul style="list-style-type: none"> <li>• Analyses the situation based on required variable</li> <li>• Proceeds by choosing formulas based on the variables in a trial-and-error manner</li> <li>• Refers to concepts as variables</li> <li>• Conducts no evaluation</li> </ul>
Memory Based Approach	<ul style="list-style-type: none"> <li>• Analyses the situation based on previous examples</li> <li>• Proceeds by trying to “fit” the given variables to those examples</li> <li>• Refers to concepts as variables</li> <li>• Conducts no evaluation</li> </ul>
No clear approach	<ul style="list-style-type: none"> <li>• Analyses the situation based on the given variables</li> <li>• Proceeds by trying to use the variables in a random way</li> <li>• Refers to variables as terms</li> <li>• Conducts no evaluation</li> </ul>

The problem-solving categories that I developed in this study were informed by the problem-solving taxonomy of Biggs and Collis (1982), Knowledge Structure Taxonomy of Anderson and Krathwohl (2001) and the problem-solving categories of Walsh et al. (2007).

## 2.7 Problem-Solving Taxonomy

This study required a taxonomy to categorise learners’ problem-solving approaches. A literature review of the SOLO taxonomy of Biggs and Collis (1982) and the Types of

Knowledge Taxonomy of Anderson and Krathwohl (2001) is therefore included in this section.

### **2.7.1 SOLO Taxonomy**

The Structure of the Observed Learning Outcome (SOLO) Taxonomy of (Biggs & Collis, 1982) and the Types of Knowledge Taxonomy of (Anderson & Krathwohl, 2001) were utilised to categorise the problem-solving approaches of learners. According to Newton and Martin (2013) “student responses and assessments can be related to increasing levels of cognitive complexity” (p. 83). The SOLO Taxonomy that was developed by Biggs and Collis (1982) classifies learning outcomes displayed by learners according to their complexity. The SOLO taxonomy can be used to assess learner performance according to well-developed criteria. It is a criterion-referenced tool to assess the quality of learner performance (Biggs & Collis, 1982). The SOLO taxonomy classifies the learning outcomes into five distinct hierarchical levels (Biggs & Collis, 1982; Newton & Martin, 2013; Shakhman & Barak, 2019). These five hierarchical categories are “pre-structural, uni-structural, multi-structural, relational and extended abstract” levels (Biggs & Collis, 1982, p. 36). In the pre-structural level the learner “avoids” the problem (Biggs & Collis, 1982, p. 36). This has also been described in the phrase “missed the point” (Shakhman & Barak, 2019, p. 4). The response of a learner that is based on only one critical feature of a concept or problem and where the learner’s approach or knowledge is “limited” is categorised as “uni-structural” in the “SOLO taxonomy” (Biggs & Collis, 1982, p. 36). At the multi-structural level, more than one critical aspect of the problem is known but their “relationships to each other and the whole are missed” (Shakhman & Barak, 2019, p. 5). At the relational level in SOLO all the aspects are known by the learner and he/she sees the connections between them (Biggs & Collis, 1982; Shakhman & Barak, 2019).

Several research studies have employed the SOLO taxonomy for a range of different purposes (Brabrand & Dahl, 2009; Hattie & Brown, 2004; Korkmaz & Unsal, 2017; Newton & Martin, 2013). In one study the SOLO taxonomy was employed to categorise and compare the levels of competencies of 734 courses at Aarhus University and University of Southern Denmark (Brabrand & Dahl, 2009). Korkmaz and Unsal (2017) conducted a different study to document the achievement levels prescribed in the

sociology curriculum at the Ministry of National Education (MoNE) in Turkey. The SOLO taxonomy was also used in a study investigating its usefulness in improving learning at a deeper level in dentistry (Lucander et al., 2010). This study had concluded that the use of the SOLO taxonomy in teaching and assessment did improve dental students' learning at a deeper level. In another study, the SOLO taxonomy, phenomenography and Bloom's taxonomy were used to categorise science students' answers to an examination paper in biochemistry by Newton and Martin (2013). This study showed that the SOLO taxonomy and phenomenography are useful tools to assess student learning at surface and deep levels of cognitive demand. My study has extended this finding of Newton and Martin (2013) to employ the SOLO taxonomy and phenomenography to categorise, determine and analyse the qualitatively different ways in which learners display their understandings and problem-solving approaches to Work Energy Power. My study further extended this idea to include VT as a theoretical framework within which the data was interpreted and analysed. Similar to Lucander et al. (2010) my study analysed the responses of learners to examination scripts but it also extended the idea by using the SOLO taxonomy to analyse Think Aloud data obtained from learners as they answered physics questions on a questionnaire.

### **2.7.2 Types of Knowledge Taxonomy**

Knowledge is generally described by a “noun” (Anderson & Krathwohl, 2001, p. 12). Knowledge is usually the “matter” or “substance” that learners are expected to acquire, make meaning of or construct (Anderson & Krathwohl, 2001, pp. 12, 13). Anderson and Krathwohl (2001, p. 27) categorise knowledge into four general types namely “factual, procedural, conceptual and metacognitive knowledge”. According to this categorisation, factual knowledge is knowledge of “discrete, isolated content elements” (Anderson & Krathwohl, 2001, p. 27). Examples of factual knowledge in Physics would be the definitions of scientific concepts like work, energy and power. Procedural knowledge is the knowledge of all steps involved in executing a task. Examples of this in Physics would be the problem-solving technique involved in simple one-step routine problems like calculate the resultant force acting on an object given its mass and acceleration. In this example the procedure would be to select the correct equation  $F_{res} = ma$ , followed by correctly substituting the values for mass and acceleration and thereafter executing the

mathematical calculation of the product of these two values. Conceptual knowledge is knowledge of “more complex, organised knowledge forms” (Anderson & Krathwohl, 2001, p. 27). For example, understanding the concept of work in Physics requires knowledge and understanding of several other concepts like mass, acceleration, velocity, time, vectors and scalars. Furthermore, the learner would need to be able to make correct relations about these concepts and to discern them in different contexts. Metacognitive knowledge includes knowledge about the tasks on hand and awareness of one’s own knowledge, limitations and strengths. In this study, the types of knowledge taxonomy of (Anderson & Krathwohl, 2001) and the SOLO taxonomy informed the categorisation of the learners’ understandings, problem-solving approaches and difficulties.

### **2.7.3 Think Aloud method**

The second and third research questions in this study are stated below:

*Research question two: What are the alternative conceptions and problem-solving difficulties of Grade 12 Physical Sciences learners on work, energy and power?*

*Research question three: Why do Grade 12 Physical Sciences learners’ hold certain alternative conceptions and problem-solving difficulties on work, energy and power?*

Both these questions relate to the thinking of learners. There are several research methods that could be employed to explore and “gain insight” into “thinking and learning” (van Someren et al., 1994, p. 14). van Someren et al. (1994) highlights seven of these methods namely observation, structured techniques, four types of verbal reports and think aloud (pp. 15-27). The four types of verbal reports mentioned are retrospection, introspection, questions and prompting and dialogue observation (van Someren et al., 1994).

The observation method of gaining insights into learners’ problem-solving approaches is an “unstructured technique” because it does not influence the behaviour of the participant (van Someren et al. (1994, p. 16). Observing the product, for example the learner’s answers to a problem-solving exercise, will fall under this category. This is called “product analysis” (van Someren et al., 1994, p. 15). Observing a learner’s behaviour while he/she is solving a problem is another way of gaining insight into the learner’s problem-solving approach. Examples of behavioural observations are: does the participant look cheerful or frustrated, how long the participant takes to solve the problem

and “eye movements” (van Someren et al., 1994, p. 16). van Someren et al. (1994) calls behavioural observations “action protocols” and they say that the analysis of these are similar to the analysis of think aloud protocols (p. 16). Data collected using the behavioural observation methodology is also subjective to the researcher’s interpretation of the participants behaviour during the problem-solving data. In this respect, the Think Aloud data is objective as the participant verbalises his/her “thinking” during the problem-solving process. Data that is collected by methodologies that are objective can be considered as raw data (van Someren et al., 1994, p. 119). According to this definition Think Aloud data is raw data. The think aloud protocol data are collected during the problem-solving process and not after. Furthermore, the participants are not given any prompts or leading questions to say anything about their problem-solving approach unlike in the observation method. This makes the data collected in the Think Aloud protocol more trustworthy as learners will be saying what they are doing as they solve the problem. It does not give them time to reflect after having done the task and to say things that they did not really do during the problem-solving process.

The second method is to use what van Someren et al. (1994, p. 16) called “structured techniques”. In this method, the researcher develops a set of questions with pre-defined answers from which the learner chooses a suitable response. An example of such a question could be: Did you use the work-energy theorem? Yes/No. Questions such as these will usually be asked after the learner has done the problem-solving exercise and this could lead to reliability issues as the learner could give a false response. The question itself could lead the learner to give an answer that he/she thinks that the researcher would want to hear.

Rosengrant et al. (2009) conducted a detailed study of students’ use of free-body diagrams. This study involved both quantitative and qualitative aspects. For the quantitative part, the study used a sample that consisted of 245 students of which the researchers had randomly selected 125 students in the first year of the study and 120 students in the second year of the study (Rosengrant et al., 2009, p. 4). The source of the data for the quantitative part were examination problems. Interviews that utilised the TA method provided the data for the qualitative part of this study. The sample consisted of six students purposively selected from the second-year class. The qualitative part of this

study was used to enhance the quantitative part of the study since the quantitative part of the study could only provide data on whether students got the problem correct or incorrect, but it could not state whether the students used free-body diagrams or not as well as why the students had used the free-body diagrams.

Rosengrant et al. (2009, p. 7) utilised the TA method to investigate how students use free-body diagrams in their problem-solving activity. In this study, Rosengrant et al. (2009) had not requested the participants to solve the given problem in any specific manner, but instead participants were required to “comment on everything they were thinking and doing while solving the problem-a think aloud protocol”. This sample of six students consisted of two high achieving students, two low achieving students and two students who had a different instructor from the first four. The researchers gave each of the six students an open-ended problem from the Electrostatics Year 1 Final Examination. The researchers had interviewed these six students about their use of multiple representations in solving the electrostatics problem. The comments that students made in the Think Aloud and in the interviews regarding the use of multiple representations were grouped into the following four categories:

- Comments that spoke to the use of representations to understand the problem or concept
- Comments that spoke to the use of representations to assist in solving the problem
- Comments that spoke to the use of representations to evaluate their answers and
- Comments that spoke to the use of representations to check for the consistency of other representations

In the quantitative part of the study, Rosengrant et al. (2009, p. 7) found that the students who correctly constructed a free-body diagram performed statistically better than those who had not constructed a diagram or had drawn incorrect or inadequate diagrams. Rosengrant et al. (2009, p. 11) found that all students who correctly “drew free-body diagrams were more likely to solve the problem correctly”.

## 2.8 Conclusion

In this chapter, a review of literature relating to critical aspects of this study has been conducted. The purpose of this study was to explore Grade 12 learners' understandings of, and problem-solving approaches to Work-Energy-Power in Physical Sciences in high schools. The following four research questions had been developed to frame this exploratory study and attempt to achieve its purpose:

- How do Grade 12 Physical Sciences learners perform on the questions on work, energy and power in the National Senior Certificate (NSC) examinations?
- What are the alternative conceptions and problem-solving difficulties of Grade 12 Physical Sciences learners on work, energy and power?
- Why do Grade 12 Physical Sciences learners hold certain alternative conceptions and problem-solving difficulties on work, energy and power?
- How can the Grade 12 Physical Sciences learners' alternative conceptions and problem-solving difficulties on work, energy and power be explained, using the variation theory of learning?

To gain a deep insight into the current literature that also dealt with the issues highlighted in the purpose and research questions of this study, a review of literature pertaining to understanding of WEP and ACs was undertaken. This was followed by a review of literature regarding problem-solving. The areas of interest on problem-solving that were reviewed were problem-solving difficulties, problem-solving strategies, problem-solving approaches and problem-solving taxonomies. Finally, a review of literature pertaining to the TA method and its use in science education research was undertaken.

## Chapter 3 - THEORETICAL FRAMEWORK

### 3.1 Introduction

This study explores Grade 12 learners' understandings of and problem-solving approaches to Work-Energy-Power in Physical Sciences in high schools. In this exploration, I used Phenomenography and Variation Theory as theoretical frameworks within which to answer my research questions. This chapter will present the theoretical framework that underpins this study, and it will be followed by Chapter 4 that focuses on the methodology that was employed to answer the research questions.

### 3.2 Variation theory

#### 3.2.1 Introduction to Variation Theory

The researcher Ference Marton wrote “He cannot, England know, who knows England only” in his foreword to the book titled Variation Theory and the Improvement of Teaching and Learning by Lo (2012, p. 1). This seemingly contradictory statement highlights the fundamental principle of Variation Theory (VT). “You cannot know what something is, without knowing what it is not” (Lo, 2012). Variation theory is a theory of learning that provides an explanation to the observation that different learners sitting in the same classroom do not necessarily understand or experience the lesson in the same way (Bussey et al., 2013). VT provides an explanation of why two learners participating in the same lesson might understand the concepts being taught differently. A learner's experience of a given phenomenon depends on the specific set of features of the phenomenon to which the learner attends (Akerlind et al., 2011; Govender et al., 2016). In VT this phenomenon is referred to as the object of learning. The aspects of the phenomenon that the learner discerns and assigns meaning to will define the way the learner experiences the phenomenon or concept (Marton & Ling, 2007). The manner in which learner's notice, recognise the importance of, and make meaning of critical features of a concept/phenomenon/event will influence their understanding of it. This “noticing” of the critical features of an object of learning is described in VT as being related to

awareness, discernment and simultaneity (Marton & Pang, 2006). This is also referred to as a “way of seeing” or looking at something (Marton & Pang, 2006, p. 198).

### **3.2.2 Key concepts of Variation Theory**

The very activity of learning suggests that there are things that need to be learned (Bussey et al., 2013; Lo, 2012). These “things” could be content knowledge such as historical facts, scientific concepts, mathematical processes and formulae. They could also refer to skills including dancing, painting, problem-solving and brick-laying. Marton and Booth (1997) describe these things that are to be learned by the learners as the objects of learning. The intended object of learning will consist of what the teacher, curriculum designers, textbooks, amongst others, intend for learners to learn (Bussey et al., 2013; Marton & Pang, 2006). The intended object of learning is either enhanced or limited by the teacher’s understanding, knowledge and experience as well as by the quality of the textbooks and the curriculum. The enacted object of learning is defined by the interactions that occur between teacher and learner, learner and learner and learner and learning materials. Several researchers refer to the enacted object of learning as opportunities to learn which is a broad view of the enacted object of learning (Euler et al., 2020; Ingerman et al., 2007; Sun, 2011). These possibilities or opportunities for learning are determined for example by the quality of the learning materials and classroom interactions that take place involving teachers and learners within and with the learning environment (Åkerlind, 2012; Akerlind et al., 2011; Lo, 2012; Marton & Booth, 1997). The lived object of learning can be described as the way learners make meaning of the object of learning after the lesson ends and beyond (Marton & Ling, 2007; Tóth & Ludányi, 2007). Several researchers focused their studies on the object of learning in trying to investigate what learning has taken place (Kullberg et al., 2017; Pang & Ki, 2016).

Any discrepancies between this lived object of learning and either the intended or enacted objects of learning can provide insight into how curricula or curriculum materials might be modified in order to help students become aware of the critical features of a given phenomenon, a condition that is necessary for learning. The aspect of variation is a key feature of Variation Theory (Åkerlind et al., 2011; Marton & Ling, 2007; Marton & Pang,

2006). This study employed Variation Theory of learning as a theoretical framework to inform the collection, interpretation and analysis of data.

### **3.2.2.1 Critical Features of the object of learning**

In general, the word “feature” refers to any characteristic, trait, attribute, highlight, etc. of anything be it a person, animal, concept, flower, plant, etc. For example one could speak of the physical features of a person and this could refer to eyes, nose, mouth etc. Lo (2012) provides an interesting example of how a person’s (say Joe’s) family, friends, colleagues and the boss understand her. According to Lo (2012) these people will understand or see Joe differently because they have had different experiences with him and will therefore focus on different features of him. For example, the boss may focus on his work ethics and competence, while friends may focus on his light-hearted and jovial characteristics. There is nothing right or wrong about how different people see Joe, “rather, they are incomplete ways of seeing him” (Lo, 2012, p. 27). If one requires that a certain object be seen in the same way by different people, then it becomes necessary that they all focus on the same features (Lo, 2012). “To see an object in a particular way, we must focus on certain features that are critical to a certain way of seeing, known as “critical features”” (Lo, 2012, p. 27). This definition of “critical features” was employed in this study to interpret the responses of participants in two questions of the Physical Sciences Paper 1 in the NSC 2017 examination. It was also employed to interpret the TAPs of the participants.

### **3.2.2.2 Variation and Discernment**

The identification of critical features and patterns of variation of the object of learning were employed to interpret the data in this study.

“Variation is about what changes, what stays constant” (Leung, 2012, p. 433). There can be no awareness of a concept or feature without there being variation (Lihua, 2017; Marton & Pang, 2013). For example, the awareness of a sweet taste would not be experienced if there were no variations to the phenomenon of taste, like sour, bitter, pungent etcetera. Discernment is about perceiving, making out, detecting, recognising or

noticing. The underlying principle of variation is to be able to discern (detect) the relationships between the parts and the whole of a phenomenon as one's focus of awareness changes (Leung, 2012; Yan, 1999). Discernment is not possible without variation (Lihua, 2017; Lo, 2012; Marton & Pang, 2013; Yan, 1999). That which remains constant is termed the invariant while that which changes is termed the variation. Four patterns of variation have been identified by (Marton et al., 2004, p. 16). These four patterns of variation are contrast, generalisation, separation and fusion.

### **3.2.2.2.1 Contrast**

According to Marton et al. (2004, p. 16), in order for a learner to experience something, a learner must experience something else in order to compare it with. This process is identified as a pattern of variation termed *contrast*. Other researchers have also provided some insight into this pattern of variation. Euler et al. (2020, p. 4) referred to contrast as “change against a background of sameness.” For a learner to understand what the colour blue is, the learner should also experience the colours that are not blue. As an example, for a learner to understand the principle of conservation of mechanical energy he/she must experience situations where this principle is observed as well as situations where this principle is not observed.

### **3.2.2.2.2 Generalisation**

In order to fully understand something, one must experience that something in various situations or appearances (Marton et al., 2004, p. 16). Marton et al. (2004) has named this pattern of variation “generalisation”. Leung (2017) says that generalisation follows the ability to contrast and this is in agreement with Marton et al. (2004). For example, in order to fully understand the Work Energy Theorem one must experience its application in different (varying) situations for example in horizontal motion, vertical motion, a combination of horizontal and vertical motion, etc. In this study, the learners' understanding of the Work Energy Theorem was studied by analysing their responses to problems requiring the application of it in different situations where some critical features were kept invariant and others were varied.

### **3.2.2.2.3 Separation**

It is essential that learners understand each critical feature of a concept in order to be able to fully understand the concept. This critical feature or aspect of a concept must vary while other aspects remain invariant (Marton et al., 2004, p. 16). For example, the researcher could explore a learners understanding of the work done by an applied force by varying the angle with respect to the horizontal, of the point of action of the applied force while at the same time keeping other critical features like friction constant. The critical feature “angle” would thus be separated from the other critical features which would have been kept constant. In this way the researcher or teacher can get the learner to focus on the “angle” and see how this affects the work done by the force. This pattern of variation is called “separation” (Marton et al., 2004, p. 16)

### **3.2.2.2.4 Fusion**

Fusing several aspects of a phenomenon together is termed “fusion” and was first explained by Marton et al. (2004, pp. 16-17). In real life situations, often several aspects of a situation vary simultaneously, and one needs to take these variations into account simultaneously and respond to them (Marton & Ling, 2007; Marton & Pang, 2006; Marton et al., 2004). Similarly, in Physics problems there are several critical features that learners need to take into account simultaneously when solving them. It is essential that learners are able to fuse their understanding of each critical feature of a concept simultaneously in order to be able to successfully solve problems involving them.

## **3.3 Phenomenography**

Variation Theory originated from Phenomenography (Bussey et al., 2013; Marton, 1981). Marton (1981) labelled the research approach that utilised “description, analysis and understanding of experiences” as “phenomenography” (p. 180). Several researchers described phenomenography as a research approach that aims to understand the

qualitatively different ways in which a group of participants experience a phenomenon (Green & Bowden, 2009; Marton, 1981; Reed, 2006; Tóth & Ludányi, 2007).

Marton and Booth (1997) speak of “first order” and “second order” perspectives from which phenomenographic studies can be done (p. 118). When a teacher assesses a learner's understanding of a Physics concept, the teacher is judging the learner's answer against a “predetermined norm” which is described as a “first-order” answer (Marton & Booth, 1997, p. 118). The physicist or the teacher say things about the world (e.g., physics concepts, laws, phenomena, etc.). These are judged by the scientific community or teaching fraternity against the knowledge of other physics concepts, laws or phenomena. The accuracy of the scientist's or teacher's statements about these concepts, laws or phenomena are not judged as their experiences but rather are judged against that which has been accepted as scientific facts or theories by the scientific community at large. This is referred to as the “first-order perspective” or approach (Marton & Booth, 1997). Research that takes the first-order perspective can be regarded as assuming a positivist paradigm. The teacher or other researcher who probes into learners' understandings of concepts, laws and phenomena by trying to see these through their eyes would be said to be adopting a second-order perspective (Marton & Booth, 1997; Reed, 2006).

According to Marton and Booth (1997) the second-order perspective is adopted in phenomenography when one is attempting to understand how learners understand concepts, laws or other phenomena in their own experience. The researcher would need to consciously step away from her own understanding of the science and see these concepts/laws/phenomena through the eyes (experiences) of the learner (second-order perspective) and thereafter use her experience of the science to understand and document the qualitatively different ways in which learners understand them (Marton & Booth, 1997). The researcher would then be working from a subjectivist stance when trying to document the learners' experiences of the concepts and a positivist stance when trying to highlight any dissonance among learners' understandings and the accepted “facts” and “theories” of science. The paradigm underpinning this study is discussed in Chapter 4.

Not all learners sitting in the same classroom understand the concepts being taught in the same way (Euler et al., 2020; Fülöp, 2015; Lo, 2012). This can be due to the way in which

the whole is understood in terms of its parts and on how the parts and their relationships to each other and to the whole are discerned (Kullberg et al., 2017; Marton & Booth, 1997; Marton & Pang, 2006). This can also be due to what aspects of the phenomenon/concept are in the learners' focal awareness at a particular time and also which critical features are simultaneously in the learners' focal awareness and simultaneously discerned (Bussey et al., 2013; Lo, 2012; Marton & Booth, 1997; Marton & Pang, 2006). The learners understanding of the work energy theorem (WET) will be used to explain the concept phenomenography.

Some of the various parts (or sub-topics) of this theorem that the learner would also need to have in their focal awareness when solving problems requiring the WET are net-work, positive work, negative work, kinetic energy, change in kinetic energy, initial conditions, final conditions and velocity. For a learner to discern the critical aspect "positive work" and be aware of it, this critical aspect must be associated with what Marton and Booth (1997) call the "dimensions of variation" (p. 112). In this case, there are three dimensions of variation regarding "positive work" that the learner would need to discern, namely positive work, negative work and zero work. Furthermore, the learner would also need to have in her focal awareness the relationship between these three dimensions (parts) of variation and the work energy theorem (whole). For a learner to understand a phenomenon fully it is not adequate for the learner to be aware of and discern only some of the features of that phenomenon. The learner would need to simultaneously be aware of and discern all the critical features of that phenomenon in order to fully understand it (Bussey et al., 2013; Lo, 2012; Marton & Pang, 2006). This variation is the "link between phenomenography and variation theory" (Bussey et al., 2013, p. 10).

Phenomenography and VT have been found to be best suited as an approach with which to tackle the research questions in this study as it allows the researcher to probe into learners' understandings and problem-solving approaches through their (the learners') eyes which is the purpose of this study. VT was also used as an analytical tool to record, categorise, analyse and account for the qualitatively different ways in which the learners experienced Work Energy Power.

### 3.4 Variation Theory in research in Science Education

According to several researchers in science education, Variation Theory provides a theoretical framework from which to explore the possible variations in experience and the resulting differences in learning and understanding (Akerlind et al., 2011; Bussey et al., 2013; Euler et al., 2020; Fülöp, 2015; Marton & Ling, 2007). Bussey et al. (2013) has shown that Variation Theory is a useful theoretical framework that can be employed to underpin research in chemistry education.

In their research on teaching strategies in Mathematics, Kullberg et al. (2017) underpin their design principles that were aimed at designing activities for learning problem-solving strategies in mathematics on variation theory. Variation Theory has been found to be useful when designing learning environments (Lo, 2009, 2012; Marton & Pang, 2006).

There are several studies involving Variation Theory in science education, including Physical Sciences Education. Park et al. (2009) successfully explored students' understandings of atomic structure in terms of variation theory of learning. This study administered pre and post questionnaires to 439 students enrolled for an introductory college chemistry course. The study analysed the student responses in the questionnaires and obtained categories of variation in student conception using VT. My current study is similar to the study of Park et al. (2009) in that it is also employing VT as an analytical lens through which to interpret the responses of learners to questions in science. In my study the science concepts are physics concepts whereas the concepts in this study are chemistry concepts.

In a study involving Physics, pre-service student teachers explored their "mix of understandings" of positive (+) and negative (-) algebraic sign conventions in vector-kinematics using a phenomenographic approach (Govender, 2007, p. 61). In particular, the interviews with the student teachers in this study were qualitatively analysed using a phenomenographic approach. This study has been reviewed in more detail in Chapter 2.

Euler et al. (2020) employed VT as a lens to understand and guide physics students in their use of digital learning environments. The emphasis on contrast in VT is a “key principle” that makes VT different from other learning philosophies (Euler et al., 2020, p. 5). The physics software Algodoo was used in a case study approach to explore how teachers guided physics students in the digital learning environment.

Zhijie and Sufahat (2021) employed VT to explore misconceptions that students hold on the Physics topic, thermodynamics. In this study Zhijie and Sufahat (2021) varied the temperatures of different materials to explore students’ understanding of thermal energy transfers from a region of higher temperature to a region of lower temperature.

Studies employing VT in research in science education is not new. However, the purpose for which VT was employed varied among the different research agenda. In this study I have employed VT as a theoretical framework to underpin it.

### **3.5 Summary**

“The link between phenomenography and VT is variation” (Bussey et al., 2013, p. 10). In this study, the phenomenographic theoretical framework was employed to describe the limited number of qualitatively different ways in which Grade 12 Physical Sciences learners experienced the phenomenon of Work Energy Power. VT was employed to explain and account for these qualitatively different ways in which the learners experienced the phenomenon.

## Chapter 4 – METHODOLOGY

### 4.1 Introduction

This research explored the understandings', problem-solving approaches and difficulties involving Work Energy and Power among Grade 12 Physical Sciences learners. The focus of this chapter is to discuss the paradigm that underpins this study. According to Krauss (2005) there are many research studies in the social sciences that are replete with the personal meanings of the researcher. The tacit belief systems or the way in which researchers view reality and how they understand that reality has a profound influence on how they collect, understand, analyse and theorise about the various aspects of their research (Otero & Harlow, 2009). It is crucial that a research design makes explicit the paradigm within which the researcher undertakes the study so that it could be understood taking that particular paradigm into account.

This chapter will initially present the research questions followed by a discussion on the paradigms selected for this study, including the justification for the choices made. A discussion of the context of the study, sampling and a description of the participants will follow. This is followed by a discussion on the data collection tools. Next the methods of data collection and recording are discussed. This is followed by a discussion on the methods of data analysis.

The ethical aspects that were considered and addressed, trustworthiness, validity and reliability follow the discussion of the data analysis methods. This is followed by a discussion on the limitations of this study. This chapter concludes with a summary.

### 4.2 Research problem, aim and purpose

The problem that had initiated this study is poor understanding of concepts and problem-solving ability involving Work Energy Power (WEP) among many Grade 12 Physical Sciences learners in South Africa. This problem has been discussed in Chapter 1.

The purpose of this study was to explore Grade 12 learners' understandings of, and problem-solving approaches to Work-Energy-Power in Physical Sciences in high schools. Four research questions were developed to frame this exploratory study and to attempt to achieve its purpose.

The overall aim of this study was to gain insight into grade 12 learners' understandings of and problem solving approaches on Work Energy Power in the selected districts of a province in South Africa.

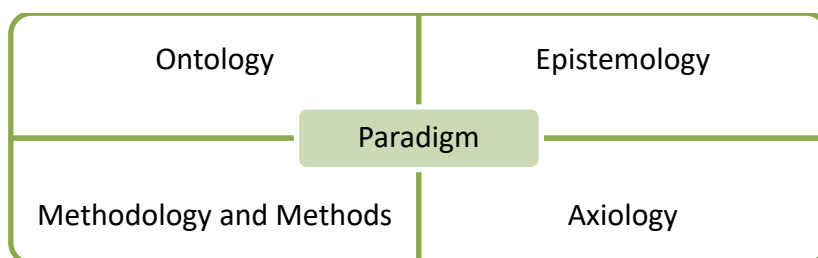
### **4.3 Research paradigm**

The notion of using the concept of a paradigm in research was introduced as early as 1962 by the historian Kuhn (1962, p. viii). He explained a paradigm as “universally recognized scientific achievements that for a time provide model problems and solutions to a community of practitioners” (Kuhn, 1962, p. viii). Later in the book he states that “a paradigm is an accepted model or pattern” (Kuhn, 1962, p. 23). According to Lincoln and Guba (1985) the term paradigm refers to a “systematic set of beliefs, together with their accompanying methods” (p. 15). Bogdan and Biklen (2007) define a paradigm as “a loose collection of logically related assumptions, concepts, or propositions that orient thinking and research” (p. 24). Cohen et al. (2018) described a paradigm as “a way of looking at or researching phenomena, a worldview ... the identity of a research community” (p. 8). These sets of beliefs, assumptions, philosophies and their accompanying methods guide the researcher in the choices that he/she makes regarding all aspects of the research. This will include the formulation of research questions, sampling, data collection and analysis. Any research is influenced by the researcher's choices (Krauss, 2005) and therefore every research has an element of subjectivity in it. It is to be noted that paradigms may not necessarily be the “drivers of research” as the research is a response to its question/s or purpose (Cohen et al., 2018, p. 9). However, choice of a paradigm assists in guiding and organising the research as well as clarifying the thinking behind the choices of approaches and methods (Cohen et al., 2018; Kivunja & Kuyini, 2017). Therefore, the researcher should always be clearly detailed in any research report. Insights into the “who” can be provided by the “who's” paradigm, the “who” being the researcher. This section is an

attempt to provide these insights by detailing the paradigm under which the study was undertaken.

According to some research, a paradigm consists of “four elements” and these are ontology, epistemology, methodology and methods (Scotland, 2012, p. 9). Other researchers have suggested that a paradigm consists of four elements namely ontology, epistemology, methodology and axiology where methods are included under methodology and axiology has been added as a separate element (Kivunja & Kuyini, 2017, pp. 27-28; Lincoln & Guba, 1985, pp. 36-39). In this study a paradigm will be considered as consisting of five elements namely ontology, epistemology, methodology, methods and axiology where it has borrowed from all three researchers namely Lincoln and Guba (1985), Scotland (2012) and Kivunja and Kuyini (2017). The elements of the paradigm are represented in Figure 4.1.

**Figure 4.1: Elements of a Paradigm**



I will begin by providing a brief description of each of the terms: ontology, epistemology, methodology, methods and axiology.

### 4.3.1 Ontology

*Ontology* is a philosophy about reality, of being or in other words what constitutes reality (Cohen et al., 2018, p. 3; Kivunja & Kuyini, 2017, p. 27; Krauss, 2005, p. 758; Scotland, 2012, p. 9).

### 4.3.2 Epistemology

The term *epistemology* has its roots in the Greek word “episteme” which means knowledge in the Greek language (Kivunja & Kuyini, 2017, p. 27; Krauss, 2005, p. 758). Epistemology is about knowledge and how one comes to obtain that knowledge (Hitchcock & Hughes, 1995, p. 19; Kivunja & Kuyini, 2017, p. 27; Krauss, 2005, p. 759; Scotland, 2012, p. 9). Epistemology is about the relationship between knowledge (that which is to be known) and the knower (researcher) (Kivunja & Kuyini, 2017, p. 25; Lincoln & Guba, 1994, p. 108).

Ontology, epistemology and methodology are closely related concepts and each one of them informs the other (Cohen et al., 2018, pp. 3-9; Crotty, 1998, p. 10; Krauss, 2005, pp. 758-759).

### 4.3.3 Methodology and Methods

*Methodology* has been defined as the overall plan that includes the choice of particular *methods*, approaches and procedures that are used to achieve the outcomes of the research (Crotty, 1998, p. 3; Kivunja & Kuyini, 2017, p. 28). Methodology is informed by the ontology, epistemology and theoretical framework.

#### 4.3.4 Axiology

*Axiology* refers to the “ethical” considerations in research (Kivunja & Kuyini, 2017, p. 28). These ethical considerations refer to the “beliefs” about “values” and morals and the part that they play in the research that is undertaken (Cohen et al., 2018, p. 3; Kaushik & Walsh, 2019, p. 1; Kivunja & Kuyini, 2017, p. 28).

#### 4.3.5 Choice of a paradigm

The choice of a paradigm to underpin this study was a long journey and research has indicated that it can be a confusing journey for some (Kivunja & Kuyini, 2017, p. 30). One of the factors that contribute to this confusion and dilemmas is that the number of paradigms have been increasing over the years. Over time several key players across various areas of study have developed, named and added “new paradigms” to the field of research and these were often challenged by other researchers across the various disciplines (Kivunja & Kuyini, 2017, p. 30). This also involved the now famous “paradigm wars” that several researchers have spoken to (Cohen et al., 2018, p. 9; Doyle et al., 2009, p. 176; Johnson & Onwuegbuzie, 2004, p. 14; Kivunja & Kuyini, 2017, p. 29). Researchers have also asked questions around power dynamics and the issue of paradigms for example: “This raised the question about who had the power to name and keep a paradigm?” (Kivunja & Kuyini, 2017, p. 30) and “who controls the list of “accepted” paradigms” (Morgan, 2007, p. 61).

There are several paradigms that are mentioned in literature but for the purpose of this study I will mention a few. Denzin and Lincoln (2018) discuss seven paradigms namely constructivism, critical theory, feminism, interpretivism, positivism, post-positivism and pragmatism. Creswell (2013) identifies four paradigms namely post-positivism, constructivism, participatory and pragmatism. Morgan (2007) discusses six paradigms namely positivism, constructivism, critical theory, post-positivism, participatory and pragmatism whilst advocating for the use of pragmatism as a “guiding paradigm” in social science research. In this study, pragmatism and interpretivism have been selected as paradigms that underpin it and the rationale for this is explained in the paragraphs that follow.

In the natural world phenomena are rarely looked at only from a quantitative perspective as one often looks at them from both a quantitative and qualitative perspective (Cohen et al., 2018). The paradigm wars that involved the choice of either a quantitative or a qualitative methodology to research and that fought for the superiority of one methodology over the other, eventually led to the mixed method research (MMR) approach (Cohen et al., 2018). Several researchers have advocated for the use of pragmatism as the paradigm under which mixed method research should take place (Brierley, 2017; Morgan, 2007). As mentioned earlier, paradigms do not necessarily drive the research but they are necessary as they guide and organise the thinking underpinning the research (Cohen et al., 2018). Pragmatism as a paradigm allows the research to be led by its purposes and questions as explained below:

This is loosely interpreted to be ‘what works’, i.e. if the methods of research and the data collected – be they numerical or qualitative – address the research purposes, problems or questions then they are acceptable. In other words, the research is driven by the research question (Cohen et al., 2018, p. 35).

According to James (1907) pragmatism involves the interpretation of different ideas/notions with respect to their “practical consequences” (p. 73). He said this in the context of Religious Philosophy, where disputes over metaphysical ideas can never be resolved. “What difference would it practically make to anyone if this notion rather than that notion be true” (James, 1907, p. 14). According to this understanding of pragmatism, there needs to be some “practical difference” that needs to be shown regarding interpretation of ideas (James, 1907, p. 14). A pragmatist does not involve himself/herself with “abstractions and insufficiency” but concentrates on “concreteness” and “action” (James, 1907, p. 16). The understanding of pragmatism given by Cohen et al. (2018) as that which answers the research question points to a method that has practical value and not loaded with abstractions is in agreement with the understanding given by James (1907).

This study is a mixed methods study and both pragmatism and interpretivism were suitable paradigms that were employed to frame the study. Paradigms are not all mutually exclusive as they share certain common characteristics (Cohen et al., 2018). Pragmatism adopts a pluralistic approach in its methodology as it draws on features from positivism

as well as interpretivism depending on “fitness for purpose” (Cohen et al., 2018, p. 36; Johnson & Onwuegbuzie, 2004). The study was led by the research questions and employed both quantitative and qualitative methods to address them in a way that worked in finding possible answers. Therefore, stating that this study adopted a pragmatic approach will also mean that it included elements of interpretivism.

Interpretivism is a research approach where the researcher “makes sense (interprets)” the views/responses/meanings that the participants have about phenomena or the world (Creswell, 2013, p. 25). The researcher brings his/her understanding, knowledge, experiences and background to bear on his/her interpretation. Interpretivism posits the view that reality is socially constructed and is subjective in contrast with positivism that posits that there is one single objective reality (Bonache & Festing, 2020; Dean, 2018). In this study the researcher attempted to make meaning of the participants’ responses to the research instruments and in this exercise employed the interpretivist approach.

The ontology that is associated with pragmatism is non-dualist where the assumptions about the nature of reality are that there can be several versions of reality and truth and that these can sometimes be subjective and sometimes objective (Cohen et al., 2018, p. 36) and it draws on whatever assists in answering the research question. One could therefore speak of “the realness of a reality independent of our perception” or “the realness of our perception” of this reality (Marton, 1981, p. 178). Marton (1981) described this distinction between reality and the perception of reality a “pragmatic” distinction (p. 178). James (1907) talks about the development of a version of reality, what one calls truth. The version of reality that a person holds before new facts/experiences come to light is termed “old truth” (James, 1907, p. 18). “New truths are the resultants of new experiences and of old truths combined and mutually modifying one another” (James, 1907, p. 39). The establishment of the new truth is at mercy of the truth-seeker’s “appreciation” (James, 1907, p. 18). “when old truth grows, then, by new truth’s addition, it is for subjective reasons” (James, 1907, p. 18). The pragmatist relies on facts and concreteness regarding what is true and truth about reality is subjective (James, 1907). “The ancient formulas are reinterpreted as special expressions of much wider principles” as new experiences and facts come to light (James, 1907, p. 19). What was regarded as truth yesterday may not be true today. In this study the researcher adopts the non-dualist

view of Cohen et al. (2018) that there are several versions of reality and truth and that these can sometimes be objective and sometimes subjective (p. 36). The epistemology associated with pragmatism is also non-dualist. This epistemology that is associated with pragmatism assumes that knowledge is both constructed (subjective knowledge) and based on the reality of the world (objective knowledge) (Johnson & Onwuegbuzie, 2004). The distinction between subject and object is replaced by the naturalistic approach where the engagement between subject and object replaces this historic distinction. According to Johnson and Onwuegbuzie (2004) all research contain some elements of subjectivity, even research conducted under the positivist paradigm. Examples of subjectivity in research conducted in the positivist paradigm are in the choice of the research question, development of the research instrument and interpretation of the results (Johnson & Onwuegbuzie, 2004). The researchers' values and beliefs influence him/her in the choice of the research question, development of instruments and interpretation of results. It is the practical utility of the philosophical theory to the research questions that dictate which philosophy could be applied or whether a philosophy should be applied (Cohen et al., 2018; Johnson & Onwuegbuzie, 2004). In this study, on the one hand there are the hard scientific facts and on the other hand there are learner conceptions of those "hard scientific facts" and the researcher's interpretation of this data and results. The hard scientific facts are the accepted version of reality about the world as it is accepted by the scientific community at this point in time and this represents the objective knowledge of the world. Some of these hard scientific facts may lose their status as objective knowledge at another time in the future as scientists make new discoveries, but for now, they are accepted as objective knowledge in this study.

Variation Theory was selected as a theoretical framework that underpins this study and it has been discussed in Chapter 3. Since Variation Theory originated from Phenomenography (Marton & Booth, 1997) they can share the same ontological, epistemological and methodological assumptions of Phenomenography. Marton (1981) labelled the research approach that utilised "description, analysis and understanding of experiences" as "phenomenography" (p. 180). Several researchers have described phenomenography as a research approach that aims to understand the qualitatively different ways in which a group of participants experience a phenomenon (Green & Bowden, 2009; Marton, 1981; Reed, 2006; Tóth & Ludányi, 2007). Phenomenography is

underpinned by a non-dualist ontology (Åkerlind, 2005; Marton & Booth, 1997) and since VT originated from Phenomenography it also espouses a non-dualist ontology. One can gain knowledge about learning by researching the experiences of learners as is done in phenomenography (Bussey et al., 2013; Ingerman & Booth, 2003; Lihua, 2017; Marton & Booth, 1997). Phenomenography incorporates certain features of pragmatism through its non-dualist approach (Feldon & Tofel-Grehl, 2018). The distinction between object and subject does not exist as stated below:

... the dividing line between “the outer” and “the inner” disappears. There are not two things, and one is not held to explain the other. There is not a real world “out there” and a subjective world “in here”. The world is not constructed by the learner, nor is it imposed upon her; it is constituted as an internal relation between them (Marton & Booth, 1997, p. 13).

Paradigms are not unique as there may be certain overlaps among them (Cohen et al., 2018). Pragmatism draws on the epistemology associated with interpretivism based on what works to answer the research questions, and making the assumption that reality can be regarded as both objectively and socially constructed (Cohen et al., 2018; Johnson & Onwuegbuzie, 2004). This study is based on the pragmatic paradigm as well as on interpretivism. These paradigms best suit the purpose of this research which is to explore Grade 12 learners’ understandings of, and problem-solving approaches to Work-Energy-Power in Physical Sciences in high schools, since this would require an understanding of the subjective world of the learners and an assumption that the science concepts involved in this study stem from an objective world of science.

In summary, this research adopts a subjectivist epistemology as the researcher makes meaning of the data collected through her own understandings, experiences and interactions with the participants (Kivunja & Kuyini, 2017). It also adopts an objectivist epistemology when making meaning of the science concepts that are included in the study. This research follows a non-dualist ontology as it makes the assumption that reality is a relationship between the knower and that which is to be known (Marton & Booth, 1997).

#### **4.4 Context of the study**

The study was located in one province in South Africa. Since the introduction of the National Curriculum Statement (NCS) in 2006 in the Further Education and Training (FET) band in the Basic Education Sector, the number of learners studying Physical Sciences averaged around 30-31%. The first cohort of learners selecting subjects in the NCS wrote the National Senior Certificate (NSC) examinations in 2008. This study is being conducted approximately 10 years after the inception of the NCS in FET. It would therefore be a reasonable assumption that all schools are implementing the NCS, albeit at different degrees of effectiveness.

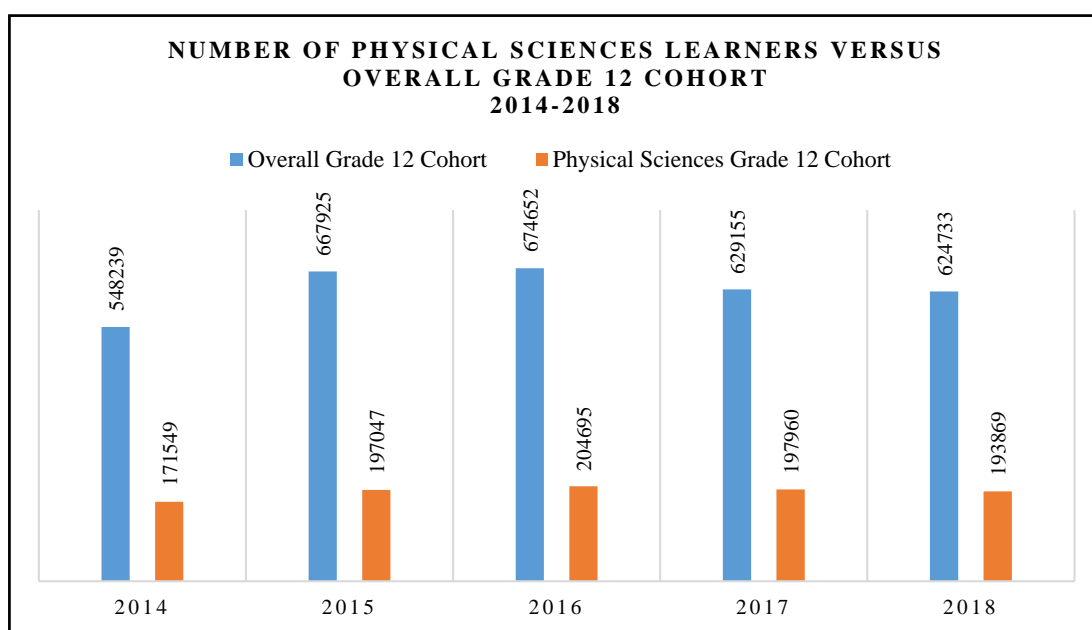
The Curriculum and Assessment Policy Statement (CAPS) was introduced to Grades 1, 2, 3 and 10 in 2012; in Grades 4, 5, 6 and 11 in 2013 and Grades 7, 8, 9 and 12 in 2014 (DBE, 2011). The CAPS is not a new curriculum but is a re-packaged curriculum that was intended to reduce the plethora of documents that teachers had to access in order to implement the NCS. One of the documents that was repealed was the Subject Assessment Guidelines (SAGs) and all matters that spoke to assessment were included in the CAPS document so that teaching, learning and assessment was integrated in a single policy statement (DBE, 2011). It was envisaged this would also assist teachers in integrating teaching, learning and assessment and hence improve learner performance and the quality thereof.

In the subsequent paragraphs, data and analysis of learner participation and achievement nationally during 2014-2018 will be discussed. This data for the period 2014-2018 is being provided because this study analysed NSC learner scripts of 2017 having collected the scripts after June 2018. Furthermore, a sample of learners from the 2018 Grade 12 cohort also participated in this study. It is for these reasons that both participation and achievement data for 2014-2018 are being presented as the context within which this study took place. Further discussion on the sources of data and sampling methodology are discussed in the following section.

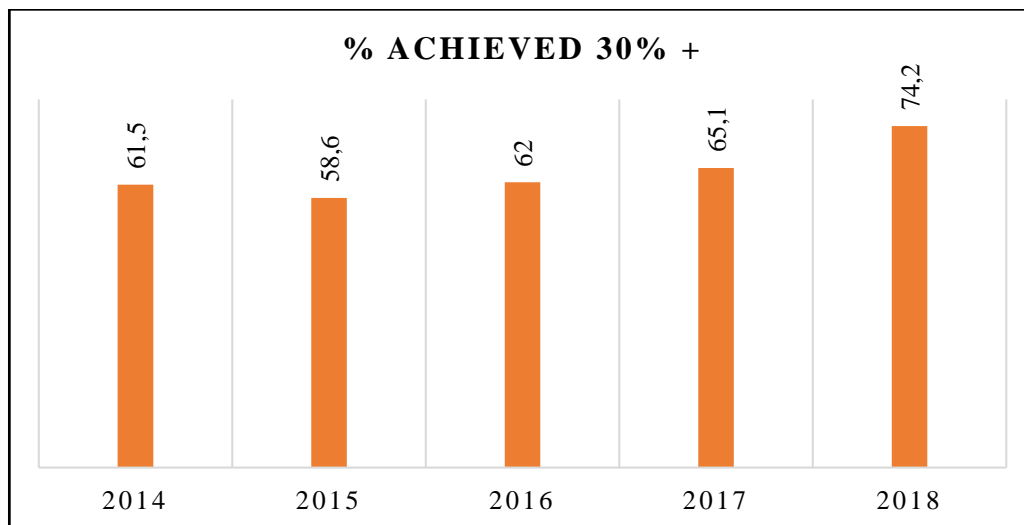
The number of learners in South Africa that have been studying Physical Sciences in Grade 12 during the period 2014-2018 hovered around 30-31% of the overall cohort of

Grade 12 learners (DBE, 2018b, pp. 15,16). The question of whether this figure is adequate or not has not been part of this study but is being provided so as to provide information about the context within which this study took place. It could be the subject of research in another study. This analysis of learner participation in Physical Sciences is presented in Graph 4-1. The data for Graph 4-1 was sourced from the National Senior Certificate Examination report of 2018 (DBE, 2018b).

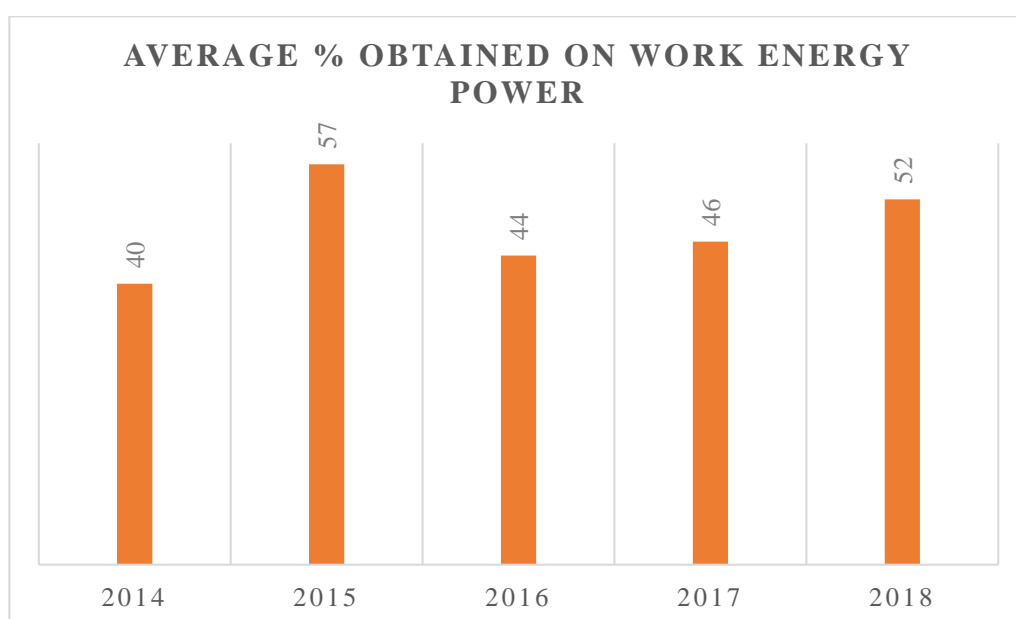
**Graph 4-1: Number of learners offering Physical Sciences 2014 – 2018**



The achievement rate in Physical Sciences was not good during the period 2014-2018 as is reflected in their achievement rates (DBE, 2018b). The achievement rate of learners at 30% and over in Physical Sciences during the period 2014-2018 is presented in Graph 4-2. The data for Graph 4-2 was obtained from the National Senior Certificate Examination report of 2018 (DBE, 2018b).

**Graph 4-2: Achievement rate at 30% + in Physical Sciences**

Learners have been performing poorly on the topic Work Energy Power during the period 2014-2018. The average mark expressed as a percentage obtained by learners on the topic Work Energy Power from 2014-2020 is presented in Graph 4-3. The data for Graph 4-3 was sourced from the National Senior Certificate Diagnostic reports ((DBE, 2014, 2015a, 2016, 2017a, 2018a)

**Graph 4-3: Average % obtained on Work Energy Power**

This research was conducted utilising data from six schools situated in one province in South Africa. The six schools were named School 1, School 2, School 3, School 4, School 5 and School 6 for purposes of confidentiality. Data from the NSC examination scripts of a sample of 100 learners were collected from all six schools and the researcher did not visit all these schools as the scripts had been collected from the district office after having obtained informed consent from the head of education in the province. The focus group interview and TA session were conducted at School 1. The pilot study was conducted at School 4. The researcher physically visited Schools 4 and 1 to conduct the pilot study, focus group interview and TA session. These two schools were well resourced as they had laboratories, well-built classrooms, good desks and chairs for learners, a large school hall and decent ablution facilities for both teachers and learners. The Physical Sciences laboratories were functional and well equipped with equipment and chemicals. On a visit to the laboratories at each school it was evident that the laboratories were being utilised by the teachers for experimental work with the learners.

#### **4.5 Research design**

This study employed mixed-methods and phenomenography approaches to explore Grade 12 learners' understandings of, and problem-solving approaches to Work-Energy-Power in Physical Sciences in high schools. In mixed methods research, both quantitative and qualitative methods are used to understand and approach the research purpose and questions (Cohen et al., 2018; Johnson & Onwuegbuzie, 2004). These methods are not utilised completely independently of each other as reality is not viewed as either quantitative or qualitative, but rather as an integrated whole of both (Cohen et al., 2018). Hence, the quantitative aspects and qualitative aspects of the study are integrated in order to arrive at the findings. An embedded mixed method design was used in this study and this is discussed further in section 4.5.3.

The phenomenographic approach in research involves the limited number of qualitatively different ways in which people could experience the same phenomenon (Bussey et al., 2013; Reed, 2006; Walsh et al., 2007). Phenomenography and VT were adopted as approaches as this study required the researcher to explore both the understandings of learners and their problem-solving approaches and difficulties (PSADs) to Work Energy

Power. Phenomenography and VT were found to be most suitable to answer the research questions as this study aimed to identify the range of understandings and PSADs of learners (as in phenomenography) and also to explain why and account for these understandings and PSADs (as in VT) (Bussey et al., 2013). VT has emerged as a consequence and development of phenomenography and has been called “a phenomenographic theoretical framework” (Bussey et al., 2013, p. 10). Research questions in this study were addressed by adopting the phenomenographic approach to generate categories of learners’ understandings and PSADs. Furthermore, the second and third research questions required the researcher to probe into the thinking of learners and Think Aloud (TA) was selected as one of the research methods to do this. According to several researchers, TA is a research method where the participants in the research voice their thoughts pertaining to the task as they are performing that task (Charters, 2003; Docktor et al., 2016; Meijer et al., 2007; van Someren et al., 1994). TA is a direct method to gain insight into the knowledge and problem-solving approaches of people (van Someren et al., 1994, p. 1).

#### **4.5.1 Sources of data and sampling**

This study used four sources of data. These four sources were the NSC examination scripts of learners, TA protocols, answer scripts of TAQ and focus group interview. I firstly discuss the sampling method employed to obtain the sample for each source of data. This will be followed by a discussion of each source of data. According to Cohen et al. (2018), researchers should decide whether the sampling method would be a probability or a non-probability sample. Probability samples are commonly referred to as random samples and non-probability samples are commonly referred to as purposive samples. As opposed to probability sampling, selectivity is built into non-probability sampling. This selectivity arises from the need to target a specific participant or group of participants (Cohen et al., 2018; Denzin & Lincoln, 2018). The method of non-probability sampling is recommended for research where there is no attempt to generalise the findings (Cohen et al., 2018). This study was an attempt to explore the understandings and PSADs of learners and it was decided that rich data and thick descriptions would best suit this endeavour and that this study will not attempt to generalise the findings. Therefore, the method of non-probability sampling was selected for all four sources of data.

Convenience sampling is the type of non-probability sampling where the researcher chooses the sample because she has easy access to it (Cohen et al., 2018, p. 218). Purposive sampling is also a type of non-probability sampling method. Purposive sampling involves the selection of participants or cases that satisfy certain criteria that the researcher has identified or chosen. According to Cohen et al. (2018) “researchers handpick the cases to be included in the sample on the basis of their judgement of their typicality or possession of the particular characteristic(s) being sought” (p. 218). The first source of data in this study was the 2017 NSC examination scripts for Physical Sciences Paper 1. Firstly, the province and districts were selected using convenience sampling. One province out of nine provinces and two districts out of 75 districts in the country were selected for this study. This province and districts were selected because they were easily accessible to the researcher. The choice of the schools in the selected districts was done using purposive sampling and typical case sampling. Typical case sampling is a type of purposive sampling (Cohen et al., 2018). The first criterion that was used to select the schools was that of pass rate in Physical Sciences in the year preceding this study. Collectively the schools covered pass rates from 26% to 99%. The reason for this criterion was that it provided a typical case. This means that it is a sample that includes typical cases of the school population under study (Cohen et al., 2018). This sample provided a representative sample in terms of performance of Physical Sciences in schools in South Africa. This sample is a non-probability sample. The second criterion that was used to select the schools was the number of learners offering Physical Sciences in Grade 12. The sampling method used was typical case sampling. The sample needed to cover very big, big, average and small schools. I categorised schools having more than 200 learners offering Physical Sciences in Grade 12 as very big, those having more than 100 learners but less than 200 as big schools, those having more than 30 learners but less than 100 as average schools and those having less than 30 learners as small schools.

Six schools were selected from which the NSC scripts of 100 learners were selected. To keep the identities of the schools confidential the schools were named School 1, School 2, School 3, School 4, School 5 and School 6. This data is presented in Table 4.1.

**Table 4.1: Typical Case Sample of Schools**

NAME OF SCHOOL	SIZE OF SCHOOL	NUMBER OF LEARNERS WROTE	PASS RATE IN %
School 1	Very Big	208	99
School 2	Big	100	68
School 3	Big	102	41
School 4	Big	100	81
School 5	Average	80	61
School 6	Small	19	26
<b>Overall</b>		<b>609</b>	<b>74</b>

After obtaining Ethical Clearance from the University of KwaZulu-Natal, I wrote to the head of education in the selected province to provide approval for the study to take place at schools in the province and to obtain the NSC examination scripts of the learners. Approval was granted by the MEC. After obtaining this approval, I approached the examinations section in the province and discussed the study with the senior official responsible for the scripts. It is a practice with the provinces that examination scripts are destroyed six months after the examinations have been written. Therefore, I was able to collect the sample of scripts belonging to the six schools presented in Table 4.1 after June of the year following the examination.

The data was sourced from 100 NSC examination scripts, focus group interview with 30 learners and eight Think Aloud Protocols. The data obtained from the 100 NSC examination scripts and the eight Think Aloud Protocols were analysed both quantitatively and qualitatively. The data obtained from the focus group interview with 30 learners was analysed only qualitatively.

During the sampling process the sample of 100 NSC examination scripts came from a different cohort of grade 12 Physical Sciences learners compared to the samples for the focus group interview and the Think Aloud Protocols. The sample of eight learners for the Think Aloud sessions were selected from the sample of 30 learners in the focus group interview. The unit of analysis in this study were the qualitatively different ways in which the phenomena of Work Energy Power were experienced by Grade 12 Physical Sciences

learners in one province in South Africa. Consequently, the responses of all the participants were examined holistically rather than individually. It was for these reasons that it was decided that the sample used for the focus group interview and Think Aloud Protocols did not necessarily need to be from the same sample used for the 100 NSC examination scripts. In this study, the 100 NSC scripts did not provide data on first year university students, as these examination scripts were written while they were still grade 12 Physical Sciences learners. It is to be noted that these NSC examination scripts can provide data on first year university students in other studies if looked at from that perspective. However, in this study the sample of 100 NSC examination scripts provided information on the learners' understandings and problem solving approaches as they experienced the topic WEP in the grade 12 classroom and while they were still grade 12 learners. All these three sources of data provided information on grade 12 Physical Sciences learners understandings and problem solving approaches in the districts belonging to the one province in South Africa.

The sampling method to select the examination scripts was typical case sampling. The 100 scripts that were selected from the 609 scripts collectively covered overall learner performance at levels 2 to 7. This means that the sample consisted of scripts of learners performing at 80% and over (Level 7), 70% and over (Level 6), 60% and over (Level 5), 50% and over (Level 4), 40% and over (Level 3) and 30% and over (Level 2). Scripts of learners performing under 30% (Level 1) had not been selected as the researcher assumed that there would be insufficient data on these scripts.

The sampling method for the participants for the Focus Group Interview was both convenience sampling and purposive sampling. One of the six schools was selected for the Focus Group Interview. The reason for this was that the distance between the schools was very large and it would have entailed a lot of cost and transport arrangements to move learners from different schools to a single venue. School 1 was chosen because it had the largest number of learners among the six schools and because the pass rates of the learners in the first quarter test ranged from level 2 to level 7. The learners in the focus group would therefore be providing a typical case scenario of pass rates ranging from levels 2 to 7.

This study sought to explore learners' understandings and PSADs and this required probing the learners' "thinking". Due to the enormity of this task, it was decided that a small sample of eight learners would be used to collect data pertaining to the "thinking" of learners using the Think Aloud (TA) method. The sampling method for the TA sessions was also purposive and was of the typical case type. In phenomenography and hence in this study, the unit of analysis is the qualitatively different ways in which a phenomenon is experienced. "Phenomenographic work provides program developers with a profile of the variation in experience across all of the participants in the program" (Micari et al., 2016, p. 460).

In a phenomenographic study, the learners are not being analysed per se, but the qualitatively different ways in which the phenomenon is experienced by them taken as a collective is studied. In this research, it is the qualitatively different ways in which learners understand and display problem-solving approaches and difficulties on Work Energy Power that was analysed. The 100 NSC learner scripts provided one source of data on the qualitatively different ways in which Work Energy Power was understood and approached by learners. The three other sources also provided data on the qualitatively different ways in which Work Energy Power was understood and approached by learners. These were the focus group interviews, TA transcripts and learners' answer scripts to the TAQ. All four sources provided data on the qualitatively different ways in which learners experienced Work Energy Power. The eight participants for the TA sessions were selected from the same group of learners who participated in the focus group interview. These eight learners were selected according to their achievement in class tests and examinations. Collectively, they covered achievement at levels 2 to 7. This typical case sampling method was used so that these eight learners could be a representative sample of Grade 12 Physical Sciences learners at the selected schools. The class teacher assisted in selecting these eight learners.

The learners were selected such that they were a representative sample of learners that covered achievement in Physical Sciences at the elementary, moderate or adequate (30%-59%), substantial (60%-69%), meritorious (70%-79%) and outstanding (80%-100%) categories (DBE, 2011, p. 151). These categories correspond to performance rating codes 2 to 7 given in CAPS (DBE, 2011, p. 151). In each of these categories two learners, one

per gender, were purposively selected from the Grade 12 Physical Sciences cohort in the selected school. This selection process resulted in the sample comprising of 4 female and 4 male participants. To protect the identity of the participants the following fictitious names were assigned to the eight learners: Ann (learner 1), Patience (learner 2), Gift (learner 3), Gold (learner 4), London (learner 5), Timber (learner 6), Jasmine (learner 7) and Blue (learner 8).

#### **4.5.2 Data collection instruments**

In this study, two instruments were developed to obtain raw data. These were the Semi-Structured Interview Schedule and the Think Aloud Questionnaire (TAQ).

I will first discuss the semi-structured interview schedule, and this will be followed by a discussion of the TAQ. The semi-structured interview schedule was developed and used in the focus group interview. This interview schedule consisted of two sections, Section A and Section B. Section A consisted of leading questions where I asked the learners about themselves, their living arrangements (residential or non-residential learners), transport to and from school and their attitudes towards the subject Physical Sciences. The questions that Section A covered were general open-ended questions. Section B of the interview schedule comprised of seventeen questions with question 17 comprising of four sub-questions. All the questions in Section B focused on understanding, problem-solving approaches and difficulties (PSADs) on Work Energy Power. The purpose of conducting the focus group interview was four-fold. Firstly, it was meant as an “ice breaker”. Secondly, it provided a platform on which both the researcher and the learners could begin communicating with each other. Thirdly, it served to focus the learners’ attention to the critical features of Work Energy Power that the TAQ was also dealing with. Fourthly, it provided the researcher with data on the learners’ understandings and problem solving approaches involving Work Energy Power. The researcher did not play the role of a teacher during the focus group interview, since the focus of the interview was to obtain data on learners’ understandings and problem solving approaches involving Work Energy Power. The researcher included follow-up questions during the focus group interview in order to obtain more clarity about learners’ understandings and problem solving approaches. In the following paragraphs in this section, the development the TAQ

(Appendix 10) will be discussed. This will be followed by the Think Aloud method. The TAQ consisted of 13 questions based on the topics work, energy and power. These questions were aligned to the Grade 12 Physical Sciences Curriculum and Assessment Policy Statement of the Department of Basic Education (DBE, 2011). These questions were based on the broad knowledge area titled Mechanics and on the topic Work Energy Power in the CAPS (DBE, 2011, p. 10). This topic forms part of the Grade 12 curriculum (DBE, 2011, p. 10).

The TAQ that was used during the TA sessions consisted of 13 questions based on the topics work, energy and power. These questions were aligned to the Grade 12 Physical Sciences Curriculum and Assessment Policy Statement of the DBE. Henceforth, the TAQ instrument will also be referred to as the questionnaire. These questions were based on the broad knowledge area titled Mechanics and on the topic Work Energy Power in the CAPS (DBE, 2011, p. 10). This topic forms part of the Grade 12 curriculum (DBE, 2011, p. 10). The first six questions in the TAQ are Multiple-Choice Questions (MCQs) and the remaining seven questions are structured (long) questions each comprising of at least two sub-questions. Four of the 7 structured (long) questions contained sub-questions. The structured (long) questions together with their sub-questions made up a total of 16 questions. This brought the total number of questions in the TAQ to twenty-two. The structured or long questions have been named as such because the learner would have needed to provide solutions containing more than one step for calculations or an explanation. The TAQ comprised of both quantitative (quant) and qualitative (qual) questions. Five of the questions were of the quantitative type of questions where learners were required to do numerical calculations. The remaining seventeen questions were of the qualitative type where learners were not required to perform numerical calculations to arrive at a solution. This classification of questions in the TAQ as being of the qualitative type and of the quantitative type has no bearing on the quantitative and qualitative type of data that was collected. The questions that required the learners to perform numerical calculations and arrive at numerical answers was classified as quantitative type questions while the questions that did not require the learners to perform numerical calculations and arrive at numerical answers was classified as qualitative type questions. The answers provided by the learners to both the qualitative and quantitative types of questions could be collected and analysed using both quantitative and qualitative

methods. For example, question 4 in the TAQ is an MCQ and is a qualitative type question as it does not require any numerical calculations to arrive at an answer. However, the data collected from the responses of learners to this question are both quantitative and qualitative. The number of learners providing a particular answer to question 4 in the TAQ provides the quantitative data in the form of frequencies. The verbalisations of learners indicating their thought processes while they were answering question 4 of the TAQ, provides the qualitative data for this question. This qualitative data is found in the TAPs of the learners. All the questions were based on the topic Work Energy Power. Five of the questions in the TAQ were developed by the researcher. Another five questions were sourced from Singh and Rosengrant (2003), four questions were sourced from the 2015 NSC Physical Sciences Examinations Paper 1, three questions were sourced from the 2017 NSC Physical Sciences Examinations Paper 1 and the remaining five questions were sourced from the Study Guide Curriculum Support Materials (DBE, 2010, 2015c, 2017c). The profiles of all twenty-two questions in terms of question type, expected learner response, object of learning and source of question are presented in Tables 4.2 – 4.7.

The five researcher developed questions in the TAQ had been subjected to rigorous checks for trustworthiness and this is discussed further in section 4.10. The five questions sourced from Singh and Rosengrant (2003) had been subjected to validity and reliability checks by the authors. Singh and Rosengrant (2003) had conducted research to study the understanding of energy and momentum by students doing introductory physics. Their methodology included the development 50 free response questions. These questions had been administered to several hundred students in the quality assurance process. The validity and reliability checks resulted in the 50-item instrument being reduced to a 25-question multiple-choice test called the Energy and Momentum Concept Survey (EMCS) (Singh & Rosengrant, 2003, pp. 612-617). Of these 25 test items, 14 focused on work and energy concepts. These concepts were the work-energy theorem, conservation of mechanical energy, work done by gravitational and frictional forces. I selected 5 of these 14 questions based on their appropriateness to the Grade 12 Physical Sciences curriculum as stated in CAPS.

The questions in the TAQ that had been taken from the 2015 NSC Physical Sciences Examination Paper 1 and the 2017 NSC Physical Sciences Examination Paper 2 are considered to be trustworthy since the NSC examinations of 2015 and 2017 had undergone rigorous quality assurance processes and had been declared “credible” by Umalusi, the Quality Assurance body (DBE, 2015b, p. 8; 2017b, p. 11). This study therefore takes this as a check for trustworthiness of these questions in this instrument. The questions in the TAQ that were taken from the Physical Sciences Curriculum Support Material were selected and discussed at the peer de-briefing meetings for trustworthiness. Initially seven questions had been selected. However, during these peer de-briefing discussions two questions were removed as they were seen to be repetitions, and this led to five questions being selected and agreed upon. One of these five questions in the TAQ in my questionnaire, Q8, is similar to Q9 of the EMCS (Singh & Rosengrant, 2003, p. 614). The objects of learning that were the focus of all twenty-two questions were work, conservation of mechanical energy, work energy theorem (WET), work and power, kinetic energy and free body diagrams (FBDs). The TAQ comprised of four questions on work, four questions on conservation of mechanical energy, eight questions on WET, two questions on relationship between work and power, two questions on kinetic energy and two questions on FBDs. The profiles of all twenty-two questions in terms of question type, expected learner response, object of learning and source of question are presented in Tables 4.2 - 4.7. Table 4.2 presents the profile of four questions in the TAQ that have the concept work as the object of learning.

**Table 4.2: Profile of questions in TAQ on Work**

QUESTION	QUESTION TYPE	EXPECTED RESPONSE	OBJECT OF LEARNING	SOURCE OF QUESTION
1	MCQ	Qual	Work	Researcher developed
2	MCQ	Qual	Work	(Singh & Rosengrant, 2003, p. 612)
9.1	Structured	Qual	Work	(DBE, 2010, p. 141)
13.2	Structured	Quant	Work	(DBE, 2017c, p. 11)

Table 4.3 presents the profile of four questions in the TAQ that have the conservation of mechanical energy as the object of learning.

**Table 4.3: Profile of questions in TAQ on Conservation of Mechanical Energy**

QUESTION	QUESTION TYPE	EXPECTED RESPONSE	OBJECT OF LEARNING	SOURCE OF QUESTION
3	MCQ	Qual	Conservation of mechanical Energy	(Singh & Rosengrant, 2003, p. 613)
5	MCQ	Qual	Conservation of mechanical Energy	(Singh & Rosengrant, 2003, p. 615)
6	MCQ	Qual	Conservation of mechanical Energy	(Singh & Rosengrant, 2003, p. 615)
8	Structured	Qual	Conservation of mechanical Energy	(DBE, 2010, p. 141) Similar to Q9 in Singh and Rosengrant (2003, p. 614)

Table 4.4 presents the profile of eight questions in the TAQ that have the WET as the object of learning.

**Table 4.4: Profile of questions in TAQ on Work Energy Theorem (WET)**

Question	Question Type	Expected Response	Object Of Learning	Source Of Question
4	MCQ	Qual	WET	(Singh & Rosengrant, 2003, p. 614)
7	Structured	Qual	WET	(DBE, 2010, p. 141)
10.2	Structured	Qual	WET	Researcher developed
10.3	Structured	Qual	WET	Researcher developed
11.3	Structured	Qual	WET	(DBE, 2015c, p. 11)
11.4	Structured	Quant	WET	(DBE, 2015c, p. 11)
12	Structured	Quant	WET	(DBE, 2010, p. 144)
13.3	Structured	Quant	WET	(DBE, 2017c, p. 11)

Table 4.5 presents the profile of two questions TAQ that have the relationship between work and power as the object of learning.

**Table 4.5: Profile of questions in TAQ on Work and Power**

Question	Question Type	Expected Response	Object Of Learning	Source Of Question
9.2	Structured	Qual	Work and Power	(DBE, 2010, p. 97)
11.1	Structured	Quant	Work and Power	(DBE, 2015c, p. 11)

Table 4.6 presents the profile of two questions in the TAQ that have the kinetic energy as the object of learning.

**Table 4.6: Profile of questions in TAQ on Kinetic Energy**

Question	Question Type	Expected Response	Object Of Learning	Source Of Question
10.1.1	Structured	Qual	Kinetic Energy	Researcher developed
10.1.2	Structured	Qual	Kinetic Energy	Researcher developed

Table 4.7 presents the profile of two questions in the TAQ that have free body diagrams (FBDs) as the object of learning.

**Table 4.7: Profile of questions in TAQ on Free Body Diagrams (FBDs)**

Question	Question Type	Expected Response	Object Of Learning	Source Of Question
11.2	Structured	Qual	FBD	(DBE, 2015c, p. 11)
13.1	Structured	Qual	FBD	(DBE, 2017c, p. 11)

### **4.5.3 Embedded Mixed Method Design**

An embedded mixed method design was used in this study. The “embedded” mixed method design provides for the quantitative data to provide additional information like frequencies to enhance the discussion of the qualitative data (Cohen et al., 2018; Creswell et al., 2011, p. 8). Alternatively, the qualitative data may be used to enhance the discussion of the quantitative data. In the embedded mixed method design, one type of data may take a higher priority over the other type of data. In this study, I used the quantitative data to enhance the discussion of the qualitative data. This study is mainly qualitative and hence the quantitative aspects are embedded within the qualitative data, data analysis and discussions. The quantitative aspects of descriptive statistics were embedded in the qualitative aspects of the analysis and discussion. This research was more heavily weighted on the qualitative methods and less on the quantitative methods.

## **4.6 Data collection methods**

### **4.6.1 Secondary Data**

One of the methods to obtain data was the use of secondary data. The 2017 NSC examination answer scripts of 100 learners was the secondary data that was used to answer research question one.

### **4.6.2 Think-Aloud**

The second method to collect data was a data collection using called Think Aloud that provided primary data. Think Aloud was the data collection method that was used to answer research questions two and three:

- Research question two: What are the alternative conceptions and problem-solving difficulties of Grade 12 Physical Sciences learners on work, energy and power?

- Research question three: Why do Grade 12 Physical Sciences learners' hold certain alternative conceptions and problem-solving difficulties in work, energy and power?

Both these questions relate to the thinking of learners. The TAQ was the data collection instrument that was used to address these two questions and it has been discussed earlier in this section.

These two research questions presented the researcher with three challenges prior to the commencement of data collection. The first of these challenges was on how to capture data that reflected the learners' thinking processes while solving physics problems. The second challenge was on how to capture data that reflected how the learners understood the concepts of work, energy and power. The third challenge was on the methodology to be used to analyse the captured data to provide insights into the understandings, problem-solving approaches and difficulties that the learners experienced involving the concepts of work, energy and power.

There are several research methods that could be employed to explore and gain insight into thinking and learning (van Someren et al., 1994, p. 14). van Someren et al. (1994, pp. 15-27) highlights seven of these methods namely observation, structured techniques, four types of verbal reports and think aloud. These methods have been discussed in Chapter 2. In this section, the TA method will be discussed as it was the method that was employed to collect data to answer research questions two and three of this study.

According to several researchers, Think Aloud is a research method where the participants in the research voice their thoughts pertaining to the task as they are performing that task (Charters, 2003; Docktor et al., 2016; Meijer et al., 2007; van Someren et al., 1994). TA is a very "direct method to gain insight into the knowledge" and problem-solving approaches of people (van Someren et al., 1994, p. 1).

The Think Aloud data is objective as the participant verbalises his/her "thinking" during the problem-solving process. Data that is collected by methodologies that are objective can be considered as raw data (van Someren et al., 1994, p. 119). According to this

definition, Think Aloud data is raw data. The think aloud protocol data are collected during the problem-solving process and not after. Furthermore, the participants are not given any prompts or leading questions to influence their problem-solving approach unlike in the observation method. This makes the data collected in the Think Aloud protocol more valid as learners will be saying what they are doing as they solve the problem. It does not give them time to reflect after having done the task and to say things that they did not really do during the problem-solving process.

A summary response to the three challenges presented at the beginning of this section is discussed in this paragraph. On the first challenge, the TA method was used to gain insights into the learners' thinking regarding concepts and problem-solving. The second challenge was addressed by combining VT, thematic analysis and phenomenography to categorise and code the raw data in the Think Aloud Protocols (TAPs). This coding and categorisation were done on NVIVO which is a software package that is used to analyse qualitative data. The third challenge was addressed by using VT as an analytical tool to analyse the "thinking" of the learners.

In this study, I employed the TA method, but there are some differences between my study and that of Rosengrant et al. (2009). One difference is that Rosengrant et al. (2009) used the TA method and focused on free-body diagrams whereas my study focused on learners' understandings and Problem-Solving approaches involving Work Energy Power. Another difference in the use of the TA method between Rosengrant et al. (2009) and my study was in the timing of the TA method. In my study, the learners "thought aloud" as they were answering the questions on the TAQ and not after. They were also not given any prompts or asked any questions about the TAQ by the researcher. In the case of the study conducted by Rosengrant et al. (2009), the students were interviewed after they had answered the questions and this was video-taped as TA data. The learners had been asked by the interviewer to state what they were thinking as they had answered the questions.

A purposive and typical case sample of eight learners had been selected from one school in the selected province for the TA session. These eight learners had been selected from the same group of learners that had participated in the focus group interview. In order to

ensure that the eight learners understood what was expected of them in the think-aloud session, they were initially trained by the researcher on what was expected of them. A different sample problem was used by the researcher in a practice think-aloud problem-solving exercise. This was practiced by the sample of eight learners. The learners were given the opportunity to raise questions about thinking aloud. These questions were clarified by the researcher using examples. The researcher took another problem-solving question and asked one of the learners to think aloud as she solved the problem, as a demonstration of the TA method. The learners were advised to literally say out aloud whatever thought, strategy, concept, value, equation, formula, reasoning, decision, calculation, etc. that they were using during the process of finding an answer to the question on hand. The learners were also advised to say out loud the question number before they began answering it. The researcher also told the learners that they will not be disturbed during the TA session by the researcher and/or teachers. No prompts were used by the researcher during the TA recordings.

Since the TA session required the learners to “speak aloud” this could have been a source of disturbance to fellow participants. It was for this reason that the school hall was utilised for the TA session. The school hall was large enough to allow the learners to be seated far enough and out of hearing from each other.

Once the learners were seated, they were each provided with an audio recording device, the TAQ and writing material. The learners were told that the audio recording device was meant for each of them to use to record his/her speech as he/she answered the questions on the TAQ. The learners were also advised to inform the researcher if the audio recording device stopped recording (due to battery going flat, etc.). Furthermore, the researcher kept a vigilant eye on the recording process to ensure that any hardware problems would be attended to immediately. Each learner had been requested to carry his/her own calculator and the researcher ensured that each had it. Care was taken to ensure that the rechargeable batteries of the audio recording devices were full. As a precautionary measure, spare batteries as well as electricity points to recharge the batteries were available in the hall. This was followed by the eight learners answering the questions on work, energy and power TAQ. The questions on the TAQ targeted deeper conceptual understanding and problem-solving involving work, energy and power.

The learners were also required to write down their answers and while doing so, to “think-aloud” as they worked their way through the questions. These sessions had been recorded for audio. The data, both written (answer scripts) and spoken (audio recordings), were collected as raw data. The answer scripts are referred to as the observation “product” and the analysis thereof is referred to as “product analysis” (van Someren et al., 1994, p. 15). van Someren et al. (1994) refers to the written data as written protocols and the spoken data as verbal protocols (p. 2). In this study the transcribed verbal protocols (audio recordings) will be referred to as Think Aloud Protocols (TAPs). The transcribed audio recordings (TAPs) were coded, categorised and analysed according to themes relating to understanding, problem-solving approaches and difficulties, emerging from the data itself. The coding, categorisation and analysis were inductive as opposed to deductive.

#### **4.6.3 Focus Group Interview**

The focus group interview was the third data collection method and it was also a method to collect primary data. A group of 30 learners had been selected from one school in the selected province. These learners covered achievement levels that ranged from 30% - 39% (level 2) to 80%-100% (Level 7) in Physical Sciences.

The Physical Sciences teacher at the school assisted in selecting the learners for the focus group interview.

At the start of the interview each learner was given a hardcopy of the Focus Group Interview Schedule. This schedule consisted of 17 questions based on WEP. The researcher conducted the interview and assumed the role of an independent observer. The Physical Sciences Teacher was present during the focus group interview but he did not participate in the interview. He was a non-participatory, silent observer. The focus group interview was recorded for audio using an audio recording device.

The focus group interview was transcribed verbatim and this data was analysed using thematic analysis. Learners responses to questions in the focus group interview schedule were coded according to two categories, correct and incorrect answers. These answers

were subsequently interpreted and analysed in order to obtain a view about learners' understandings and problem solving approaches and difficulties involving WEP.

## **4.7 Stages of the research**

Permission to conduct research had been obtained from the head of the province and the principals of the schools where parts of the study were located as this was a requirement to obtain ethical clearance from the University of KwaZulu-Natal. The study was conducted in two stages.

### **4.7.1 Stage 1: Piloting the Semi-Structured Interview Schedule and TAQ**

During Stage 1 of the research the semi-structured interview schedule and the TAQ were piloted. School 4 from the sample of schools given in Table 4.1 had been selected for the pilot. A meeting was held with the school principal where the purpose of the research was discussed. The principal referred the researcher to the subject teacher who was requested to assist in the process. The process of piloting the semi-structured interview schedule and the TAQ were discussed with the teacher. A group of 30 learners were selected by the teacher for the focus group interview where the semi-structured interview schedule was piloted. Informed signed consent was obtained from the learners and their parents.

During the pilot the teacher was present during the focus group interview. The focus group interview was recorded. Observations made during the focus group interview highlighted certain shortcomings in the interview schedule. These pertained mainly to the language and the length of the questions. It was also found that the learners needed more clarity about the problem-solving contexts that the interview had presented. After the focus group interview had ended, the semi-structured interview schedule was discussed with the teacher. This led to making adjustments to the questions by making the language simpler and including practical demonstrations of the problem-solving contexts in the final semi-structured interview schedule that was later used in the study. The questions were also made more direct, clear and shorter so that learners could understand them and respond appropriately.

Due to time constraints and the workload of the teacher and learners who participated in the focus group sample, only two learners were selected by the teacher for piloting the TAQ. These two learners had been selected from the sample of 30 learners who had

participated in the focus group interview. An explanation of what was expected of them during the TA session was made to the two learners that had been selected. The two learners were seated in the hall at a sufficient distance from each other so that they would not disturb each other when they “thought aloud”. Each learner was given an audio recording device, TAQ and writing material. Each learner also had his/her calculator on hand. The learners were told to use the audio recording device to record his/her speech as he/she answered the questions on the questionnaire. The learners answered the questions and verbalised their “thinking”. The learners also wrote down their responses to the questions on their scripts. The learners’ spoken words which are verbalisations of their knowledge, thoughts conceptions, ideas, difficulties and approaches were recorded as data on the audio recording devices.

After the TA session the questions on the TA and answers were discussed with the learners. This was done to ascertain whether the questions were appropriate and clear and also whether they were suitable for the purpose of the research. After this discussion three questions on the TAQ were modified as they were ambiguous as to what was expected of the learners. It was also observed that telling learners what to do during the TA session was insufficient. It was therefore decided that learners in the study would be trained to “think aloud” by using a pre-recorded example of a learner “thinking aloud” while answering a question. This was done and the pre-recorded example was developed to train learners about the “think aloud” process. Furthermore, the recordings of the focus group interview and the TA sessions were transcribed and analysed to see whether they were suitable in providing sufficient data to answer the research questions. It was found that the interview schedule and TAQ would be sufficient with the modifications described above.

At the end of the TA sessions in the study that followed the pilot, it was found that the learners were able to clearly voice their “thinking” as they answered the questions in the TAQ. This led to rich data that was collected during the study.

#### **4.7.2 Stage 2: The study**

The participants in the study were selected based on the sampling methods discussed in the section on data sources. Participants had been selected for the focus group interview and the TA session. One part of the study did not entail any visits or engagement with the schools from where data was sourced. This part involved the collection of NSC examination scripts of 100 learners. I will first discuss this part of the study and then move on to the parts of the study that involved contact with the participants.

After ethical clearance had been obtained from the university, email and telephonic contact was made with the district official in charge of NSC examination scripts of examinations that have already been written and resulted. Scripts can only be made available for research purposes six months after the examination processes involving those scripts had been concluded. This was verified with the district official in charge of the NSC examination scripts. The contact with the district official was made eight months after the relevant NSC examination had been written. The signed letter of informed consent by the head of the province was forwarded via email to the district official in charge of examination scripts in the province. The center numbers and number of scripts were detailed in the request for scripts to the district official. The center numbers were identification numbers for the schools that had been selected during the sampling process that has already been described in this chapter. A date and time for the collection of the scripts was agreed upon and the scripts had subsequently been collected. A total of 609 scripts from 6 schools had been collected from the district office. The sampling of the schools and scripts are indicated in Table 4.1 in the section on data sources.

The second part of the study consisted of having a meeting with the principal of the school that had been selected for conducting the focus group interview and TA sessions. A meeting was held with the principal where the purpose and process of the research was discussed. This was followed with a meeting with the head of the science department and the Physical Sciences teacher. The purpose and process of the meeting was discussed in detail. The teacher had offered to assist me with identifying the learners for the focus group interview and for the TA session. We discussed and agreed on the sampling

method. The teacher selected 30 learners for the focus group interview and selected 8 learners from this group for the TA session.

This meeting was followed with the focus group interview. A Physical Sciences classroom for this interview was selected and the Physical Sciences teacher accompanied the researcher to the classroom. The 30 learners who participated in the focus group interview had been identified by the teacher according to the sampling criteria that we had discussed, and they were seated in the classroom. Although the learners had been briefed about the focus group interview and informed consent had already been obtained from their parents, an introduction to the interview process was provided. The learners were given the opportunity to excuse themselves and not participate in the interview if they chose to do so without any consequences. The learners were informed that the interview was being recorded for audio. Each learner was handed a copy of the semi-structured interview schedule to facilitate the interview process. It was necessary for the learners to each have a copy of the interview schedule since Section B of it comprised of questions pertaining to understanding and problem-solving involving Work Energy Power. Having the questions in hardcopy assisted learners when they needed to refer to the questions more than once when looking for solutions.

Some of the questions on the interview schedule required demonstrations of the context. For example, in question B.11 of the focus group interview schedule, the question stated “Let us suppose you do work on a box that is placed on the floor? (Interviewer places the box on the floor and asks the group how work can be done on the box.). Do you think the work that you do on the box will have any effect on the Kinetic Energy of the box?” This resulted in learners coming forward and demonstrating how work could be done on the box. Some of them gave the box a forceful push with his/her hands and then removed his/her hands, others lifted the box while some just dragged the box for a distance and then left the box.

The discussions highlighted both good understandings and alternative conceptions about work and kinetic energy. The focus group interview was conducted in a classroom at the school, where an attempt was made to identify the critical features of energy and mechanical work, awareness of these critical features and discernment regarding them.

The focus group interview also included questions on problem solving. The focus group interview was recorded for audio and transcribed. The data from the focus group interview was used in triangulating data about learners' understandings, problem-solving approaches and problem-solving difficulties with data obtained from the other sources of data, namely the NSC examination scripts, written answer scripts to the TAQ and the TAPs.

Following the focus group interview, the Think Aloud session was conducted to collect further qualitative and quantitative data on Grade 12 Physical Sciences learners' understandings, problem-solving approaches and problem-solving difficulties on work, energy and power. The purposive typical case sample of 8 learners that had been selected for the Think Aloud session were seated in the hall, a sufficient distance apart so that they could not be audible to each other. Each learner was given the TAQ, audio recording device and writing materials. To ensure that the eight learners understood what was expected of them in this think-aloud strategy, they were first trained by the researcher. A different sample problem was used by the researcher in a think-aloud problem-solving strategy and recorded. The eight learners listened to this recording and their questions relating to the implementation of the think-aloud strategy were clarified. All the learners said that they understood what was expected of them and expressed eagerness to participate. It was a novel experience for the learners and yet they did not express any anxiety about "thinking aloud" and being recorded. To the contrary the learners appeared very excited and confident about themselves participating in the process. These observations by the researcher were recorded in the field notes taken during the Think Aloud process for the study.

This training was followed by the eight learners answering the questions on work, energy and power on the TAQ. The learners engaged with the questions on the TAQ and verbalised their "thinking" while doing so. They also wrote down their answers on the writing material that had been provided to each of them. The researcher remained in the hall for the full duration of the Think Aloud session and did not provide any prompts or leading questions. The think aloud data were collected via the audio recordings and answer scripts to the TAQ, during the problem-solving process and not after. Furthermore, the participants were not given any prompts or leading questions that would

have influenced their understandings or problem-solving approaches unlike in the observation method. This made the data collected in the Think Aloud protocol more trustworthy as learners were saying what they are doing as they solved the problems. This TA method did not give learners time to reflect after having completed the tasks and to have said things that they did not really do during the problem-solving process. The data, both written and verbal, were analysed and coded as per themes relating to understanding, problem-solving approaches and problem-solving difficulties, emerging from the data itself. The analysis was inductive. The data analysis is discussed in the next section.

#### **4.8 Data analysis**

This study used both quantitative and qualitative data to answer the research questions. Data were analysed using both quantitative and qualitative methods. The sequence, timing and priority of the quantitative and qualitative data analysis phases need to be decided by the researcher (Cohen et al., 2018). The data that were collected from all the data sources discussed in this chapter were subjected to both quantitative and qualitative analysis. The quantitative and qualitative analysis of the data took place concurrently. The weighting of the qualitative data analysis was greater than the weighting of the quantitative data analysis. The qualitative data analysis was of a greater priority than the quantitative data. The quantitative data analysis utilised only descriptive statistics. The descriptive statistics was integrated in the qualitative data analysis as well as in the discussion phase. For example, all the questions in the TAQ elicited responses from all eight learners in the Think Aloud session. The responses of the learners were recorded for audio and transcribed verbatim to provide the TAPs. The answers of the learners to the questions in the TAQ were analysed both quantitatively and qualitatively. The qualitative analysis involved the coding of the responses of the learners in the TAPs according to themes in order to identify and record the alternative conceptions that learners had verbalised while they were answering the questions. The quantitative analysis involved counting the number of ACs as well as the number of questions in which each of the ACs were verbalised by each learner. In this manner the quantitative data and analysis was embedded within the qualitative data and analysis in the form of frequencies in order to enhance the analysis and findings. This study was mainly qualitative and used mainly descriptive statistics to support and enhance the qualitative analysis.

Four software packages were utilised to record and analyse the data. These were Transcribe, Nvivo, Microsoft Excel and Statistical Package for the Social Sciences (SPSS). Nvivo is a qualitative data analysis software package. Microsoft Excel is a spreadsheet software program that can be used for data analysis and documentation. Transcribe is an online transcription software package. The software package Transcribe was used to transcribe the audio recordings of the focus group interviews and the TA sessions. The qualitative data were recorded and analysed using Nvivo. The quantitative aspects of the data found in the 100 NSC examination scripts were recorded and analysed using SPSS. Microsoft Excel was used to undertake further quantitative analysis of the qualitative data found in the eight TAPs, especially those discussed in Chapter 7 and 8. This quantitative analysis of the qualitative data found in the eight TAPs involved mainly the frequencies of occurrence of ACs and PSADs.

“Document analysis is a systematic procedure for reviewing or evaluating documents, both printed and electronic (computer-based and Internet-transmitted) material” (Bowen, 2009, p. 27). Like other analytical methods in qualitative research, document analysis requires that data be examined and interpreted in order to elicit meaning, gain understanding, and develop empirical knowledge (Corbin & Strauss, 2008). Documents can contain written words (text), pictures, graphs and other images that have been recorded without a researcher’s intervention. Some researchers also include audio/visual materials as documents (Bowen, 2009; Corbin & Strauss, 2008). There are several different kinds of documents such as policy documents, regulations, guidelines, examination papers, learner answer scripts, advertisements, agendas, attendance registers, minutes of meetings, manuals; journal papers, books, brochures; government bills, diaries, government acts, journals and programs (Bowen, 2009; Corbin & Strauss, 2008; Dillon, 2012). This is certainly not an exhaustive list of document forms. In a basic interpretive qualitative study, the researcher is interested in understanding how participants make meaning of a phenomenon (Corbin & Strauss, 2008; Sharan, 2002). In this type of study, data could be collected through document analysis or interviews (Sharan, 2002). Document analysis involves “skimming” (superficial reading), reading (thorough reading), and interpretation (Bowen, 2009, p. 32). Document analysis is an iterative exercise and it includes aspects of both content analysis and thematic analysis

(Bowen, 2009). During content analysis the researcher begins by skimming through the document to get a broad overall idea of the gist of it. This is followed by a more focused reading that also begins to find resonance with his/her research questions. This process of document analysis will include an interpretation phase where the researcher makes meanings of and arrives at conclusions regarding the document. During the different stages of content analysis, the researcher may code and categorise the data contained in the document so that it is organised in a manner that can be used to answer his/her research questions. The categorisation will usually pertain to key features of his/her research questions. Content analysis has been employed to analyse interview transcripts or notes and this process shares similarities with the process of analysing think aloud protocols (van Someren et al., 1994, p. 121).

Thematic analysis may include recognising patterns that emerge from the data. These themes that emerge from the data can be used to determine the codes and categories of description of the data and also to facilitate the process of analysis (Fereday & Muir-Cochrane, 2006). The process involves taking a more focused re-reading and review of the data. The process furthermore involves taking a closer look at the selected data and performing coding and category construction, based on the data's features, to uncover themes critical to the phenomenon. When predefined codes or categories are used, the process is referred to as a deductive process (Fereday & Muir-Cochrane, 2006). When categories that emerge from the data are used in the analysis process it is called an inductive process (Fereday & Muir-Cochrane, 2006). The codes used in interview transcripts or other research articles, for example, may be applied in the analysis of documents in a deductive process. Fereday and Muir-Cochrane (2006) utilised this method of inductive and deductive thematic analysis to identify pertinent themes in the self-assessment of nursing practice in Australia. They explained how they succeeded in identifying themes that categorised and described the feedback from nurses in their self-assessment of their nursing practice in Australia. In this process of analysis, Fereday and Muir-Cochrane (2006) obtained raw data from organisational documents and interview transcripts. In my study, I employed this method of thematic analysis underpinned by the VT of learning and phenomenography. This underpinning of thematic analysis with VT has not yet been undertaken to analyse the CAPS document, focus group interviews, think aloud protocols and NSC Physical Sciences Paper 1 examination scripts in South Africa.

The CAPS document was analysed using both content analysis and thematic analysis in order to identify the critical features of the concepts of work, energy and power that formed part of the Grade 12 Physical Sciences curriculum. These critical features that were identified in the CAPS formed the intended object of learning in this study.

According to VT and phenomenography there are qualitatively different ways in which the learners in the same classroom understand the concepts being taught (Åkerlind, 2005; Bussey et al., 2013; Lo, 2012). The observation method of gaining insights into learners' problem-solving approaches is an unstructured technique because it does not influence the behaviour of the participant (van Someren et al. (1994, p. 16). Observing the product, for example the learner's answers to a problem-solving exercise, will fall under this category. This is called product analysis (van Someren et al., 1994, p. 15). Observing a learner's behaviour while he/she is solving a problem is another way of gaining insight into the learner's problem-solving approach. Examples of behavioural observations are: does the participant look cheerful or frustrated, how long the participant takes to solve the problem and eye movements (van Someren et al., 1994, p. 16). Data collected using the behavioural observation methodology is also subjective to the researcher's interpretation of the participants behaviour during the problem-solving data. The NSC examination scripts of the learners are regarded as "products" in this study and the analysis thereof is regarded as product analysis.

A thematic analysis of the 100 examination scripts, focus group interview and TA transcripts which provided data on the lived object of learning of learners was conducted. Variation Theory of Learning combined with tools of thematic analysis were utilised to analyse learner responses to questions on the concepts of work, energy and power in the NSC examination scripts of the 100 learners in the sample, focus group interview and the TA transcripts of the eight learners. This was done in order to collect qualitative data on learners' alternative conceptions and problem-solving difficulties.

The thematic analysis was done by combining it with VT in an interpretive paradigm. Learner responses were categorised according to categories that had emerged from the responses. Further details of the recording and analysis of the raw data are provided in Chapters 5, 6 and 7.

The categories that were developed to describe the qualitatively different ways in which the learners in the sample in my study experienced the problem-solving exercises were informed by the SOLO taxonomy of Biggs and Collis (1982) and the Types of Knowledge Taxonomy of Anderson and Krathwohl (2001). Initially four hierarchical codes were developed and these four codes were used to categorise the learner responses in the 100 NSC learner answer scripts. The lowest category was Missed the Point State (MPS) which is similar to the pre-structural category in SOLO. The second category was Limited Factual State (LFS) which is similar to the uni-structural category in SOLO. This was followed by the Disjointed Relationships State (DSR) which is similar to the multi-structural category in SOLO. The fourth category was the Linked and Integrated State (LIS) which is similar to the relational category in SOLO. Later four additional categories were developed to describe the qualitatively different ways in which the learners experienced the problem-solving exercises. These were Plug and Chug Trial and Error (PACT), Layman's Approach (LAY), By Elimination (BE) and Not Shown (NS). The additional four categories and three of the initial categories, namely MPS, LFS and LIS, were used to categorise the learner responses in the TAPs. These categories are described further in Chapters 5 and 6.

The eight recordings of the Think Aloud sessions were transcribed to provide eight Think Aloud Protocols (TAP). I did the transcription using Transcribe which is an online transcription software package. Altogether the TAPs comprised of 54 423 words and had a total duration of 10 hours 22 minutes and 48 seconds. The first step in the analysis of the TAPs was to divide each of them into segments (Muntjewerff, 2014; van Someren et al., 1994). The criterion that was used to divide the TAPs into segments was the question number. Hence, each TAP was divided into 22 segments giving a total of 176 segments. The reason to segment in this way was that each question focused on specific critical features, and this would assist in coding the "thoughts" into themes.

During the analysis phase the data was coded according to themes. The data which consisted of the responses of the learners were analysed using VT combined with phenomenography and thematic analysis according to two broad categories namely Alternative Conceptions (ACs) and Problem-Solving Approaches and Difficulties

(PSADs). These themes were further categorised into sub-themes which are described in further detail in Chapters 5, 6, 7 and 8.

After the coding process the data were further analysed quantitatively to provide descriptive statistics about the themes that had emerged. These descriptive statistics were primarily frequencies. The qualitative analysis of the emergent themes then followed. The qualitative analysis used VT to interpret the themes that had emerged. The aspects of VT relating to awareness, discernment and simultaneity were used to interpret the emergent themes in the data and this applied to the TAPs, written answer scripts to the TAQ and to the NSC examination scripts. The interpretation of the data was made using thick descriptions that would assist the reader to understand these interpretations.

In my study, I used the quantitative as well as qualitative methods to analyse learners' responses to examination questions to find out how they are performing on the concepts of Work Energy Power and Problem-Solving. The written responses of learners on their examination scripts were analysed both quantitatively and qualitatively.

The quantitative analysis was limited to descriptive statistics that was used to enhance the qualitative analysis. However, analysing learners' written answers to questions does not provide sufficient data on the "thinking" of learners and a lot of the analysis is dependent on what inferences about the learners' "thinking" the researcher can make from their written answers. To probe deeper and gain insights into the learners' thinking while they answered physics questions, another approach was required. I used the Think Aloud method, a qualitative strategy, to probe deeper into the learners' thinking. This TA method provided rich data on the learners' alternative conceptions and problem-solving approaches. To answer my second and third research questions fully, I conducted the TA part of my study.

## **4.9 Ethics**

Prior to the commencement of this research, an application for ethical clearance was made to the University of KwaZulu-Natal. Ethical clearance was granted, and the researcher was issued with an ethical clearance certificate.

A letter requesting approval to conduct this research was written to the provincial Ministry of Education. Approval to conduct this research was provided by the provincial Ministry of Education. A meeting was held with the principal of the school where this study was located. At this meeting, the aims, objectives, research plan and school involvement were discussed and a request for written informed consent was made to the principal. The principal granted the researcher written informed consent. This was followed by obtaining informed consent from the two Physical Sciences teachers at the school and the parents of the learners that would participate in this study. After obtaining these, signed consent forms were obtained from the learners who participated in the study. The participants were informed that they were free to leave the study at any point of their participation and that they would not be required to provide any reasons for their departure. The participants were assured that their identities would remain confidential and that fictitious names will be used in the study. Furthermore, the participants were assured that the identity of the school will also be kept confidential. The participants were given the assurance that the data provided by them will not reveal their identity (Bogdan & Biklen, 2007; Cohen et al., 2018).

#### **4.10 Trustworthiness**

Whilst quantitative research employs the terms validity and reliability when addressing issues relating to how rigorous the study had been, qualitative research employs the term trustworthiness. The concept of trustworthiness in research can be explained as the steps that a researcher could take to persuade his/her audience that the findings of the study are “worth paying attention to” (Lincoln & Guba, 1985, p. 290). This study is a mixed methods study having aspects of both quantitative and qualitative data and analysis. These aspects are not utilised completely independently of each other as reality is not viewed as either quantitative or qualitative but rather as an integrated whole of both (Cohen et al., 2018). Hence, the quantitative aspects and qualitative aspects of the study are integrated to arrive at the findings. In this study, I used the quantitative data to enhance the discussion of the qualitative data. This study is mainly qualitative and hence the quantitative aspects are embedded within the data, data analysis and discussions. For the quantitative aspects descriptive statistics were embedded in the qualitative aspects of the

analysis and discussion. It is because of this choice that trustworthiness is discussed when addressing the quality (rigor) of this study.

Once trustworthiness is established people are more likely to “share their most intimate thoughts with persons who establish their trustworthiness” (Bogdan & Biklen, 2007, p. 135). It was important to establish an atmosphere of trustworthiness with the learners in this study since this study required learners to share their “thinking process” as they answered the questions in the TAQ with the researcher and also to have this “thinking” recorded by the researcher. This required trust between the researcher and the participants. Trust is not only about the personal characteristics of the researcher that he/she is a “nice” person but rather is process that is developed by “prolonged engagement” between the researcher and the participants (Lincoln & Guba, 1985, p. 303).

The trustworthiness of qualitative data and its analysis is sometimes discussed by using terms such as credibility, dependability, conformability, transferability, and authenticity (Elo et al., 2014). The terms internal and external validity associated with positivist research have been replaced by concepts like trustworthiness and authenticity by researchers adopting constructivism as a paradigm (Denzin & Lincoln, 2018). Lincoln and Guba (1985) have used the four terms credibility, transferability, dependability and confirmability to address rigor in naturalistic enquiry as equivalents to internal validity, external validity, reliability and objectivity respectively, in quantitative research (Lincoln & Guba, 1985). These four constructs, credibility, transferability, dependability and confirmability, speak to the concept of trustworthiness (Shenton, 2004). These constructs have been acknowledged as speaking to rigor in qualitative research by other researchers (Elo et al., 2014; Shenton, 2004).

Sampling methods may influence the trustworthiness of the methods of data collection and of the data collected (Cohen et al., 2018). The researcher needs to provide a short description of the sampling methods used in order to demonstrate the trustworthiness of the study (Creswell, 2013). In this study, convenience sampling and purposive sampling methods have been used and these have been described in section 4.5.1 titled sources of data and sampling.

*Credibility* is the qualitative researcher's equivalent for internal validity. It looks into the question of whether the research is addressing what it intended to study. The "truth value" of a study is the focus of a credibility check (Cohen et al., 2018, p. 248; Lincoln & Guba, 1985). Credibility of research is established by ensuring congruence between the data and findings with reality.

One of the ways of achieving credibility is through prolonged engagement to build trust between the researcher and the participants (Cohen et al., 2018; Lincoln & Guba, 1985). Prolonged engagement is about the researcher not being a "stranger in a strange land" so that researcher distortions and participant distortions are avoided (Lincoln & Guba, 1985, p. 302). The researcher in this study is an insider in terms of the education system but is not a member of any of the schools that participated in the research. However, the researcher is a Physical Sciences educator by profession and therefore is an insider in this regard. Furthermore, the researcher is an outsider in terms of the school communities that formed part of the study. This partly addressed the "stranger in a strange land" issue. Being an "outsider" in terms of the school community was addressed by the researcher visiting the schools on three occasions and providing other support material like electronic versions of learner study guides on content in Physical Sciences and teacher guide on School Based Assessment. It is important that the participants also see some "benefit" in being involved in the research process and providing these educational support material was seen as a way in which the participants benefited in the process (Cohen et al., 2018, p. 307). This was done to build an amicable and trustworthy relationship between the researcher and the participants. Although the Physical Sciences teachers were not the subject of study, they played a crucial role in providing access to the learners and in assisting with the selection of the sample.

In order to also build further trust with the participants, the teacher was present in the focus group interviews and, in the Think, Aloud sessions. An example of a participant distortion can be a learner responding to a question by either saying what he/she thinks the researcher wants to hear or avoiding responding honestly because he/she feels vulnerable and does not trust what the researcher is going to do with the data. To ensure that data obtained is credible, the researcher needs to obtain the trust of participants. A common practice among researchers to obtain the trust of participants is to guarantee

confidentiality and privacy. Researchers need to also ensure that information that identifies the participants need to be withheld. These could be the names of participants and the names of the sites (e.g school) where the research was conducted. In this research the names of the province, schools and participants have been withheld and participants were informed of this in letters that were written to them before the research had begun. The head of the province, school principal, parents, teachers and learners were informed of this confidentiality in the letters that were written to them requesting informed consent.

Another way to achieve credibility is by triangulation (Lincoln & Guba, 1985; Shenton, 2004). Triangulation refers to the use of several theoretical and methodological approaches to study the same phenomenon (Denzin & Lincoln, 2018, pp. 561-562). In mixed methods research triangulation is sometimes replaced by concepts such as “multigenre crystallization” (Denzin & Lincoln, 2018, p. 785). Two modes of achieving triangulation are by using multiple sources of data or multiple methods of data collection for the same type of data (Creswell, 2013). When there are other sources of information that resonate or corroborate the findings of a particular study people are more likely to view that study as trustworthy or credible (Bowen, 2009). In this study three methods of data collection were utilised. The first method was document and thematic analysis of the NSC examination scripts of learners. The second method was focus group interviews and the third method was individual Think Aloud sessions. Multiple sources of data were also used to ensure credibility. The document and thematic analyses methods were used to analyse the individual NSC examination scripts of 100 learners. This rendered 100 sources of data. The Think Aloud sessions were conducted on 8 individual learners rendering a further 8 sources of data. All the data collected provided information on Grade 12 Physical Sciences learners’ understandings, problem-solving approaches and difficulties on Work Energy Power.

Peer debriefing is another way to strengthen the credibility of the study (Creswell, 2013; Lincoln & Guba, 1985). The person who assists to debrief should be a person of comparable standing to the researcher in terms of knowledge of the area under study (Lincoln & Guba, 1985). The reason for this is that if the de-briefer is junior his/her inputs may have the danger of being ignored and if the de-briefer is senior his/her inputs may be given undue weight (Lincoln & Guba, 1985). Peer debriefing is a process whereby the

researcher involves one or more of his/her peers to test some of the steps in the methodology or analysis of data. This exposes the research to scrutiny that can expose biases, faulty or unjustifiable interpretations and methodological inconsistencies. However, in phenomenographic studies there can be different interpretations of the same data therefore this needs to be taken into account when the study is subjected to trustworthiness checks (Åkerlind, 2012). This may result in peers having interpretations that may be vastly different from those of the researcher. This argument also applies to coder reliability checks. While Marton and Booth (1997) discusses the importance of coder reliability checks, Åkerlind (2012) argues against this, using the reasoning that in phenomenography there are several different interpretations of the same data. In phenomenography the discussion is not about a right or wrong interpretation but rather about an interpretation that can be defended adequately. A valid check for rigor in qualitative studies is the ability of the researcher to defend his/her interpretations and findings (Cohen et al., 2018; Lincoln & Guba, 1985). Another trustworthiness check could be congruence with findings or similar interpretations in peer reviewed journals (Lincoln & Guba, 1985).

Notwithstanding the arguments against peer debriefing and coder reliability checks in the preceding paragraph, this study did employ them, but cautiously. The interpretations and criticisms provided by my peers were used as to check for any biases, blind spots, faulty coding etc. that I may have done. These inputs by my peers were not taken verbatim and used as is, but rather were taken as a point of departure to strengthen my work. Hence, in this study I employed the strategy of peer debriefing so that I could find my blind spots regarding my coding and analysis of data. As an example of this, I requested two Physical Sciences teachers to develop categories pertaining to understanding, problem-solving approaches and difficulties (PSADs) involving work for two questions in the Think Aloud Protocols (TAPs) of two learners. These two teachers played the role of “devil’s advocate” (Green & Bowden, 2009, p. 62). One of my peers was given the TAP of one of the eight learners and the other was given the TAP of another one of the eight learners. This process was followed by a discussion with the two teachers. During this discussion it was found that all three of us had highlighted alternative conceptions (ACs) in the learners’ understandings but that we had categorised these ACs differently. During the discussion we arrived at an understanding of the categories to be used and this assisted

me in refining all the categories about ACs in my coding. The same process applied to the coding regarding PSADs. All three of us identified PSADs in the TAPs of the two learners pertaining to the two questions that were used for the peer debriefing process. Again, this process was followed with a discussion with the two teachers. During the discussion it was found that although we had some PSADs categorised using similar words like “jumbled” and “plug and chug” there were also others for which we had used different words although the meanings were the same. During the discussion we compared the differences in our categorisations and arrived at an understanding regarding them. This assisted me in refining the categories for the PSADs.

“Respondent validation” is about obtaining feedback from the participants (Cohen et al., 2018, p. 318). Some researchers advocate for respondent validation (Cohen et al., 2018; Denzin & Lincoln, 2018). However, Åkerlind (2012) cautions against the use of respondent validation in phenomenographic studies. Obtaining feedback from participants is not a recommended validity check in phenomenographic studies (Åkerlind, 2012). Two arguments are provided to support this stance. Firstly, in phenomenographic studies the researcher’s interpretations and findings are made on the range of qualitatively different ways in which a phenomenon is experienced by the entire sample taken as a collective and not on individual participants. This means that the unit of analysis in phenomenographic studies can be considered as the categories of description of the qualitatively different ways in which a phenomenon is experienced (Reed, 2006). This means that all the responses taken from participants are treated holistically rather than individually. Secondly, the ontological assumptions in phenomenography state that the experience of the participant is context dependent and not fixed in time (Åkerlind, 2012). This means that people change as they become aware of new things and have new experiences. A participant’s response to a probe by the researcher at a particular time may not be the same at another time as the participants experiences may have changed during that time. Hence, the understandings of individual participants may not necessarily be the same as at the time when they initially participated in the study. This would make trustworthiness checks with the participants invalid. I did not involve the participants in this kind of trustworthiness check. The reason for this was that teaching and learning would have continued at the school after the learners had participated in my study. This would have impacted on how they would have responded for a second time to the TAQ

and therefore would not have been an appropriate trustworthiness check. However, I used several other checks for trustworthiness as discussed in this section.

The construct *transferability* used in qualitative research is the equivalent of external validity used in quantitative research. In quantitative studies, external validity refers to the generalisability of the findings of the study to the population from which the sample was selected. Transferability is about the generalisability of the findings or the potential for the findings to be applied to other settings or contexts (Elo et al., 2014). But according to some writers, the researcher in a qualitative study is responsible only up to the point of providing sufficient, rich and thick descriptive data and findings to make replication or transferability possible (Elo et al., 2014; Lincoln & Guba, 1985). The onus is upon the person requiring such transferability to conduct his/her own small study to verify transferability (Elo et al., 2014; Lincoln & Guba, 1985). In this study, I have not attempted to generalise the findings. Instead, rich data was used as in the form of the TAPs and the NSC learner scripts and thick descriptions were provided for the coding and analysis of this data. This would assist the prospective researcher who intends to replicate this study or transfer the findings to other settings and contexts to conduct his/her verification process.

According to Lincoln and Guba (1985) there can be no validity without reliability and hence no credibility without *dependability*. The establishment of credibility can therefore be a sufficient demonstration of dependability as well (Lincoln & Guba, 1985). Dependability is the qualitative researcher's equivalent to the quantitative researcher's reliability (Creswell, 2013; Elo et al., 2014; Lincoln & Guba, 1985). Dependability speaks to consistency (Cohen et al., 2018). According to Elo et al. (2014) the construct dependability refers to the "stability" of the data under different conditions of time and context (p. 4). It is therefore crucial that the study provides sufficient information about the sampling techniques, relevant characteristics of the participants and thick descriptions of the context. Dependability in this study was established by keeping a sound and secure audit trail as recommended by Lincoln and Guba (1985). The NSC learner examination scripts were kept in a secure locked cupboard. These scripts were numbered and open to verification by the researcher's peers who assisted with the peer debriefing process to

establish credibility. The Think Aloud recordings and transcripts were also kept in a secure storage for accountability.

*Confirmability* is the construct used in qualitative studies and is the equivalent of objectivity used in quantitative studies. Cohen et al. (2018) also refers to confirmability as “neutrality” (p. 248). In phenomenographic studies and interpretive studies, researchers argue that the processes can never be objective as there can be multiple interpretations of the same data and that these processes represent the data as it is “experienced by the researcher” (Åkerlind, 2012, p. 330; Marton, 1981). Phenomenography focuses on the qualitatively different ways in which the participants in a study experience a phenomenon. One can also argue that there are qualitatively different ways in which the researcher can experience this data. According to some researchers, the focus of the research quality should be directed to ensuring that the research aims are adequately reflected in the research methods that are employed (Åkerlind, 2012; Green & Bowden, 2009). In this study, confirmability is established by keeping an authentic audit trail of rich raw data, thick descriptions, data analysis, methodological notes and field notes. The raw data in the form of the audio tape recordings, transcripts and learner answer scripts were kept in a systematic manner and have been carefully indexed so that they are easily identifiable in the research report. The coding and categorisation of the data were done and captured on SPSS for the NSC examination scripts. The quantitative analysis of this data was done using descriptive statistics on SPSS. The Think Aloud transcripts called Think Aloud Protocols (TAPs) were captured according to themes on NVIVO. These TAPs were also analysed using NVIVO. The two teacher peers who assisted with the de-briefing process had been invited to engage with the data on SPSS and NVIVO and question and critique the recording, coding and analysis of this data. The researcher and peer de-briefers engaged with the criticisms in a manner that led to common understanding and strengthening of the process of coding and analysis. This was done to establish confirmability of the research process and research product.

*Reflexivity* plays a central role in qualitative research and it recognises that the researcher is part of the world that he/she is studying (Cohen et al., 2018). This is about a researcher being aware of his/her own pre-knowledge, values, biases and beliefs that he/she is

bringing into the study. The researcher also needs to be critically aware of the possibility that participants may behave differently from their usual behaviour in his/her presence. Researchers need not be defensive about what they bring into the research situation, but rather be reflexive and seek to “understand their part in, and influence on the research” (Cohen et al., 2018, p. 303). The researcher’s work and other life experiences can also influence different parts of the study for example data collection, data recording and interpretation of results (Creswell, 2013). The use of checks on trustworthiness are crucial in addressing any matters that may negatively affect the quality of the research.

In this study, I maintained a journal and field notes to record and reflect on all the processes and products of this research. I utilised trustworthiness checks pertaining to credibility, dependability, transferability and confirmability as described in the paragraphs in this section to minimise if not eradicate any adverse effects of my pre-knowledge and values on the study.

#### **4.11 Positionality**

“Positionality addresses relationships” (Cohen et al., 2018, p. 306). Positionality relates to power relationships between the researcher and the researched. Often the researcher is in a position of higher power and the participants are in a position of lower power in relation to the researcher (Cohen et al., 2018; Creswell, 2013). The researcher should be open to the participants about his/her position in the field that is under study and show respect and acknowledge appreciation for the time and effort that participants spend on the research (Büthe & Jacobs, 2015; Cohen et al., 2018). The researcher should conduct the study in a spirit of mutual respect, humanity and dignity towards the participants (Cohen et al., 2018). In this study, I provided detailed letters explaining the methodology and purpose of the research to all participants including the head of the province, school principal, Physical Sciences teachers, parents and learners. My role in the research was also detailed in the letters. In these letters I requested informed consent from each of the participants and I included a clause that stated that the participants were free to leave the study at any time without any prejudice whatsoever. The participants were also assured of confidentiality. Therefore, the names of the province, schools and learners were kept confidential.

The researcher in this study can be considered as an outsider. Firstly, the researcher is not a member of the staff or the school community. Therefore, the researcher can be considered as an outsider. Secondly, during the focus group interviews, the researcher took the stance of an independent observer. The researcher followed-up to the responses of the learners to the questions on the semi-structured interview schedule, by asking further questions. This means that the researcher made follow-up questions on the spot to assist her to come to a better understanding of the learners' responses to the questions on the interview schedule.

Secondly, the researcher could also have been viewed by the learners as an outsider as she was not part of the school community. However, from the view of the researcher, this did not seem to negatively impact on the study as all the participants were very helpful during the study. The subject teacher assisted by distributing the consent letters and forms to learners and their parents for informed consent. Furthermore, the head of the subject at the school willingly loaned the researcher three tablets to supplement the audio recording devices that the researcher had brought along for the Think Aloud Sessions. The researcher had bought five audio recording devices. The subject teachers willingly assisted in making hard copies of the focus group semi-structured interview schedules and the TAQs. One may interpret this assistance by the head of the subject and the subject teachers as acts relating to an imbalance of power between themselves and the researcher. However, in the view of the researcher these acts stemmed from mutual respect among the researcher and the participants. these activities pointed to the notion that the study was taking place in an atmosphere of mutual trust, respect, dignity, excitement and happiness.

The three main sources of data were the NSC examination scripts, the focus group interview and the TA sessions. The province had provided the scripts without any challenges being experienced by the researcher. The data that was provided by all the learners in the focus group interviews and TA sessions also attest to the notion that the study was conducted in an atmosphere of mutual trust, respect, dignity, excitement and happiness.

## **4.12 Limitations**

Although measures were employed to ensure credibility one possible limitation of this study is that other researchers working with different samples of participants could come to a different set of findings. This is inherent in phenomenographic studies. Just as there are qualitatively different ways in which participants in a study experience a phenomenon, there could be qualitatively different ways in which researchers experience the study (which will be the “phenomenon” to the researchers). The trustworthiness checks that were put in place during the study have been discussed in the preceding section and these were meant to also mitigate against this limitation.

## **4.13 Conclusion**

This study explored Grade 12 learners’ understandings of, and problem-solving approaches to Work-Energy-Power in Physical Sciences in high schools. In this chapter, the research paradigm, research design, methodology and methods were discussed.

This study adopted a subjectivist epistemology at times as the data was interpreted through one’s own understandings, experiences and interactions with the participants. It also adopted an objectivist epistemology when making meaning of the science concepts that are included in the study. This research followed a non-dualist ontology as it assumed that reality is a relationship between the knower and that which is to be known. The research was underpinned by pragmatism and interpretivism as research paradigms.

This was a mixed methods study where both qualitative and quantitative methods were used concurrently to analyse data. The qualitative methods were of a higher priority than the quantitative methods. The qualitative analysis was informed by the phenomenographic approach and variation theory.

The research was conducted using data from six schools from one province and one district. The province and district were selected using the convenience sampling method. The sources of data were NSC examination scripts of 100 learners and the TAPs of 8 learners. The examination scripts and the sample of eight learners were selected using

typical case sampling which is a type of purposive sampling method. This sampling method was selected as this study made no attempt to generalise its findings.

The study employed multiple data collection methods to ensure trustworthiness. Document analysis, think aloud method, and thematic analysis underpinned by VT and the phenomenographic approach provided rich data. The use of multiple sources of data assisted with triangulation and ensuring trustworthiness. Strategies like peer debriefing and coder reliability checks were undertaken to ensure credibility of the study. The results of the study are discussed in the four chapters that follow.

## Chapter 5 - LEARNER PERFORMANCE ON WORK ENERGY POWER

### 5.1 Introduction

This chapter is the first of the four chapters on my analysis and findings. Chapter 5 focuses on research question one, Chapter 6 focuses on research question two, Chapter 7 focuses on research question three and finally Chapter 8 focuses on research question four. This chapter presents my findings and analysis of the data sourced from the 100 Grade 12 Physical Sciences learner scripts in the National Senior Certificate (NSC) examinations. These findings and analysis have addressed research question one of this study:

*Research Question One: How do Grade 12 Physical Sciences learners perform on the questions on work, energy and power in the National Senior Certificate (NSC) examinations?*

### 5.2 Source of data

The source of data for this research question were the 100 learner scripts from the NSC 2017 Physical Sciences Paper One examination. The responses of learners to questions 1.5 and 5 in the NSC examination scripts were the raw data that was used to answer research question one of this study. Q1.5 is a multiple-choice question (MCQ) and Q5 is a structured question (SQ) with four sub-questions. I will refer to the structured question as a long question (LQ) as well. The sub-questions of Q5 will be referred to as Q5.1, Q5.2, Q5.3 and Q5.4.

I used the SPSS data editor to record and analyse the data contained in the 100 learner scripts. The learner responses to the MCQ and LQ were recorded in the SPSS data editor.

### **5.3 The sample**

The sampling method used to select the scripts was typical case sampling which is a purposive sampling method. Details of the sampling method have been discussed in Chapter 4 of this study. One hundred scripts were selected from six schools in two education districts in South Africa. The scripts collectively covered overall learner performance at levels 2 to 7. This means that the sample consisted of scripts of learners performing at 80% and over (Level 7), 70% and over (Level 6), 60% and over (Level 5), 50% and over (Level 4), 40% and over (Level 3) and 30% and over (Level 2). Scripts of learners performing under 30% (Level 1) had not been selected as the researcher assumed that there would be insufficient data on these scripts. The sample contained learner scripts of low, medium and high overall performance in the paper.

The 100 learner scripts that constituted the sample in this study, were marked scripts that were provided by the provincial education department after informed consent was obtained from it. Both the questions in this examination paper and the marking of the scripts have undergone rigorous quality assurance processes and had been declared as credible (DBE, 2017b). This study therefore takes this as a check for trustworthiness of the questions in this instrument and of the marking of the scripts.

### **5.4 Data collection and recording**

On a first scanning of the learner responses in the 100 scripts, I found that there were several variations in their responses. I therefore categorised and coded the learner responses to questions 1.5 and 5 as found on their NSC Physical Sciences Paper One examination scripts along the themes that emerged from their responses. I recorded the data obtained from the written responses of each of the 100 learners in the SPSS data editor for quantitative and qualitative analysis.

The category for the MCQ was the option chosen by the learners. The MCQ required the learners to write down only the letter corresponding to their selected option and this is what the learners in all 100 scripts did. I therefore had only one category for Q1.5. The

learners' chosen option, A, B, C or D was recorded in the category labelled Question 1.5 Option Chosen.

## **5.5 Assumptions**

The analysis of the learner responses to the Multiple-Choice Questions (MCQ) in the Physical Sciences Paper One in the NSC examination assumes that there is no guesswork involved on the part of the learner.

## **5.6 The intended objects of learning**

In this chapter, I will discuss four intended objects of learning: work, energy, power and problem-solving. There are several concepts and laws that are dealt with in the Intended Curriculum, which for the purposes of this research is contained in the Physical Sciences CAPS. These concepts and laws pertaining to the topic WEP have been analysed using VT to identify their critical features and dimensions of variation. The CAPS document was analysed to identify the intended object of learning.

## **5.7 The enacted object of learning**

The enacted object of learning is the act of learning, and it is defined by the interactions that occur between teacher and learner, learner and learner and learner and learning materials. The possibility for learning is dictated by what is actually presented to learners and is co-constructed through the interactions that occur between teacher and learner, learner and learning materials and among learners within and with the learning environment (Akerlind et al., 2011; Bussey et al., 2013; Euler et al., 2020; Lo, 2012; Marton, 1981; Marton et al., 2004). The enacted object of learning is not the focus of this study. However, some inferences about the enacted object of learning from the exploration of the lived object of learning are made and discussed.

## **5.8 The lived object of learning**

The lived object of learning can be described as the way learners make meaning of the object of learning after the lesson ends and beyond (Marton & Ling, 2007; Tóth & Ludányi, 2007). The responses of learners in the 2017 NSC examination paper, focus group interviews and think aloud protocols provide data on the lived objects of learning. In this chapter, the lived object of learning is comprised of the responses of learners in their examination scripts.

## **5.9 Learners' understandings of Work Energy Power in the NSC**

This section presents the results of the study regarding the first research question, followed by a discussion about these results and analysis thereof of learners' understandings of work, energy and power in the NSC.

In order to explore how Grade 12 Physical Sciences learners, perform on the questions on the topic Work Energy Power in the National Senior Certificate examinations, I conducted both a quantitative and qualitative analysis of the responses of learners to the questions on these concepts in 100 NSC scripts for Physical Sciences Paper 1 of 2017. There are two questions in this examination paper that related directly to Work Energy Power and these are questions 1.5 and 5 (Appendix 12).

In the analysis of question one point five (Q1.5) the frequency of occurrence of a particular category of learner response and the percentage of that occurrence are the same, since I recorded the data collected from 100 learner scripts.

Q1.5 is the MCQ, and it probes learner understanding of work as compared to power. Q5 is a structured question consisting of four sub-questions, namely Q5.1-Q5.4. Question 5.1 probes the learner's factual knowledge of the work energy theorem (WET) as it required the learner to state the work-energy theorem. Question 5.2 required the learner to draw a labelled free-body diagram for the 6 kg block. Question 5.3 required the learner to calculate the work done by the gravitational force. Question 5.4 required the learner to

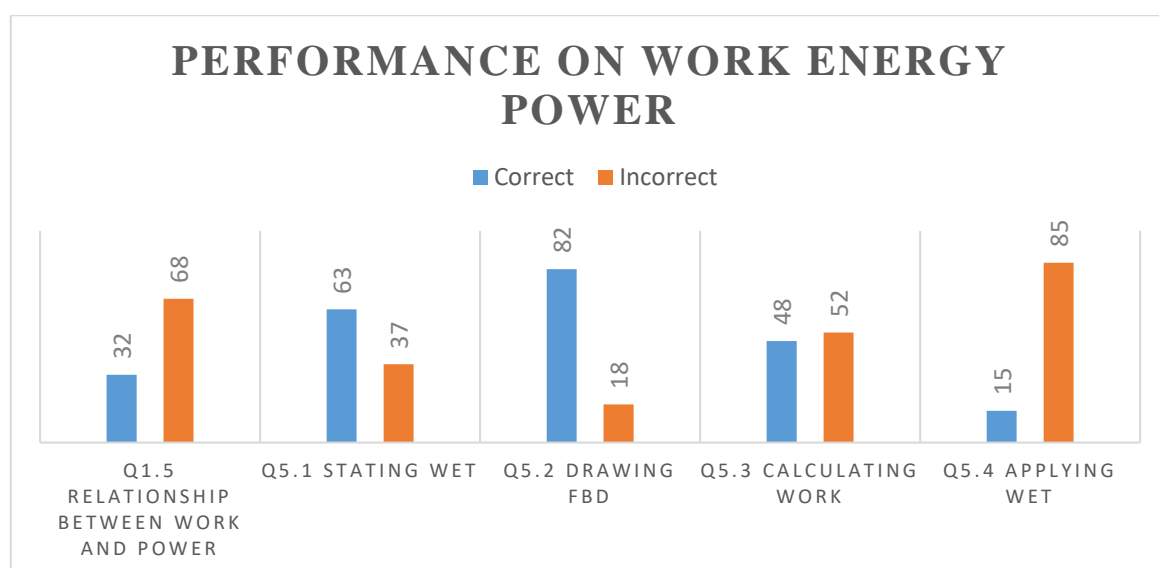
use energy principles to calculate the speed of the 6 kg block when it fell through a 1,6 m while still attached to the 4 kg block.

### 5.9.1 Results and analysis: Alternative conceptions about Work Energy Power

In this section the alternative conceptions about Work Energy Power displayed by learners in the NSC will be presented and analysed.

The MCQ question (Q1.5) provided the learner with four options, one of which is the correct option, and the remaining three options are distractors and incorrect. All four options were recorded in a category labelled Option Chosen in the SPSS data editor. I used the SPSS data editor to analyse the data for Q1.5 and Q5. Q1.5 was an MCQ where learners were only expected to write down the correct option A, B, C or D. Q5.1 required learners to write down the WET. Q5.2 required the learners to draw a free body diagram. Q5.3 and Q5.4 were structured questions that required learners to do calculations and provide numerical answers to the problems. The quantitative analysis was followed by a qualitative analysis that focused on identifying the alternative conceptions, problem-solving approaches and problem-solving difficulties that emerged from the written responses of the learners in their examination scripts. The quantitative analysis of the performance of learners on Work Energy Power in the NSC is presented in Graph 5-1.

**Graph 5-1: Performance of learners on Work Energy Power**



The analysis presented in Graph 5-1 shows that 32% of the learners chose the correct option for the MCQ that focused on the relationship between work and power. This means that 68% of the learners chose the wrong option. This quantitative analysis shows that in this sample, 68% of the learners have a very poor understanding of the relationship between work and power and of the concepts of work and power.

The significance of the data presented in Graph 5.1 is that it is showing that there is a marked variation in learner responses regarding the concept of work and power. This supports the notion that there are qualitatively different ways in which learners experience the same phenomenon (Bussey et al., 2013; Euler et al., 2020; Lo, 2012; Marton & Pang, 2006; Reed, 2006).

Many learners, 37%, displayed difficulty in recalling and writing down the WET. Eighty-two percent which represents most of the learners in the sample were able to correctly draw the free body diagram (FBD) in Q5.2. This FBD consisted of two forces namely the force of gravity and the tension in the inextensible string. However, 18% of the learners were unable to correctly draw the FBD. According to Graph 5.1 only 48% of the learners could correctly calculate the work done by the gravitational force. 52% of the learners could not solve the problem in Q5.3 that required them to calculate the work done by the gravitational force. This meant that more than half of the number of learners in the sample could not calculate the work done by the gravitational force on a single object. Only 15% of the learners could correctly apply the WET to solve the problem in Q5.4. A very large percentage of the learners, 85%, could not solve the problem in Q5.4 that required them to apply the WET in the presence of both conservative and non-conservative forces.

A qualitative analysis followed the quantitative analysis that was presented in the preceding paragraphs. Q1.5 and Q5 in the 100 learner scripts were analysed according to three broad themes namely alternative conceptions, problem-solving approaches and problem-solving difficulties. In this section the qualitative analysis regarding alternative conceptions about work, energy and power will be presented. In section 5.9.2 the quantitative and qualitative analysis regarding problem-solving approaches and problem-solving difficulties will be presented.

These questions were qualitatively analysed to identify several features that are critical to answering the questions correctly. These critical features include the concepts of work (W), energy (E) and power (P). Variations in each of these critical features have been identified and are included in Table 5.1 as dimensions of variation. This categorisation of learner responses to Q1.5 (which is an MCQ) and to Q5 (which is a structured question) in the NSC examination has limitations since it depends only on the written responses of the 100 learners. One limitation is that the researcher makes inferences about the learners' thinking as they answered the questions, by looking at their written responses. Some of the learner responses have accordingly been categorised as probable alternative conceptions and others as probable guesswork as they may not necessarily be conclusive. Even a correct answer in an MCQ may not necessarily indicate correct understanding as this could also be due to guesswork (lucky guess), familiarity, etc. It is for these reasons that this study took into account the frequency of the choice of an option in the MCQ during categorisation. Taking these limitations into account, these categorizations provide an indication about learners' performance on work, energy and power in the NSC examinations, which is the focus of research question one. In order to probe more deeply into learners' understandings this study therefore implemented the Think Aloud method discussed in Chapter 4, to answer research question two. In contrast to making inferences about learners' thinking when analysing their written responses, in the Think Aloud method the learners verbalise their thinking as they answer the questions. The Think Aloud method gives the researcher a "direct method to gain insight into the knowledge" and thinking of learners (van Someren et al., 1994, p. 1).

The choice of an incorrect option in Q1.5 was recorded under the theme Alternative Conceptions Work Power (ACWP). A term or equation in the learners' answers to Q5.3 and Q5.4 that was inconsistent with accepted scientific knowledge was also categorised as an alternative conception and was placed in the category ACW or ACE if it related directly to work or energy respectively. Calculations that were incorrect were studied to find the probable alternative conception that was evident in them, and these were categorised under the themes ACW or ACE depending on whether they focused on work or energy. "In order to truly understand a phenomenon, learners must be simultaneously aware of multiple features of that phenomenon and able to discern the phenomenon from its environment" (Govender et al., 2016). For a learner to choose the correct option in the

multiple-choice question (Q1.5) the learner would have to simultaneously have the critical features of W, E and P in his/her focal awareness at the time of answering the question. For a learner to answer Q5.3 and 5.4 correctly, the learner would need to simultaneously have the critical features of W and E in their area of focal awareness. Table 1 in Govender et al. (2016, p. 405) was modified to present the critical features and alternative conceptions about Work Energy and Power and this is shown in Table 5.1. I included a column in Table 5.1 to show the evidence of alternative conceptions or probable guesswork.

The CAPS document was analysed using content analysis and thematic analysis in order to record the intended objects of learning and the critical features of these intended objects of learning. The CAPS content was analysed to identify all the topics that dealt with Work Energy and Power. These topics were identified as: Definition of Work and net work, Work –Energy Theorem, Conservation of energy with non-conservative forces present and Power. These topics were recorded in Table 5.1 as the intended object of learning. This process was followed by thematic analysis that entailed the categorization of sections in the CAPS under the themes concepts, definitions, formulae, laws, principles and skills that involved WEP. The names of the four objects of learning were used to group all the concepts, definitions, formulae, laws, principles and skills. For example, all the concepts, definitions, formulae, laws, principles and skills that pertained to the definition of work and net work were categorized under the object of learning “Definition of Work and Net Work”. The same process of categorization using thematic analysis was applied to each of the four objects of learning.

**Table 5.1: Alternative Conceptions and Guesswork about Work Energy Power**

Topics Grade 12: Intended Object of Learning Work Energy Power	Dimensions of Variation of the Critical Features of Work Energy Power	Evidence of possible Alternative Conception (PAC)
Definition of Work and net work	Define the work done on an object by a force as: $W = F\Delta x \cos\theta$ . Know that work is a scalar quantity and is measured in joules (J) Calculate the net work done on an object by applying the definition of work to each force acting on the object while it is being displaced, and then adding up (scalar) each contribution Positive net work done on a system will increase the energy of the system and negative net work done on the system will decrease the energy of the system	<b>ACWP Work is time dependent</b> <b>Learner chooses Option A in Q1.5</b> If a force is applied for double the time over the same distance, half the work is done by that force. <b>Learner chooses Option C in Q1.5</b> If a force is applied for double the time over the same distance, double the amount of work is done by that force. This is an alternative conception regarding Power and Work, where learners cannot understand the distinction between the two concepts.
Work -Energy Theorem	Know that the net work done on an object causes a change in the object's kinetic energy - the <i>work-energy theorem</i> - $W_{\text{net}} = E_{\text{kf}} - E_{\text{ki}}$ Apply the work-energy theorem to objects on horizontal and inclined planes (frictionless and rough)	
Conservation of energy with non-conservative forces present	Define conservative forces and give an example Define non-conservative forces and give examples Know that when only conservative forces are present, mechanical energy is conserved Know that when non-conservative forces are present mechanical energy (sum of kinetic and potential) is not conserved, but total energy (of the system) is still conserved Solve conservation of energy problems (with dissipative forces present) using the equation: $W_{nc} = \Delta E_k + \Delta E_p$ Use the above relationship to show that in the absence of non-conservative forces, mechanical energy is conserved	<b>PG1: Possible Guesswork</b> <b>Learner chooses Option D in Q1.5</b> If a force is applied for double the time over the same distance, the work done by that force increases by a factor of 4.  <b>ACW1: Angle between force of gravity and displacement as an object falls downwards is 180° or 90°</b> <b>Learner displays ACW1 in Q5.3.</b>

Topics Grade 12: Intended Object of Learning Work Energy Power	Dimensions of Variation of the Critical Features of Work Energy Power	Evidence of possible Alternative Conception (PAC)
Power	<p>Define power as the rate at which work is done</p> <p>Calculate the power involved when work is done</p> <p>Understand the average power required to keep an object moving at a constant speed along a rough horizontal surface or a rough inclined plane and do calculations using <math>P_{av}=Fv_{av}</math></p> <p>Calculate the minimum power required of an electric motor to pump water from a borehole of a particular depth at a particular rate using <math>W_{nc}=\Delta E_k +\Delta E_p</math></p> <p>Recommended practical investigation for informal assessment:</p> <p>Perform simple experiments to determine the work done in walking up (or running up a flight of stairs). By timing the run and walk (same flight of stairs) one can enrich the concept of power</p> <p>Materials for practical activity: Flight of stairs, stopwatch, measuring tape (5m) or meter stick.</p>	<p><b>ACW2: The formula for work done is</b> <math>W = F\Delta x\sin\theta</math> <b>Learner displays PACW2 in Q5.3.</b></p> <p><b>ACE1: System: Work done by a force only changes the kinetic energy of the object on which it is acting</b> <b>Learner displays PACE1 in Q5.4.</b></p> <p><b>ACE2: Mechanical Energy is conserved in the presence of non-conservative forces</b> <b>Learner displays PACE2 in Q5.4.</b></p>

Initially the researcher had found a total of seven ACs. These ACs were sent to an academic in Science Education at a university for the purpose of moderation. The moderator agreed that MCQs are sometimes used in research to identify alternative conceptions (Hestenes et al., 1992; Luangrath et al., 2011; Neidorf et al., 2020; Wells et al., 2020). Following moderation of the findings on alternative conceptions in this study it was decided that the incorrect answers to Q5.1 and Q5.4 in the NSC scripts will be categorized as alternative conceptions but with a few changes. There were four changes that were made to the findings after moderation. Firstly, a category “probable guesswork (PG)” was added to the category labels. Secondly the category that was originally named Alternative Conception Power (ACP) was changed to Alternative Conception Work Power (ACWP) as this AC spoke to both work and Power. Thirdly, the number of ACs were reduced from seven to five PACs. Two of the ACs about Power in the original categorisation were combined into one AC about Work and Power, since both of these ACs displayed the same incorrect understanding about Work and Power. One AC was re-categorized as Probable Guesswork as the frequency of learners choosing this answer was only 10% and this was considered to be too low during the moderation process. The fourth change was in the naming of one of the two ACs about energy. The name was changed from “ACE1: System: Work done by a force only changes the kinetic energy of the object on which it is acting” to “ACE1: System: The energy of one part of a system can be determined independently of the other parts of the system” as it was believed that this would convey the message more appropriately.

A total of five alternative conceptions (ACs) and one probable guesswork (PG) were displayed by the learners in the sample of 100 learners. One of the ACs related to both work and power, two related to work and two related to energy. In section 5.9.1.1 the AC that relates to both work and power as well as the PG will be discussed. This will be followed by section 5.9.1.2 where the ACs about work will be discussed. The ACs about energy will be discussed in section 5.9.1.3. In each of these sections, a quantitative analysis will be done first, followed by a qualitative analysis.

### **5.9.1.1 Alternative conception about work and power and probable guesswork**

In order to identify the AC and PG about work and power displayed by learners in the sample, a quantitative analysis of the option chosen by learners in the multiple-choice question (Q1.5) was made. This question is probing the learners' understanding of work and power by bringing in the concept of time. The work done on the crate by the person is equal to the negative of the work done by the gravitational force on the crate.  $W_{person} = -W_g = F_g \Delta x \cos \theta$  where  $\theta$  is the angle between the gravitational force  $F_g$  and the displacement  $\Delta x$  of the 6 kg object. In this equation both  $F_g$  and  $\Delta x$  are positive quantities (Knight, 2013, p. 283). The sign of the work done is either positive or negative and is determined by the sign of  $\cos \theta$ . Power is defined as the rate at which work is done in CAPS (DBE, 2011, p. 120). The formula to calculate power given in the data sheet of Physical Sciences Paper 1 is  $P = \frac{W}{\Delta t}$  (DBE, 2017c). The formula to calculate work done  $W = F \Delta x \cos \theta$  is also given in the data sheet of Physical Sciences Paper 1 (DBE, 2017c).

Table 5.2 presents the learners' understandings of Work and Power which is informed by the analysis of the option chosen by learners in the MCQ 1.5.

**Table 5.2: Learners' Understandings of Work and Power**

CATEGORY: OPTION CHOSEN	PERCENT	EVIDENCE OF AC ABOUT POWER
Option $\frac{1}{2}x$	19.0	ACWP
Option B: $x$	32.0	No AC
Option C: $2x$	39.0	ACWP
Option D: $4x$	10.0	PG
Total	100.0	

The data presented in Table 5.2 shows the high prevalence of incorrect answers about work and power. 32% of the learners chose the correct option which is option B. 68% of learners had selected the incorrect option. This shows a probable alternative conception or guesswork regarding the concepts of work and power as they chose the distractors which are options A, C and D as the correct answer. Each of these three distractors tested the learners understanding of both work and power.

There can be several different reasons why learners choose a particular option in an MCQ. Some of these reasons are: good understanding of the concepts, familiar context, incorrect

understanding, guesswork, silly mistakes, inadequate knowledge or not understanding the question (Leonard et al., 2014; Luangrath et al., 2011; Wells et al., 2020). Where the percentage of learners selecting the different options are evenly distributed across all options in the MCQ, then this could indicate guesswork because this would indicate a random selection by learners (Luangrath et al., 2011). An even distribution of learner choices would result in 25 of them choosing each option in this study. There is no evidence of an even distribution in Table 5.2. However, since only 10% of learners chose the incorrect option D, this study made an assumption that this could be PG and that it could show poor understanding of the concepts of work and power. It is possible that learners could guess an answer for other reasons like not understanding the question or not having learnt the work, but this study makes the assumption that this is not the case and records this as a limitation to the study. There are three critical ways of looking at the responses of the learners to the MCQ under study. Firstly, the choice of the correct option in the MCQ provides evidence that the learner is simultaneously aware of all the critical features of pertaining to the definitions of work and power and are able to discern all the dimensions of variation in these critical features. The choice of this option shows that the learners understand the difference between work and power. Secondly, the choice of an incorrect option provides evidence that the learner could probably hold certain alternative conceptions or has guessed. The assumption here is that the learners have not misunderstood the question and have not made silly mistakes in choosing the incorrect option. Thirdly the choice of a specific incorrect option provides further data on the probable alternative conceptions and guesswork. The distractors A, C and D test the learners' understanding of both work and power and their ability to discern the difference between them. The choice of option A, C or D shows that the learner has the alternative conception that the work done on an object by a force  $F$  moving it a displacement of  $\Delta x$ , is dependent on the time taken to do the work. The learner is thus displaying that he/she does not fully understand both work and power as well as the relationship between them. As shown in Table 5.2 most of the learners in the sample (68%) chose options A, C or D showing that they either hold alternative conceptions or have guessed. The AC and PG about work and power are described below:

**Alternative Conception about Work and Power (ACWP): Work is time dependent  
Learner chooses Option A or Option C in Q1.5**

The distractor Option A suggests that if a force is applied for double the time over the same distance, half the work is done by that force. The distractor Option C suggests that if a force is applied for double the time over the same distance, double the amount of work is done by that force. 19% of the learners displayed this AC by choosing Option A in Q1.5. 39% of the learners displayed this alternative conception by choosing Option C in Q1.5. Altogether 58% (39% + 19%) of the learners chose either Option A or Option C. Both these distractors, Option A and Option C, suggest that work is time dependent. These learner choices have been categorized as Alternative Conception about Work and Power (ACWP) where learners cannot discern work from power.

### **PG1: Probable Guesswork**

#### **Learner chooses Option D in Q1.5**

The distractor Option D suggests that if a force is applied for double the time over the same distance, the work done by that force increases by a factor of 4. 10% of the learners displayed this alternative conception by choosing Option D in Q1.5. Since the percentage of learners choosing this option was considered to be low, the choice of this option was considered as evidence for Probable Guesswork (PG).

The incorrect understandings about power that were displayed by the learners in this sample show that they are not aware that the work done by a force is not time-dependent (Brown, 2013, p. 149). It is the concept of power that is time dependent, and these learners have clearly displayed that they did not discern this difference between work and power. This evidence is showing that VT theory can assist in identifying alternative conceptions of learners. Lo (2012, pp. 182-184) argues that teachers could draw on the variation in learners' responses to questions in order to address their (learners') misconceptions and give them appropriate feedback. "Different answers provided by students are excellent resources for teaching, as they provide extra variation for students to contrast the correct and incorrect answers and the explanations for them." (Lo, 2012, p. 183). I am arguing that VT can also be applied to identify the misconceptions that learners hold by applying it to analyse the responses that learners give in various situations, in this case, to their responses to questions in an examination paper.

### 5.9.1.2 Alternative Conceptions about Work

Two alternative conceptions about work were displayed by some learners as they answered Q5.3. Graph 5.1 shows that 52% of the learners were unable to solve the problem in Q5.3 and one of the reasons for this performance is that probably learners hold alternative conceptions about work. On closer examination of the analysis presented in Graph 5.1, a marked variation in learner responses regarding the calculation of work done by the gravitational force is observed. In order to correctly calculate the work done by the gravitational force, the learner would need to identify or determine several critical features of work. Furthermore, the learner would also need to identify the critical features of the gravitational force to calculate the work done by it. Variation Theory was employed to further analyse the responses of learners to this question that required them to calculate the gravitational force. According to VT the internal horizon of the object of learning are the critical features and their relationships to each other and to the whole system (Lo, 2012). One can also refer to the critical features of the object of learning as the aspects and parts that a learner would need to understand in order to understand the whole object (Bussey et al., 2013; Lo, 2012; Marton & Ling, 2007; Marton & Pang, 2006). The external horizon is constituted of those parts of the system that are not the object of learning per se but are linked to it (Lo, 2012). As an example, the knowledge that  $F_g$  is a conservative force when answering Q5.3, is part of the external horizon of the learner at the time of answering the question. The learner may not necessarily use this knowledge to calculate the work done by the gravitational force, so this knowledge recedes to her external horizon. She may call upon this knowledge if it becomes necessary, for example in a verification/checking process.

This question was analysed from a qualitative perspective to identify the critical features that a learner would need to be aware of, to correctly answer it. These critical features are the formula to calculate work, force, mass, angle, displacement and the formulae used. This was followed with identifying the dimensions of variation for each critical feature and the evidence for alternative conceptions as presented in Table 5.1. Two probable alternative conceptions (AC) regarding the calculation of work done emerged from the

analysis of the 100 learner scripts. These are Alternative Conception Work 1 (ACW1) and Alternative Conception Work 2 (ACW2) that are discussed below.

**ACW1: Angle between force of gravity and displacement as an object falls downwards is  $180^\circ$  or  $90^\circ$ .**

Q5.3 required the learners to calculate the work done by the gravitational force on a 6 kg block that falls through a vertical distance of 1,6 m. Learner scripts that displayed the correct formula for work but used an incorrect angle between the force of gravity and the displacement, were categorised as displaying the alternative conception ACW1. There were two variations of this alternative conception that was displayed. Some learners understood the angle between the force of gravity and the displacement to be  $180^\circ$  while others understood it to be  $90^\circ$ .

Snapshot 5.1 presents Script 23 that displays the response of a learner who understood the angle between the gravitational force and the displacement of a falling object to be  $90^\circ$ .

**Snapshot 5.1: Script 23 School 1: ACW1: Angle between force of gravity and displacement as an object falls downwards is  $90^\circ$ .**

$$\begin{aligned}
 \text{Q5.3 } F_g &= Mg \\
 &= 6 \times 9.8 \\
 &= 58.8 \\
 W_{F_g} &= F \cdot \Delta x \cdot \cos \theta \quad \checkmark \\
 &= 58.8 (1.6) \cos 90^\circ \quad \times \\
 &= 0
 \end{aligned}$$

Similarly, Snapshot 5.2 presents Script 53 that displays the response of a learner who understood the angle between the gravitational force and the displacement of a falling object to be  $180^\circ$ .

**Snapshot 5.2: Script 53 School 2: ACW1: Angle between force of gravity and displacement as an object falls downwards is  $180^\circ$ .**

Handwritten student work for Snapshot 5.2:

$$\begin{aligned}
 \text{s.3. } W_{fg} &= F_g \Delta x \cos \theta \quad \checkmark \\
 &= 9,8 = 6 \times 9,8 \times 1,6 \cos 180^\circ \quad | \\
 \therefore W_{fg} &= -94,08 \text{ J. } \times
 \end{aligned}$$

**ACW2: The formula for work done is  $W = F\Delta x \sin \theta$**

Learner scripts that displayed an incorrect formula for work where only the “cos” in the formula  $W = F\Delta x \sin \theta$  was replaced by “sin”, was categorised as displaying the alternative conception ACW2. Scripts 37, 39 and 124 provide evidence that the learners have an alternative conception about work specifically regarding the formula to calculate work and the replacing of “cos” with “sin” in the formula for work. Snapshots 5.5 gives the responses of learners from schools 1 and 4 to Q5.3 displaying the alternative conception ACW2 about work.

**Snapshot 5.3: Script 37 from school 1: The formula for work done is  $W = F\Delta x \sin \theta$**

Handwritten student work for Snapshot 5.3:

$$\begin{aligned}
 \text{s.3 } W &= F_g \Delta x \sin \theta \quad \checkmark \\
 &= (6)(9,8)(1,6) \sin (0^\circ) \\
 &= 94,08 \sin (0^\circ) \\
 &= 0 \text{ J. } \times
 \end{aligned}$$

Snapshot 5.4: Script 39 from school 1: The formula for work done is  $W = F\Delta x \sin\theta$

53.  $W = F \Delta x \sin \theta$   
 $W = mg \sin \theta$   
 $W = 58 (1,6) \sin(0)$   
 $W = 0$   
 No work is being done.

$F = ma$   
 $= (6)(-9,8)$   
 $58,8$

Snapshot 5.5: Script 124 from school 4: The formula for work done is  $W = F\Delta x \sin\theta$

5.3  $W_{\text{gravity}} = F \Delta x \sin 90$   
 $= F \Delta x \cos \theta$   
 $= mg \Delta x \sin \theta \Delta x$   
 $= 6 \times 9,8 \sin 90 \Delta x$   
 $= 84,11 \text{ J.}$

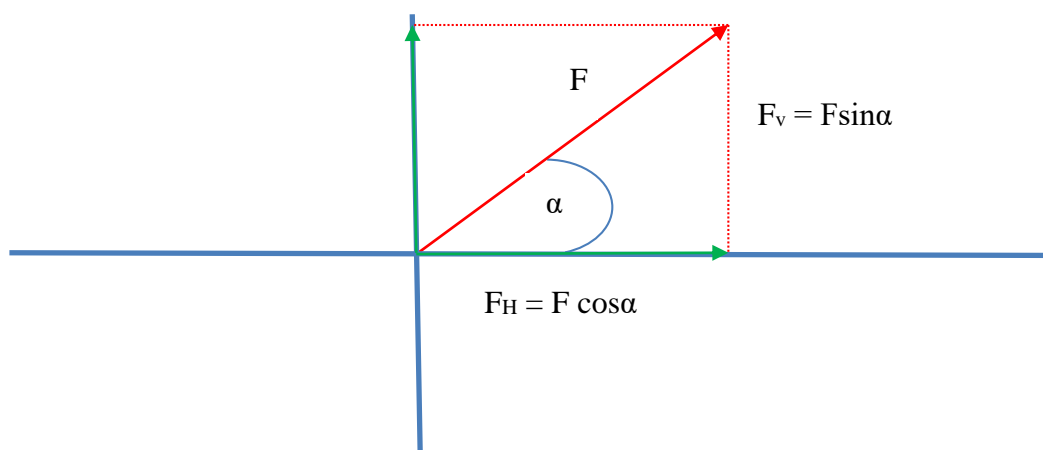
Scripts 37, 39 and 124 provide evidence that the learners have a misconception about work specifically regarding the formula to calculate work. The learners are changing the formula to calculate work, namely  $W = F \Delta x \cos \theta$  to  $W = F \Delta x \sin \theta$ . In the formula  $W = F \Delta x \cos \theta$ , the angle  $\theta$  is the angle between the force  $F$  and the displacement  $\Delta x$ . In this question, both the force and displacement are pointing vertically downwards. The

question that arises regarding the learner responses, in scripts 37, 39 and 124 is about the idea of  $\sin \theta$  in the “new” formula for work given in the learner’s responses. It is interesting to note that the formula for work is given in the data sheet that was given to each learner in the examination sitting. The learners in these examples in Snapshots 5.3-5.5 chose not to use this formula for work that was given, in the data sheet.

The two trigonometric ratios namely  $\sin \theta$  and  $\cos \theta$  are found in the curriculum in Grade 11 under the topic “Resolution of a vector into its horizontal and vertical components” (DBE, 2011, p. 61). The curriculum prescribes the following: “Use  $R_x = R\cos(\theta)$  for the resultant x-component” and “Use  $R_y = R\sin(\theta)$  for the resultant y-component” (DBE, 2011, p. 61). The trigonometric ratio is also found in the curriculum in Grade 12 under the topic Work Energy Power (DBE, 2011, p. 117). The curriculum states the formula to calculate the work done on an object by a force as “ $W = F\Delta x\cos\theta$ ”. It is possible that the learners’ responses are showing that they cannot distinguish between the “ $\theta$ ” used in the formula to resolve a vector into its components and that used in the formula to calculate work done.

To ensure validity of my interpretation of this response of the learner, I discussed it with two experienced teachers who agreed with my interpretation of the learners’ alternative conception that is displayed in Snapshots 5.3-5.5. We looked at the possibility that this error is due to thinking of the vertical and horizontal components of vectors. Figure 5.1 shows a force  $F$  acting at an angle  $\alpha$  to the horizontal. It also shows the vertical and horizontal components of  $F$ , where the vertical component is  $F_v = F \sin \alpha$  and the horizontal component is  $F_H = F \cos \alpha$ . In Q5.3 the force  $F$ , is not a force acting at an angle  $\theta$  to the horizontal, but it is a force acting vertically downwards. It is the gravitational force acting on the 6 kg block.

**Figure 5.1: Vertical and Horizontal Components of F**



The alternative conception that the learner is displaying is that in the formula  $W = F\Delta x \cos \theta$  the learner is probably taking the “ $F \cos \theta$ ” part of the formula to denote the horizontal component of  $F$  as he/she has learnt under the topic “Resolution of vectors” mentioned above. Hence, to this learner the formula for work  $W = F\Delta x \cos \theta$  can be changed to  $W = F\Delta x \sin \theta$  since the motion is vertically downwards in this question. There are three possible reasons for learners’ displaying this alternative conception. The first reason could be due to rote learning where the learner associates the horizontal component of a force  $F$ , with  $F \cos \theta$  and the vertical component with  $F \sin \theta$  without understanding the context. This would bring the learner to the alternative conception that since the 6 kg block is moving in the vertical direction, the vertical component of  $F$  should be in the formula for work and that this component is  $F \sin \theta$ . This learner failed to discern that in the concept of work it is the component of the force in the direction of the displacement that is the “ $F$ ” in the formula  $F\Delta x \cos \theta$  and  $\theta$  is the angle between  $F$  and  $\Delta x$ . The formula for work is the scalar product (dot product) of two vectors but this aspect is not included in the school curriculum. This could be a possible reason why the “ $\cos \theta$ ” part of the work formula is being confused with the formulae for the resolution of a vector into its components. The “ $\cos \theta$ ” in the work formula follows from the definition of the dot product and it determines the sign of the scalar product. It is perhaps the omission of this aspect regarding the dot product that leads to this alternative conception. This will be the case irrespective of whether the displacement is in the vertical or horizontal direction or whether it is on an incline. The second reason for this alternative conception is a lack of

discernment between the angle  $\theta$  in the formula to resolve the force into its vertical and horizontal components and the angle  $\theta$  that is the angle between the component of  $F$  acting in the direction of the displacement and  $\Delta x$ . It is important that the learner is aware of these critical features of work and is able to discern the variations regarding work to be able to apply the work formula to solve problems. The example depicted in Figure 5.1 refers to an object that is pulled a distance  $\Delta x$  to the right by a force  $F$  at an angle  $\alpha$  to the horizontal. In this example the force that is doing work is  $F \cos \alpha$  and the angle between this force and the displacement is  $\theta = 0^\circ$ . If the object had moved a distance  $\Delta x$  to the left under the action of the same force, then  $\theta = 180^\circ$  and the force will remain  $F \cos \alpha$ . The third reason could be an inability to understand the use of the symbol  $F$  in the work equation and the equations to resolve forces into their component vectors.

### 5.9.1.3 Alternative Conceptions about Energy

Two alternative conceptions about energy were displayed by some learners as they answered Q5.4. Graph 5.1 shows that 85% of the learners were unable to solve the problem in Q5.4 and one of the reasons for this low performance is that learners hold alternative conceptions about work. On closer examination of the analysis presented in Graph 5.1 a marked variation in learner responses regarding the application of the Work Energy Theorem (WET) is observed. In order to correctly apply the WET, learners would need to understand the critical features friction, conservative, non-conservative, force, system and displacement.

This question was analysed from a qualitative perspective to identify the critical features that a learner would need to be aware of in order to correctly answer it. These critical features are: total mechanical energy in an isolated system is conserved,  $W_{\text{net}} = \Delta E_K$  and  $W_{\text{nc}} = \Delta E_K + \Delta E_p$ . This was followed with identifying the dimensions of variation for each critical feature and the evidence for alternate conceptions as presented in Table 5.1. Two alternative conceptions regarding the application of the WET emerged from the analysis of the 100 learner scripts. These are Alternative Conception Energy 1 (ACE1): ACE1: System: **The energy of one part of a system can be determined independently of the other parts of the system, and** Alternative Conception Energy 2 (ACE2): Mechanical

Energy is conserved in the presence of non-conservative forces. These two alternative conceptions about energy are discussed below.

**ACE1: System: The energy of one part of a system can be determined independently of the other parts of the system.**

The alternative conception ACE1: System: **The energy of one part of a system can be determined independently of the other parts of the system.**, was displayed by some learners on their NSC examination scripts as they answered Q5.4. This question required the learners to use energy principles to calculate the speed of a 6 kg block when it falls through a vertical distance of 1.6 m while it is attached via a light inextensible string to a 4 kg block that is lying on a rough horizontal surface. Learner scripts that displayed the non-scientific understanding of the transfer of energy by the work done on a system were categorised as displaying the alternative conception ACE1.

Examples of learner responses displaying this AC are presented in Snapshots 5.6 and 5.7. Snapshots 5.6 and 5.7 give the responses of learners to Q5.4 displaying the alternative conception ACE1 about energy. Snapshot 5.6 presents Script 35 School 1 and Snapshot 5.7 presents Script 55 School 2.

Scripts 35 and 55 of schools 1 and 2 provide evidence that the learners have an alternative conception about the energy transfer that takes place under the action of a non-conservative force like friction. In Script 35, the learner equates the work done by the non-conservative force to the sum of the kinetic energy and potential energy of the 4 kg mass instead of to the sum of the change in kinetic energy and change in potential energy of both the 6kg and 4kg masses. He also incorrectly calculates the potential energy of the 4kg mass by substituting the height of the 6kg mass. He fails to see that the change in  $E_p$  for the 4kg mass is zero. Another error that the learner makes is in calculating the work done by the frictional force by omitting  $\Delta x$  which is 1.6m. A further error that the learner makes is in including the  $W_g$  as part of the  $W_{nc}$ . Script 35 also shows that the learner displays a lack of understanding that the force of gravity is a conservative force and not a non-conservative force. While the learner made several errors in Script 35, one of the errors displays the alternative conception ACE1 which has been explained above. In

Script 55 the learner calculates the change in kinetic energy and potential energy of only the 6 kg mass, but does not use this to solve the problem. The change in potential energy of the system of two objects that she calculates is correct because the change in potential energy is zero for the 4kg object. However, the  $\Delta E_k$  is incorrect as the learner has not included the  $\Delta E_k$  for the 4kg object. The learner had correctly started with the correct formula to calculate the work done by the non-conservative forces ( $W_{nc}$ ). This learner displays two errors in her Script 55. The one error that she made displays the alternative conception ACE1 and the other error that she made was in equating the  $W_{nc}$  to the non-conservative forces. All her other formulae, equations and calculations were correct. In both scripts the learners fail to see that the work done by the non-conservative force is equal to the sum of the changes in kinetic energy of both the 4 kg and 6 kg masses and the changes in potential energy of both these masses as depicted in the equation  $W_{nc} = \Delta E_{k_{4kg}} + \Delta E_{k_{6kg}} + \Delta E_{p_{4kg}} + \Delta E_{p_{6kg}}$ . In Script 55 the learner also could not distinguish between work and force as he/she equates the two. The response is showing a lack of awareness that work is a mechanical way to transfer energy either to a system or from a system. This alternative conception points to a lack of understanding of a system and an inability to apply the WET to the system.

**Snapshot 5.6: Script 35 School 1: AC about energy transfer to a system**

Learner omits  $\Delta x$  which is 1.6m

The change in kinetic energy should be the sum of the change in kinetic energies of both the 4kg and 6kg blocks

5.4.  $W_{nc} = \Delta K + \Delta U$

$$f_f + F_g - f_f = \frac{1}{2}mv_i^2 + mgh$$

$$(0.4)(4)(9.8) \cos 180^\circ + 94.08 = \frac{1}{2}(4)v_i^2 + (4 \times 9.8)(1.6)$$

$$(0.4)(4)(9.8) \cos 180^\circ + 94.08 = \frac{1}{2}(4)v_i^2 + (4)(9.8)(1.6)$$

$$-15.68 + 94.08 = 2v_i^2 + 62.72$$

$$-15.68 - 62.72 + 94.08 = 2v_i^2$$

$$\frac{15.68}{2} = \frac{2v_i^2}{2}$$

$$\sqrt{v_i^2} = \sqrt{7.84}$$

$$v_i = \text{desired } 2.8 \text{ m s}^{-1}$$

Learner incorrectly includes  $W_g$  as

**Snapshot 5.7: Script 55 School 2: AC about energy transfer to a system**

(5.4)  $W_{nc} = \Delta E_K + \Delta E_P$  ✓

$$= \Delta \left( \frac{1}{2}mv^2 \right) + \Delta mgh$$

but  $W_{nc} = -f_f + T$

$\Delta E_K = \Delta \left( \frac{1}{2}mv^2 \right)$

$$= \left( \frac{1}{2}mv^2 \right)_f - \left( \frac{1}{2}mv^2 \right)_i$$

$$= \left( \frac{1}{2} \right) (6)(v^2) - \left( \frac{1}{2} \right) (6)(0^2)$$

$\therefore \Delta E_K = 3v^2$

$\Delta E_P = \Delta mgh$

$$= (mgh)_f - (mgh)_i$$

$$= [(6)(9.8)(0)] - [(6)(9.8)(1.6)]$$

$$= -94.08$$

The change in kinetic energy should be equal to the sum of the change in kinetic energies of the 6kg block and the 4kg block

$f_{\text{net}} = ma$

$T - f_f = 4a$

$T - 15.68 = 4a$

$\therefore T = 4a + 15.68 \dots \textcircled{1}$

$[16 \text{ kg}]$

$f_{\text{net}} = ma$

$F_g - T = ma$

$58.8 - T = 6a$

$\therefore T = 58.8 - 6a \dots \textcircled{2}$

Learner makes an incorrect relationship

① = ②

$$4a + 15,68 = 58,8 - 6a$$

$$4a + 6a = 58,8 - 15,68$$

$$\frac{10a}{10} = \frac{43,12}{10}$$

$$\therefore a = 4,31 \text{ m} \cdot \text{s}^{-2}$$

Subs  $a = 4,31$  into ①

$$T = 4a + 15,68$$

$$T = 4(4,31) + 15,68$$

$$\therefore T = 32,93 \text{ N}$$

$$\therefore W_{nc} = F_f + T$$

$$= \mu_k N + T$$

$$= [(0,4)(6)(9,8)] + 32,93$$

$$= 56,45 \text{ J}$$

$\therefore W_{nc} = \Delta E_k + \Delta E_p$

$$56,45 = 3v^2 + (-94,08)$$

$$56,45 = 3v^2 - 94,08$$

$$56,45 + 94,08 = 3v^2$$

$$\frac{150,53}{3} = \frac{3v^2}{3}$$

$$\sqrt{v^2} = \sqrt{50,177}$$

$$\therefore v = 7,08 \text{ m} \cdot \text{s}^{-1}$$

$$\therefore \text{Speed } 4\text{kg block} = 1,08 \text{ m} \cdot \text{s}^{-1}$$

Learner makes an incorrect relationship. Learner equates  $W_{net}$  to Force

### ACE2: Mechanical Energy is conserved in the presence of non-conservative forces.

The alternative conception ACE2: Mechanical Energy is conserved in the presence of non-conservative forces, was displayed by learners on their NSC examination scripts as they answered Q5.4. The requirements of this question have been discussed above under the discussion for ACE1. Learner scripts that displayed the application of the conservation of mechanical energy to solve this problem were categorised as displaying the alternative conception ACE1.

Examples of learner responses displaying this AC are presented in Snapshots 5.8 and 5.9. Snapshots 5.8 and 5.9 give the responses of learners to Q5.4 displaying the alternative conception ACE2 about energy. Snapshot 5.8 presents Script 124 School 4 and Snapshot 5.9 presents Script 156 School 5.

Scripts 124 and 156 of schools 4 and 5 provide evidence that the learners have an alternative conception about the principle of conservation of mechanical energy as they have applied this principle to the context in which a non-conservative force, is present. In both Script 124 and Script 156 the learners apply the principle of conservation of mechanical energy to the 6 kg block. The responses shown in Snapshots 5.8 and 5.9 show a lack of awareness of the effect of the presence of non-conservative forces on a system. The following two critical features of the conservation of mechanical energy need to be in the learners' area of focal awareness for them to fully understand it. Firstly, the total mechanical energy of a system is conserved in an isolated system, and this means that energy is neither added to nor removed from the system. Secondly, when non-conservative forces do work on a system it means that energy is either removed from or added to the system, hence the total mechanical energy of the system changes. The learners' responses in Snapshots 5.8 and 5.9 show that they do not attend to these critical features of the principle of conservation of mechanical energy and therefore display this AC.

**Snapshot 5.8: Script 124 School 4: AC about conservation of mechanical energy**

$$5.4. (\Delta E_p + \Delta E_k)_{\text{top}} = (\Delta E_p + \Delta E_k)_{\text{bottom}} \quad \times$$

$$(mgh + \frac{1}{2}mv^2)_{\text{top}} = (mgh + \frac{1}{2}mv^2)_{\text{bottom}}$$

$$(6)(9,8)(1,6) + \frac{1}{2}(6)v^2 = 0 + \frac{1}{2}(6)v^2 \quad \times$$

$$94,08 = 3v^2$$

$$\sqrt{31,36} = \sqrt{v^2}$$

$$v = 5,6 \text{ m} \cdot \text{s}^{-1} \quad \times$$

$$N = F_g \cdot mg$$

$$= 4(9,8)$$

$$= 39,2 \text{ N} \quad \times$$

**Snapshot 5.9: Script 156 School 5: AC about conservation of mechanical energy**

$$5.4. \sum E_f = \sum E_i$$

$$mgh + mv^2 = mgh + mv^2 \quad \times$$

$$0 + 0 = (6+4)(9,8)(1,6) + (6+4)v^2$$

$$0 = (10)(9,8)(1,6) + 10v^2$$

$$0 = 156,8 + 10v^2$$

$$10v^2 = 156,8$$

$$v^2 = 15,68 \quad \times$$

$$\therefore v = 3,96 \text{ m} \cdot \text{s}^{-1}$$

### **5.9.2 Results and analysis: Learners' problem-solving approaches and difficulties in the NSC**

In section 5.9.1 the ACs about Work Energy Power displayed by learners in the NSC examinations were presented and analysed. In this section the Problem-Solving Approaches and Difficulties (PSADs) about Work Energy Power displayed by learners in the NSC examinations will be presented and analysed. A quantitative analysis and qualitative analysis of the learner responses to Question Five of the Physical Sciences Paper One of the NSC examinations was conducted. The quantitative analysis was done with a purpose to identify the various approaches to problem-solving that is evident in the sample. The quantitative analysis is not serving a purpose of providing statistical data that could be generalised to a larger sample. The qualitative analysis was done to identify the qualitatively different ways in which the learners experienced the problem-solving exercises.

Q5.3 is probing the learner's ability to calculate the work done by the gravitational force. To do this calculation correctly the learner needs to recall the procedure, select the correct formula and then substitute the correct values of the force  $F$ , displacement ( $\Delta x$ ) in the direction of the force  $F$  and the angle  $\theta$  between  $F$  and  $\Delta x$  into the formula. The context in which this calculation is based is not a routine and simple plug-and-chug calculation. The 6 kg block is attached to a 4 kg block that is placed on a rough horizontal surface. Hence, there is more than one force acting on the 6 kg block, namely tension and the force of gravity. The learner would need to discern the two forces and isolate the gravitational force.

Q5.4 requires the learner to apply energy principles to calculate the velocity of a 6 kg block that falls a vertical distance of 1,6 m while still attached via a light inextensible string to a 4 kg block that is lying on a rough horizontal surface. In order to solve this problem, the learner would need to understand the critical features of the WET namely conservative forces, non-conservative forces, friction, gravity, kinetic energy, potential energy and mechanical energy.

The NSC scripts in the sample had already been marked and assigned marks during the marking process and I used this as a trustworthiness check to my coding of the learner responses. I re-marked Q5.3 and Q5.4 and compared my marking with the marking that already had been done. This was done to assist in ensuring trustworthiness of my coding of the learner responses. In cases where my marking differed with the marks on the script, I requested an experienced teacher to independently mark this question on the script and followed this up with rigorous discussions until we came to a consensus. After this rigorous exercise of ensuring trustworthiness, I recorded the mark obtained by the 100 learners for questions 5.3 and 5.4 in the SPSS Data Editor. Q5.3 had a maximum mark of 3 and learners could obtain a mark of 0, 1, 2 or 3 depending on the quality and accuracy of their written responses to the question. Q5.4 had a maximum mark of 5 and learners could obtain a mark of 0, 1, 2, 3, 4 or 5 depending on the quality and accuracy of their written responses to the question. This initial set of quantitative data was then analysed to obtain the qualitatively different ways in which the learners experienced the problem-solving exercises on Work Energy Power in the NSC. In order to conduct this qualitative analysis a set of categories needed to be developed. The following three paragraphs explain this process.

According to Newton and Martin (2013) “student responses and assessments can be related to increasing levels of cognitive complexity”. The Structure of the observed Learning Outcome (SOLO) Taxonomy that was developed in 1982 by Biggs and Collis classifies learning outcomes displayed by learners according to their complexity. The SOLO taxonomy can be used to assess learner performance according to well-developed criteria. It is a criterion-referenced tool to assess the quality of learner performance (Biggs & Collis, 1982). The SOLO taxonomy classifies the learning outcomes into five distinct hierarchical levels (Biggs & Collis, 1982; Newton & Martin, 2013; Shakhman & Barak, 2019). The categories that were developed to describe the qualitatively different ways in which the learners in the sample in my study experienced the problem-solving exercise are informed by the SOLO taxonomy of Biggs and Collis (1982) and the Types of Knowledge Taxonomy of Anderson and Krathwohl (2001).

The responses of the learners were initially categorised into six categories using VT and representing the qualitatively different ways in which the learners experienced the

problem-solving exercise. To ensure validity of my categorisation, I gave these categories to an experienced teacher to quality assure. I further requested another experienced teacher to categorise the learner responses. This exercise with the two teachers determined that two of the categories were not distinct and that the critical features of the responses of learners overlapped in these two categories. I utilised the inputs from both teachers to change the initial six categories into four distinct categories. These four categories emerged from the learner responses. They were not determined in isolation from the learner responses. To ensure confirmability I compared these four categories of the learner responses to the descriptions of expected learner responses in the memorandum for Physical Sciences Paper 1 and found them to be in agreement (DBE, 2017e). Since the memorandum had been quality assured by DBE, this exercise ensured the confirmability of the categories that I had developed.

The four themes that emerged from the learner responses to Q5.3 and Q5.4 are arranged according to their complexity in Table 5.3. These four themes are coded into four categories. The four categories that emerged are: Missed the Point State (MPS), Limited Factual State (LFS), Disjointed Relationships State (DRS) and Linked and Integrated State (LIS). The coding of the four categories presented in Table 5.3 are informed by the SOLO taxonomy of Biggs and Collis (1982) and the Types of Knowledge Taxonomy of Anderson and Krathwohl (2001).

**Table 5.3: Description of codes for learners' problem-solving approaches involving work energy and power**

CATEGORY DESCRIPTION	CODE	RANK
None of the critical aspects are dealt with. The learner has missed the point completely	Missed the Point State (MPS) (Pre-structural in SOLO)	1
Only one critical aspect is discerned, and learner's understanding is highly limited. Some factual information is incorrect or missing.	Limited factual state (LFS) (Uni-structural in SOLO)	2
More than one critical aspect is known but some of their relationships to each other and the whole are missed. Incorrect relationships may be made amongst the critical aspects.	Disjointed Relationships State (DRS) (Multi-structural level in SOLO)	3
All critical aspects are discerned and dealt with in a coherent and integrated manner	Linked and Integrated State (LIS) (Relational level in SOLO)	5

Learner responses in which none of the critical aspects pertaining to the problem-solving exercise are dealt with were categorised as Missed the Point State (MPS). The learner responses that showed that only one critical aspect was discerned, and that learner's understanding was highly limited with some factual information incorrect or missing were categorised as Limited Factual State (LFS). In learner responses where more than one critical aspect is known, but some of their relationships to each other and the whole are missed or incorrect relationships amongst them were made, were categorised as Disjointed Relationships State (DRS). Learner responses that showed that all critical aspects are discerned and dealt with in a coherent and integrated manner were categorised as Linked and Integrated State (LIS). This data was captured in the SPSS Data Editor and a descriptive analysis of it was done to reveal the prevalence of each PSAD in the NSC on Work Energy Power. This analysis is presented in Table 5.4.

**Table 5.4: Prevalence of Problem-Solving Approaches and Difficulties (PSADs) displayed in the NSC on Work and Energy**

<b>Object of learning</b>	Calculation of work done by the gravitational force	Using energy principles to calculate velocity of a falling object
<b>PSAD</b>	Q 5.3: Frequency	Q5.4: Frequency
Missed the Point State (MPS)	17	38
Limited Factual State (LFS)	23	23
Disjointed Relationships State (DRS)	12	24
Linked and Integrated State (LIS)	48	15
<b>Total</b>	<b>100</b>	<b>100</b>

Each of the PSADs identified in Table 5.4 will be discussed with evidence from learner scripts in the paragraphs that follow this one.

### 5.9.2.1 Missed the Point State (MPS)

In the category Missed the Point State, the learners are unable to solve the problem and are also do not display any of the critical aspects relevant to the problem. The learner has missed the point completely. A large percentage of the learners had no clue where to start the problem-solving exercises. These learners were in the Missed the Point State (MPS). Biggs and Collis (1982) refer to this quality of learner's work as being at the pre-structural level. At this level the learner "avoids the question" (Biggs & Collis, 1982) or the task has been incorrectly approached (Shakhman & Barak, 2019). Table 5.4 shows that 17% of the learners provided responses that were completely incorrect for Q5.3 and were categorised as MPS. This percentage rose to 38% of learners who were categorised in the MPS for Q5.4. Snapshots 5.10, 5.11 and 5.12 of learner scripts given below are examples of learner responses that are in the Missed the Point State (MPS).

Snapshot 5.10 is the response of a learner from school 1 to Q5.3.

#### Snapshot 5.10: Missed the Point State: Script 5 from school 1: Q5.3

5.3.  $W = mg$  X  
 $= (6)(4,8)$   
 $= 50,$   
 $= 58,6$  X

In Snapshot 5.10, the learner is probably equating work to the force of gravity on the 6 kg block or alternatively the learner is possibly confusing the symbols "W" (for work) and "w" (for weight). This first error about this is from a mathematical dimension. Work (W) has the unit joule and mg has the unit newton. The learner is showing no meaningful ability to distinguish between work and force. The force in this case being the weight.

This is the state where the learner has some bits of information like knowing that there is some calculation involving “mg” and that somewhere “W” is equal to something. Furthermore, this learner is unable to make any meaning out of these symbols and bits of calculation, nor can this learner make any meaningful or correct relationships between the bits of information.

This learner does not write down the correct relationship between mg and weight with an equation that is given in the data sheet, namely  $w = mg$ . There could be a possibility that the learner failed to discern the two symbols “w” and “W” from each other. The state of understanding where the learner’s response shows a lack of discernment of any meaning or relationships, is being categorised as Missed the Point State (MPS) in this study.

Snapshot 5.11 gives the response of a learner to Q5.3, form school 2.

**Snapshot 5.11: Missed the Point State: Script 44 from school 2: Q5.3**

Handwritten student response for Q5.3:

$$\begin{aligned} \text{i. 3 } W_{\text{net}} &= \Delta E_k \quad \times \\ W_{\text{net}} &= mg \\ &= (6)(9.8) \quad \times \\ &= 58.8 \quad \text{N} \quad \times \end{aligned}$$

This is a response of a learner to the same examination question, in the same sitting but from a different school. Although from different schools, the responses are similar, and both have been categorised as Missed the Point State.

Although the equation  $W_{\text{net}} = \Delta E_k$  is a meaningful equation that is given in the data sheet and that this learner wrote in his/her response, it has no relevance in the solution to Q5.3.

After writing this equation, the learner then proceeds to equate  $W_{\text{net}}$  to  $mg$  which is a response very similar to the “ $W = mg$ ” that the learner in school 1 made.

Both these responses are incorrect and showing that this learner too is showing no meaningful ability to distinguish between work and force, as is the case of the learner in Script 5 from school 1. This is another example showing evidence of the Missed the Point State regarding learner understanding of work done by the gravitational force.

Snapshot 5.12 gives the response of a learner to Q5.4, form school 1.

### Snapshot 5.12 Missed the Point State: Script 16 School 1. Q5.4

The image shows a student's handwritten work on lined paper. The work is as follows:

$$W_{\text{net}} = \vec{F} \cdot \vec{d}$$

$$= (0, 4)(4)(0, 8)$$

$$= 15, 68 \text{ N}$$

This first calculation is crossed out with a red 'X'.

$$W_{\text{net}} = \Delta K + \Delta U$$

$$= \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 + mgh_f - mgh_i$$

$$= \frac{1}{2}mv^2$$

$$\Delta K = K_f - K_i$$

$$=$$

$$W_{\text{net}} = \Delta K + \Delta U$$

This final equation is also crossed out with a red 'X'.

Snapshot 5.12 displays a learner's attempt to solve Q5.4. The learner calculates the frictional force correctly but does not know what to do with that information. This response is showing that the learner does not have any idea how to solve the problem.

### 5.9.2.2 Limited Factual State (LFS)

In the category Limited Factual State (LFS), the learners are unable to solve the problem, but they have a limited amount of knowledge that is relevant to solving the problem. These learners are able to pick up some critical features of the concepts, but not all features that are necessary to solve the problem. In this LFS, the learners also display certain alternative conceptions regarding the concepts pertaining to the problem. These

learners were able to discern more than one critical aspect, but they did not show any evidence of relating these critical aspects to each other and worked with these aspects in a fragmented manner. The facts or items of knowledge were written down as separate unrelated aspects. These critical aspects of the problem appear to be simply written down as facts or knowledge from memory. These responses provide evidence that some learners possess some factual knowledge necessary to solve the problem but are “stuck” in terms of arriving at a solution (Anderson & Krathwohl, 2001, p. 90). It seems as if these learners were simply writing down formulae or doing calculations hoping to get somewhere or to earn some part marks, without having any direction as to where they were going with these critical aspects. Biggs and Collis (1982) refer to this quality of learner responses as being at the Uni-structural Level. At this level, the learner discerns one critical aspect of the problem but his/her understanding is limited (Biggs & Collis, 1982; Shakhman & Barak, 2019).

Table 5.4 shows that 23% of the responses are in the Limited Factual State (LFS) for both Q5.3 and Q5.4. These learners had some idea of how to calculate the work done or apply energy principles and they picked up at least one critical feature of the tasks. However, these learners have a limited understanding of both the task at hand as well as the concepts of work and energy (Shakhman & Barak, 2019).

Snapshots 5.13-5.16 provide evidence of learner responses that display the LFS.

**Snapshot 5.13: Limited Factual State (LFS): Script 53 school 2: Q5.3**

Handwritten student work for Q5.3:

$$\begin{aligned} \text{5.3. } W_{fg} &= F_g \Delta x \cos \theta \quad \checkmark \\ &= \cancel{9,8} = 6 \times 9,8 \times 1,6 \cos 180^\circ \\ \therefore W_{fg} &= -94,08 \text{ J. } \quad \times \end{aligned}$$

**Snapshot 5.14: Limited Factual State (LFS): Script 64 school 3: Q5.3**

5.3  $W = F \Delta x \cos \theta$  ✓

$W = 9.8 (6, 9.8) \cos 90^\circ$  X

$W = 0 \text{ J}$  X

**Snapshot 5.15: Limited Factual State (LFS): Script 137 school 5: Q5.3**

5.3.  $W = F_g \Delta x \cos \theta$  ✓

$= (6 \times 9.8) (1, 6) \cos 90^\circ$

$= (58, 8) (1, 6) \cos 90^\circ$

$= 0 \text{ J}$  X

The three scripts shown above as evidence of the LFS, are of learners from three different schools and are their responses to Q5.3. Script 53 is from school 2, script 64 is from school 3 and script 137 is from school 5. These learners were able to write down the formula to calculate the work done, namely  $W = F \Delta x \cos \theta$ . In script 53 and 137, the

learners were able to substitute the correct values for mass and gravitational acceleration to obtain  $F$ , but they could not get the correct angle between the force and the displacement.

In script 64, the response is in a more nonsensical state as there is no indication as to which variables are being substituted. However, all three learner responses show a limited factual state in being able to calculate the work done by the gravitational force.

Snapshot 5.16 provides evidence of the learner response to Q5.4 that display the LFS.

**Snapshot 5.16: Limited Factual State (LFS): Script 91 School 4: Q5.4**

Sol.  $W_{nc} = Fd \cos \theta$

$W_{nc} = \Delta E_k + \Delta E_p$  ✓

$= \left( \frac{1}{2} m v_f^2 - \frac{1}{2} m v_i^2 \right) + (m g h_f - m g h_i)$

$= \frac{1}{2} (6) v^2 - 0 + (0 - 6 \times 9,8 \times 1,6)$

$= 30v^2 - 94,08$

$94,08 = 30v^2$

$\sqrt{v^2} = \sqrt{31,36 \text{ m.s}^{-1}} = 5,6 \text{ m.s}^{-1} \text{ downwards}$

$\mu_k = 0,4$

$\therefore F_k = 6 \times 9,8 \times 0,4$

$\therefore F_k = 15,68$

Learner equates  $W_{nc}$  to  $W_{\text{force of gravity}}$

Learner does not use this information in his/her solution to the problem

In snapshot 5.16 the learner is only able to write down the formula to calculate the work done by non-conservative forces correctly. Thereafter the learner is not aware that this work done by the non-conservative force ( $W_{nc}$ ) would be equal to the sum of the change in the kinetic and potential energies of both objects in the system. Instead, the learner incorrectly equates  $W_{nc}$  to the sum of the kinetic and potential energies of only the 6 kg object. The learners' problem-solving approach is thus limited by a lack of awareness of this critical feature of the WET. This response is therefore categorised as LFS.

These responses show that the learners have the correct procedural knowledge, that is they know the steps that need to be followed in order to solve the problem, but they lack in the awareness or knowledge of critical features of the WET or of the mathematical dimension involving vectors and trigonometry. In the mathematical dimension they were unable to obtain the correct angle between the force ( $F$ ) and the displacement ( $\Delta x$ ). Hence, their problem-solving approach was limited and categorised as LFS.

### **5.9.2.3 Disjointed Relationships State (DRS)**

In the Disjointed Relationships State (DRS) learners could discern more than one of the critical aspects of the problem but could neither discern the relationships amongst them nor to the whole problem. In this category, the learners would make incorrect relationships amongst the critical aspects of the problem that they had discerned. This quality of learner responses is placed under the multi-structural level in SOLO (Biggs & Collis, 1982). According to Table 5.4 Twelve percent (12%) of the learner responses for Q5.3 and twenty-four percent for Q5.4 were categorised as DRS.

Snapshots 5.17 and 5.18 provide evidence of the DRS. It is evident from these two scripts, Script 34 and Script 55 that the learners have the procedural knowledge to solve the problem, but they are making an incorrect relationship regarding the net work done and the change in kinetic energy. In Script 34, instead of equating the net work done to the sum of the changes in kinetic energy of both blocks, the learner equates it to only the change in kinetic energy of one block. In Script 55 the learner fails to equate the work done by the non-conservative force to the sum of the changes in kinetic and potential energies of both blocks. This is probably due to a lack of understanding of the concept of a system.

Snapshot 5.17: Script 34 School 1: Q5.4 Disjointed Relationships State (DRS)

$$5.4. W_{net} = \Delta E_k.$$

$$W_{fg} + W_{ff} = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2.$$

$$F \cdot \Delta x \cdot \cos\theta + f \cdot \Delta x \cdot \cos\theta = \frac{1}{2}mv^2 - \frac{1}{2}mv^2.$$

$$(9)(9,8) \cdot 1,6 \cdot \cos 0 + (0,4)(4)(9,8) \cdot 1,6 \cdot \cos 180 = \frac{1}{2}(6)v^2 - \frac{1}{2}(6)(0)^2$$

$$94,08 - 25,088 = 3v^2$$

This is the  $W_{net}$  for the system. The learner then incorrectly equates the  $W_{net}$  for the system to the change in kinetic energy of only the 6kg block, instead of for both the 6kg and 4kg blocks

$$\frac{68,992}{3} = \frac{3v^2}{3}$$

$$\sqrt{v^2} = \sqrt{22,997}$$

$$v = 4,8 \text{ m. s}^{-1}$$

Snapshot 5.18 Script 55 School 2. Q5.4 Disjointed Relationships State (DRS)

(5.4)  $W_{nc} = \Delta E_k + \Delta E_p$  ✓ but  $W_{nc} = f_f + T$  (circled in red)

$= \Delta \frac{1}{2}mv^2 + \Delta mgh$  [4kg]

$f_{net} = ma$

$T - f_f = 4a$

$T - 15,68 = 4a$  ✓ 2

$\therefore T = 4a + 15,68 \dots \textcircled{1}$

$\Delta E_k = \Delta \frac{1}{2}mv^2$

$= (\frac{1}{2}mv^2)_f - (\frac{1}{2}mv^2)_i$

$= ((\frac{1}{2})(6)v^2) - ((\frac{1}{2})(6)(0)^2)$

$\therefore \Delta E_k = 3v^2$

$\Delta E_p = \Delta mgh$  [16 kg]

$f_{net} = ma$

$F_g - T = ma$

$58,8 - T = 6a$

$\therefore T = 58,8 - 6a \dots \textcircled{2}$

Learner makes an incorrect relationship

The change in kinetic energy should be equal to the sum of the change in kinetic energies of the 6kg block and the 4kg block

$$\begin{aligned}
 \textcircled{4} - \textcircled{3} \\
 4a + 15,68 &= 58,8 - 6a \\
 4a + 6a &= 58,8 - 15a \\
 \frac{10a}{10} &= \frac{43,12}{10} \\
 \therefore a &= 4,31 \text{ m} \cdot \text{s}^{-1} \\
 \text{Subs } a &= 4,31 \text{ into } \textcircled{4} \\
 T &= 4a + 15,68 \\
 T &= 4(4,31) + 15,68 \\
 \therefore T &= 32,93 \text{ N} \\
 \therefore W_{nc} &= F_j + T \\
 &= \mu_k N + T \\
 &= [(0,4)(6 \times 9,8)] + 32,93 \\
 &= 56,45 \text{ J} \\
 \therefore W_{nc} &= \Delta E_k + \Delta E_p \\
 56,45 &= 3v^2 + (-94,08) \\
 56,45 &= 3v^2 - 94,08 \\
 56,45 + 94,08 &= 3v^2 \\
 \frac{150,53}{3} &= \frac{3v^2}{3} \\
 \sqrt{v^2} &= \sqrt{50,177} \\
 \therefore v &= 7,08 \text{ m} \cdot \text{s}^{-1} \\
 \therefore \text{Speed } 4 \text{ kg block} &= 7,08 \text{ m} \cdot \text{s}^{-1}
 \end{aligned}$$

Learner makes an incorrect relationship. Learner equates  $W_{net}$  to Force

In the snapshots below Scripts 9 is from a learner from school 1 and script 59 is from a learner from school 3. These learners were able to select the correct formula and substitute correctly for the gravitational force, displacement and the angle between the gravitational force and the displacement. However, they could not provide the correct unit in which work is measured. In scripts 59 and 62, the learners gave the work done in Newton (N). This could be an oversight, or it could be pointing towards a lack of understanding of or an alternative conception about, the difference between work and force.

**Snapshot 5.19: Script 9 School 1: Q5.3 Disjointed Relationships State (DSR)**

$$\begin{aligned}
 5.3. \quad W_{Fg} &= F_g \Delta x \cos \theta \\
 &= (mg) \Delta x \cos \theta \\
 &= (6 \times 9,8) (1,6) \cos 0 \\
 &= (58,8) (1,6) \cos 0 \\
 &= 94,08 \text{ N}
 \end{aligned}$$

### Snapshot 5.20 Script 59 school 3: Disjointed Relationships State (DSR)

$$\begin{aligned}
 \text{S.3 } W_{fg} &= F_g \Delta x \cos \theta \quad \checkmark \\
 &= (6)(9.8)(1.6) \cos(0) \quad \checkmark \\
 &= 94,08 \text{ N} \quad \times
 \end{aligned}$$

#### 5.9.2.4 Linked and Integrated State (LIS)

Responses of learners that were categorised as being in the Linked and Integrated State (LIS) show a clear, logical and step-wise solution to the problem. In this category the learners have picked up all the relevant critical features that are needed to solve the problem and they succeed in providing a correct solution to the problem.

Table 5.4 shows that 48% of the learners in the sample displayed the LIS problem solving approach when required to calculate the work done by the gravitational force and that this percentage dropped to 15% of the learners when required to use energy principles to calculate the velocity of a falling object that is attached to another object. These learners could discern all the critical aspects of the problem and dealt with them in a coherent and integrated manner. They were able to link all the critical aspects that they discerned to solve the problem. These learners are in the Linked and Integrated State (LIS). According to the SOLO taxonomy these learners are at the “Relational Level” (Biggs & Collis, 1982; Newton & Martin, 2013; Shakhman & Barak, 2019).

Snapshot 5.21 provides evidence of the LIS problem solving approach displayed by learners.

## Snapshot 5.21: Script 123 School 4. Q5.4 Linked and Integrated State

$$5.4 \quad f_k = 4 \text{ kN} \quad \text{6 kg block}$$

$$= (0,4)(4)(9,8)$$

$$= 15,68 \text{ N}$$

$$f_g + T = mg$$

$$-58,8 + T = 6g \quad \dots (2)$$

$$f_{\text{net}} = mg \quad (1) \quad -T + 15,68 - 58,8 + T = 10g$$

$$T + f_k = mg \quad (2) \quad -43,12 = 10g$$

$$-T + 15,68 = 4g \quad (1) \quad -4,312 \text{ m/s}^2 = g$$

$$\therefore -58,8 + T = 6g$$

$$-58,8 + T = 6(-4,312)$$

$$T = 39,32,93 \text{ N.}$$

$$\therefore f_{\text{net}} = T - f_g$$

$$= 32,93 - 58,8$$

$$= -25,87$$

$$W_{\text{net}} = \Delta E_k$$

$$f_{\text{net}} \cdot \Delta x \cos \theta = \frac{1}{2} m v_f^2 - \frac{1}{2} m v_i^2$$

$$-25,87 \cdot 1,6 \cdot \cos 0 = \frac{1}{2} (6) (v_f)^2 - \frac{1}{2} (6) (0)^2$$

$$-41,392 = 3 v_f^2 - 0$$

$$-13,797 = v_f^2$$

$$v_f = 3,71 \text{ m/s}^{-1}$$

$\therefore$  Speed of the 6 kg block when it falls through  
1,6 m =  $\frac{3,80}{3,71} \text{ m/s}^{-1}$

### **5.9.3 Discussion: Alternative conceptions, Problem-Solving Approaches and Difficulties displayed in the NSC**

This chapter addressed research question one of the study which states: how do Grade 12 Physical Sciences learners perform on the questions on work, energy and power in the NSC examinations. The results and analysis presented in sections 5.9.1 and 5.9.2 show the limited number of qualitatively different ways in which learners understand WEP as well as the qualitatively different ways in which they approach problem-solving. This chapter showed the prevalence of alternative conceptions and problem-solving difficulties that many learners in the sample display on the questions on work, energy and power in the NSC. Sixty-eight percent of the learners displayed alternative conceptions about work, energy and power. Three ACs on Power, two on Work and three on Energy were identified. Fifty-two percent of the learners displayed problem solving difficulties when solving simple one-step plug-and-chug type problems. Eighty-five percent of the learners displayed problem-solving difficulties when solving multi-step problems.

The analysis of the learner responses to question 1.5 illustrate the following three findings:

Firstly, learners have trouble in understanding Newton's first and second laws. It is evident that learners cannot discern from the given information that constant velocity implies that the acceleration is zero and therefore the resultant force is zero.

Secondly, learners have trouble in simultaneously applying their knowledge of the force of gravity and the state of motion of the object to come to a conclusion, in this case that the upward force that moves the crate is equal in magnitude and opposite in direction to the force of gravity.

Thirdly, learners harbour alternative conceptions about work, energy and power namely, that the work done on an object is dependent on time. It is evident from the sample that some of the learners believe that if a force is applied for double the time over the same distance, half the work is done by that force (AC1). A second variation of this alternative conception that emerged in the sample is that if a force is applied for double the time over the same distance, double the amount of work is done by that force (AC2). A third

variation of this alternative conception is that if a force is applied for double the time over the same distance, the work done by that force increases by a factor of 22 (AC3).

Fifty-two percent (52%) of the learners could not calculate the work done by the gravitational force and 85% of them could not apply energy principles to calculate the velocity of a falling object that is attached to another object. This analysis shows that most of the learners in the sample are experiencing difficulty in problem-solving. Q5.3 is a simpler one step problem and requires the learner to select the correct formula, substitute correct values and compute the answer. Q5.3 can be regarded as a plug-and-chug question that requires a plug-and-chug response. Q5.4 however, is a more complex multi-step problem. It requires the learners to understand the WET and its application in the presence of non-conservative forces. The learner would need to be aware that the net work done is the sum of the work done by both the conservative and non-conservative forces and that this equals the change in kinetic energy of both objects in the system. If the learner used the formula to calculate the work done by the non-conservative forces the learner would need to be aware that this would be equal to the change in the kinetic and potential energies of both objects in the system. A qualitative analysis of the learner responses shows that this understanding of the WET and the work done by the non-conservative forces is not displayed by most of the learners in the sample of 100 learners. This was also revealed in their ACs about work and energy discussed in the previous section.

This study has found that learners have a poor understanding of concepts and poor problem-solving skills. Four PSADs have been identified namely MPS, LFS, DRS and LIS. This chapter has shown using phenomenography and VT that there is a small number of learners who display a linked and integrated problem-solving approach which led them to successfully solve the problems. However, a larger number of learners could not solve the problems successfully because they missed the point (MPS), had limited factual knowledge to tackle the problem (LFS) or made disjointed and incorrect relationships between aspects/concepts (DRS).

The majority of the learners have displayed ACs about WEP in the NSC. This finding is supported by Maseko et al. (2010) who found that learners display a “naïve” and “superficial” understanding of scientific concepts in the NSC examinations (p. 31). The

study also resonates with the findings of ACs in mechanics by Mchunu and Imenda (2013). This study has found that learners experience difficulties in applying energy principles to solve problems. This finding supports the finding that learners are “often unable to employ energy concepts appropriately” when solving problems (Singh & Schunn, 2009, p. 26).

The phenomenographic approach and VT were used to identify the “qualitatively different” ways in which learners understand WEP and approach problems regarding WEP (Marton & Pang, 2007, p. 203). This chapter focused on research question one: How do Grade 12 Physical Sciences learners perform on the questions on work, energy and power in the National Senior Certificate (NSC) examinations. The next chapter will focus on research question two of this study.

## **5.10 Conclusion**

This chapter is the first of four chapters on the analysis of data and findings in this study. Research question one of this study was addressed in this chapter.

*Research Question One: How do Grade 12 Physical Sciences learners perform on the questions on work, energy and power in the National Senior Certificate (NSC) examinations?*

The sample that was used to answer this research question was the 100 Grade 12 Physical Sciences Paper One NSC examination scripts. The sample was selected using typical case sampling which is a type of purposive sampling. It was a mixed methods study where both qualitative and quantitative methods were used concurrently to analyse data. The qualitative methods were of a higher priority than the quantitative methods. These methods were not utilised completely independently of each other as “reality” is not viewed as either “quantitative or qualitative” but rather as an “integrated” whole of both (Cohen et al., 2018, pp. 1-35). The significance of this part of the study was that it employed VT to explore learners’ understandings and problem-solving approaches on WEP and that such an approach on this topic has not been undertaken in South Africa. It is anticipated that this study will fill this missing gap in such studies in South Africa.

On the performance of learners in the NSC Physical Sciences examinations the study found that many learners have a poor understanding of concepts and poor problem-solving skills involving the topic WEP. Four PSADs have been identified namely MPS, LFS, DRS and LIS. It had been found through using phenomenography and VT, that there was a small number of learners in the sample who displayed a linked and integrated problem-solving approach which led them to successfully solve physics problems. However, a larger number of learners in the sample could not solve physics problems successfully because they missed the point (MPS), had limited factual knowledge to tackle the problem (LFS) or made disjointed and incorrect relationships between aspects/concepts (DRS).

The majority of the learners in the sample have also displayed ACs about WEP in the NSC. This finding is supported by Maseko et al. (2010) and Mchunu and Imenda (2013) who also found that learners display ACs. Another finding was that learners experience difficulties on applying energy principles to solve problems. This finding supports the finding that learners are “often unable to employ energy concepts appropriately” when solving problems (Singh & Schunn, 2009, p. 26).

The AC that work done on an object is dependent on time was displayed by most of the learners in the sample. It was evident from the sample that some of the learners believed that if a force is applied for double the time over the same distance, half the work is done by that force (AC1). A second variation of this alternative conception that emerged in the sample was that if a force is applied for double the time over the same distance, double the amount of work is done by that force (AC2). A third variation of this alternative conception was that if a force is applied for double the time over the same distance, the work done by that force increases by a factor of  $2^2$  (AC3).

It was also found that most of the learners in the sample were experiencing difficulty in problem-solving for situations that required either single step or multi-step responses. A qualitative analysis of the learner responses showed that correct application of the WET in the presence of both conservative and non-conservative forces was not displayed by most of the learners in the sample of 100 learners. In the case of two-body systems, most

of the learners displayed that they were not aware that the net work done is the sum of the work done by both the conservative and non-conservative forces and that this equals the change in kinetic energy of both objects in the system. The understanding of energy transfer in a system is not well understood by many learners.

The phenomenographic approach and VT were used to identify Grade 12 Physical Sciences learners' "qualitatively different" understandings and problem-solving approaches regarding WEP (Marton & Pang, 2006, p. 203). This chapter had focused on research question one: How do Grade 12 Physical Sciences learners perform on the questions on work, energy and power in the National Senior Certificate (NSC) examinations. The next chapter will focus on research question two of this study.

## Chapter 6 - ALTERNATIVE CONCEPTIONS, PROBLEM-SOLVING APPROACHES AND PROBLEM-SOLVING DIFFICULTIES

### 6.1 Introduction

This section presents my results, analysis and findings of the focus group interview and the Think Aloud protocol data. These findings and analysis address research question two of this study.

*Research Question Two: What are the alternative conceptions, problem-solving approaches and problem-solving difficulties of Grade 12 Physical Sciences learners on work, energy and power?*

The sources of data to answer this research question were the focus group interview and the TA session. The Think Aloud Protocols (TAPs) were obtained from the TA session and the focus group interview provided the Focus Group Transcript. More details about the focus group interview are provided in section 6.4. The TAPs were obtained by administering the TAQ (Appendix 10) that consisted of 13 questions based on the topics work, energy and power. These questions were aligned to the Grade 12 Physical Sciences Curriculum and Assessment Policy Statement of the Department of Basic Education. Henceforth, the Think Aloud instrument will be called the questionnaire. All questions were based on the broad knowledge area titled Mechanics and on the topic Work Energy Power in the CAPS (DBE, 2011, p. 10). This topic forms part of the Grade 12 curriculum (DBE, 2011, p. 10). All 22 questions were based on the topic Work Energy Power.

After obtaining all the informed consent forms mentioned in paragraph 4.9, the questionnaire was given to eight learners to answer in a single sitting and at the same time. All eight learners were purposively selected from one school in a province in South Africa. The learners were selected such that they were a representative sample of learners that covered achievement in Physical Sciences at the adequate (50% - 59%), substantial

(60% - 69%), meritorious (70% - 79%) and outstanding (80% - 100%) categories (DBE, 2011, p. 151). These categories correspond to performance rating codes 4 to 7 given in CAPS (DBE, 2011, p. 151). In each of these categories two learners, one per gender, were again purposively selected from the Grade 12 Physical Sciences cohort in one school. This selection process resulted in the sample comprising of 4 female and 4 male participants. In order to protect the identity of the participants the following fictitious names were assigned to the eight learners: Ann (learner 1), Patience (learner 2), Gift (learner 3), Gold (learner 4), London (learner 5), Timber (learner 6), Jasmine (learner 7) and Blue (learner 8).

The learners were requested to Think Aloud as they answered the questions. Each learner was given an audio recording device to record his/her speech as he/she answered the questions on the questionnaire. The learners also wrote down their responses to the questions on their scripts. There were thirteen questions in the questionnaire with four questions containing sub-questions. This brought the total number of questions in the TAQ to twenty-two. All eight learners had responded to all the questions resulting in a total of 176 learner responses in the TAPs and 176 learner responses in the learner written scripts that were analysed. Chapter 4 provided further detail on the methodology of collecting the Think Aloud protocol data.

The eight recordings of the Think Aloud sessions were transcribed to provide eight Think Aloud Protocols (TAPs). I did the transcription using Transcribe which is an online transcription software package. Altogether the TAPs comprised of 54 423 words and had a total duration of 10 hours 22 minutes and 48 seconds. Table 6.1 provides the duration and number of words in the TAPs per learner.

**Table 6.1: Duration and number of words in the Think Aloud Protocols**

Item	Ann: L1	Patienc e: L2	Gift: L3	Gold: L4	London : L5	Timber : L6	Jasmin e: L7	Blue: L8	Total duratio n and words
Respon se Duratio n:	01:14:4 7	01:41:5 4	00:28:4 8	01:38:1 0	01:35:1 2	01:07:0 1	01:37:2 1	00:59:3 5	10:22:4 8
Number of words	7668	8593	4335	7635	8209	7007	5614	5362	54423

Table 6.1 shows that Gift spoke for the shortest duration of time compared to the other participants during the Think Aloud Session. The duration of his recording was the shortest at 28 minutes and 48 seconds followed by Blue at 59 minutes and 35 seconds. The number of words spoken by Gift in his TAP was the lowest at 4335 followed by Blue at 5362 words. The remaining six participants spoke for longer than one hour and more than 5362 words. Patience spoke for the longest duration at 1 hour 41 minutes and 54 seconds. She spoke the largest number of words at 8593 compared to the other participants. The fact that Gift spoke the lowest number of words in his TAP could be a possible reason why he did not articulate many alternative conceptions although he was unable to answer many of the questions correctly.

The reason that the recording of Gift was less than 30 minutes was that he tended to switch the recorder off while he was writing down his answers and only after writing down his answers, he “thought aloud”. Therefore, the thinking process of Gift that was recorded was not strictly a “Think Aloud” as it was for the remaining seven learners as his was more of a report after the fact. The remaining learners spoke as they were answering the questions. They “thought aloud” as they had been guided to do. I decided to retain the recording of Gift as a TAP although the process that he followed was slightly different from the others and I will note any limitations regarding this inclusion, if any.

The TAPs were analysed utilising thematic analysis underpinned by the phenomenographic approach and VT. The coding process was repeated three times with each being at least one week apart. This was done to ensure accuracy and validity of the data collected.

The coding was done on the transcripts that dealt with the same question for all eight learners before proceeding to the next question. This assisted the researcher to focus on the question and code the Alternative Conceptions (ACs), Problem-Solving Approaches and difficulties (PSADs) that emerged from the transcripts more accurately. The coding process was mostly iterative as I often went back to re-code a learner's transcript after I had read and coded the transcript of another learner. This iterative process assisted in increasing the trustworthiness of the coding process.

The responses of the learners to each of the twenty-two questions were analysed according to two broad categories namely Alternative Conceptions (ACs) and Problem-Solving Approaches and Difficulties (PSADs). The choice of these two broad categories stemmed from research question two of this research and was designed to answer this research question. A further category named Critical Features (CFs) was added to the categorisation process. Initially the transcripts were read while listening to the recordings. The reason for this was twofold. Firstly, this process assisted in checking the transcripts for accuracy of transcription. Secondly, it assisted in developing the first set of themes for each broad category (open-coding).

For the first broad category, namely Alternative Conceptions, three themes emerged from the first stage of reading the transcripts in conjunction with listening to the recordings. These themes are alternative conceptions for each of work, energy and power. The coding was a time-consuming iterative process, but it was necessary to ensure validity of the data collected and recorded. To illustrate this, initially five sub-themes on energy emerged from the transcripts on the first attempt of coding and this included an AC on mechanical energy. However, I later decided to merge this sub-theme on mechanical energy with the sub-theme on kinetic energy as both spoke to the energy of a falling body. This alternative conception about energy is recorded as AC E2 in Table 6.5.

### *Coding and recording of data*

The TAPs were recorded according to three broad themes namely work, energy and power under the broad category alternative conceptions. The transcripts contained the verbalised thinking processes of learners as they answered the questions in the questionnaire. The transcripts were recorded verbatim, and care was taken to record all the words voiced by the learners including interjections like “mmm” and “ughm” etcetera. However, the interjections were not a focus of this study and were not analysed.

The learners’ spoken words which are verbalisations of their knowledge, thoughts conceptions, ideas, difficulties and approaches were recorded as data under specific themes. For example, sentences and phrases that spoke to an alternative conception of energy was recorded under the category Alternative Conceptions (AC) and the theme AC Energy. Sentences and phrases that are taken as scientifically correct were recorded under the category Critical Features (CF) and the theme Critical Features Energy. The sentences and phrases that were categorised under the theme AC Energy were analysed in order to determine the alternative conception that they exhibited and then categorised under the sub-theme that was named after the alternative conception for example: AC Change in velocity equals change in kinetic energy. The following example which is an extract of the TAP of Gold will illustrate this process: While answering Q10.1.2 that required the learners to state whether the kinetic energy of a box increases, decreases or remains the same when its velocity changes from  $-4 \text{ m}\cdot\text{s}^{-1}$  to  $-1 \text{ m}\cdot\text{s}^{-1}$ , Gold said the following in lines 233 to 238 in his TAP:

233 *So from 4 minus 4 meters per second to 1 meters so initial think it increased by*

234 *its minus 1 minus 4 (-1-4)*

235 *so final - initial.*

236 *So minus negative 4. Minus negative 4.*

237 *So it increased by three.*

238 *Yes it increased.*

This extract was coded under the category Alternative Conceptions and the theme AC Energy and the sub-theme AC Change in velocity equals change in kinetic energy.

## **6.2 Understanding Work Energy Power**

This section presents the results of the study regarding the second research question, followed by a discussion on these results and analysis thereof of learners' understandings of work, energy and power. To ensure validity of the results the researcher had these results and findings moderated by an academic from a university in South Africa. The moderator had stated that the findings in this study are consistent with her own observations of her students' work. She had also stated the data in this study is very interesting. The moderator had made a few recommendations that led to changes in the way in which some of the results were formulated. Firstly, results showing learners correct understandings regarding WEP were included in the results, following the moderator's recommendations. Secondly, the phrasing of AC E4 was changed from "Mechanical Energy remains constant when an object moves uphill at constant velocity" to "A change in mechanical energy depends only on changes in velocity and not on changes in height". Thirdly, the phrasing of the three ACs on Power were also changed following the recommendations of the moderator. The focus of research question two is on alternative conceptions, problem solving approaches and problem solving difficulties. However, a discussion showing learners understanding of some Physics concepts involving Work Energy Power that is more in line with the intended object of learning is included in this chapter so as to broaden the perspective on the lived object of learning.

### **6.2.1 Results: Understanding Work Energy Power**

It is evident from the TAPs that learners display ACs as well as a good understanding of some CFs involving Work Energy Power. Table 6.2 presents the results on the prevalence of ACs and CFs involving Work Energy and Power.

**Table 6.2: Number of questions to which the response contained ACs and CFs**

<b>Learner</b>	<b>Total Number of Questions Answered</b>	<b>Number of questions to which the response contained ACs on physics concepts in general</b>	<b>% Responses with ACs in physics topics in general</b>	<b>Number of questions to which the response contained ACs on Work Energy Power</b>	<b>% responses with ACs on Work Energy Power</b>	<b>Number of questions to which the response contained CFs on Work Energy Power</b>	<b>% responses with CFs on Work Energy Power</b>
Ann	22	8	36	4	18	8	36
Patience	22	7	32	3	14	7	32
Gift	22	8	36	3	14	8	36
Gold	22	8	36	7	32	11	50
London	22	3	14	3	14	15	68
Timber	22	7	32	3	14	5	23
Jasmine	22	7	32	4	18	6	27
Blue	22	9	41	4	18	8	36
Total	176	57	32	31	18	68	39

It is shown in Table 6.2 that in 57 of the 176 responses of learners in this sample there is a demonstration of alternative conceptions and in 31 of these 57 responses the alternative conceptions relate directly to work, energy and power. It is also shown in Table 6.2 that in 68 of the 176 responses, learners displayed an understanding of the CFs relating to WEP that is more in line with the intended object of learning. This demonstrates that although learners hold some ACs, all the learners do have some acceptable understanding of physics concepts relating to WEP.

The TAPs of the learners were further categorised to record the ACs and CFs. The alternative conceptions were recorded in one of three sub-themes namely AC Work, AC Energy and AC Power. The alternative conceptions in each of these three sub-categories were further categorised into themes that spoke to that specific alternative conception for example *AC W3 Work by gravitational force is dependent on the path taken*. “AC W3 Work by gravitational force is dependent on the path taken” would refer to the third (3) alternative conception (AC) on work (W). “Work by gravitational force is dependent on the path taken” is the specific alternative conception. The CFs were recorded under three sub-themes CF Work, CF Energy and CF Power. Table 6.3 presents the questions to which the learner responses contained ACs and CFs on Work Energy and Power.

**Table 6.3: Alternative Conceptions and Critical Features involving WEP**

Topic	Learner	Question Number for AC	Question Number for CF
Work	Ann	Q2, Q4, Q9.1	Q4, Q6, Q13.2, Q13.3
	Patience	Q2, Q6	Q4, Q12, Q11.3, Q13.2
	Gift		Q10.2, Q11.4, Q12
	Gold	Q4, Q9.1, Q10.2	Q3, Q4, Q6, Q9.1, Q12, Q13.2, Q13.3
	London	Q10.1.2, Q10.2, Q10.3	Q4, Q6, Q8, Q9.1, Q10.1.2, Q11.4, Q12, Q13.2, Q13.3

Topic	Learner	Question Number for AC	Question Number for CF
	Timber	Q2, Q4	Q4, Q6, Q12
	Jasmine	Q4, Q7, Q9.1, Q9.2	Q6, Q7, Q9.1
	Blue	Q4, Q9.1, Q10.3	Q12
Energy	Ann		Q6, Q10.1.1, Q10.1.2, Q10.3, Q13.3
	Patience	Q6	Q3, Q8
	Gift	Q6, Q8	Q4, Q10.1.1, Q10.2
	Gold	Q10.1.1, Q10.1.2, Q10.3	Q3, Q4, Q6, Q9.1, Q12, Q13.2, Q13.3
	London		Q3, Q5, Q6, Q8, Q9.1, Q12, Q10.1.2, Q13.3
	Timber	Q13.3	Q6, Q10.1.2
	Jasmine		Q6, Q8, Q10.1.1
	Blue		Q6, Q8, Q10.1.1, Q10.1.2
Power	Ann	Q9.2	Q11.1
	Patience	Q9.2	Q11.1
	Gift	Q9.2	Q2, Q9.2, Q11.1
	Gold	Q9.2	Q9.2, Q11.1
	London		Q2, Q9.2, Q11.1
	Timber		Q11.1
	Jasmine	Q9.2	Q11.1
	Blue	Q9.1, Q9.2	Q2, Q9.2, Q11.1

It can be seen from Table 6.3 that all learners demonstrated the presence of alternative conceptions as well as critical features as they worked their way through the questions in the TAQ. Table 6.3 also indicates the questions in which learners demonstrated ACs and CFs on work, energy and power. For example, Gift demonstrated alternative conceptions

in his responses to questions 6, 8 and 9.2 and critical features in his responses to Q2, Q4, Q9.2, Q10.1.1, Q10.2, Q11.1, Q11.4 and Q12. Jasmine demonstrated alternative conceptions in her responses to questions 4, 7, 9.1 and 9.2 and critical features in her responses to Q6, Q7, Q8, Q9.1, Q10.1.1, Q11.1. This data was subsequently analysed to decipher further details of the critical features and more especially of the alternative conceptions.

Section 6.2.2 presents a discussion on the CFs that were articulated by learners in their TAPs. Sections 6.2.3, 6.2.4 and 6.2.5 present the alternative conceptions that were articulated by the learners in their TAPS. Section 6.2.3 presents the alternative conceptions about work, section 6.2.4 presents the alternative conceptions on energy and section 6.2.5 presents the alternative conceptions on power.

### **6.2.2. Critical Features on Work Energy Power**

The learners TAPs were categorised to reveal the critical features on Work Energy Power that the learners had an understanding of in terms what is acceptable by the scientific community. All eight learners demonstrated an understanding of some of the critical features of WEP that were relevant to the questions that they were working through.

An example of the display of understanding CFs is found in the TAP of London as he answered Question 8. Question 8 provided the learners with two scenarios from which to select the scenario in which mechanical energy is conserved. In lines 416 – 427 of his TAP London demonstrated that he understands the critical feature of the principle of conservation of mechanical energy, which is that the system must be isolated. He verbalises this quite clearly in lines 426 – 427 of his TAP given below: “Er in scenario two ... there is there is a presence of an external applied force which is the force of the engine ...thus making the system no longer isolated isolated”. His reasoning led him to the correct answer which he wrote down on his answer script.

*416 The conservation of the mechanical energy is observed in scenario one o*

*417 because according to this principle there has to be no effect of external forces.*

418 *In scenario one the car the car's engine is switched off so and so it freewheels it freewheels upwards up up up the hill up the hill I'm basing backwards up the hill*

419 *and therefore when it freewheels it has no ... it has no applied force ...*

420 *we have been told we have been told to ignore friction,*

421 *therefore ...*

422 *ughm*

423 *(suddenly from slow speaking his speech gets back to a faster pace)*

424 *therefore only gravitational force acts on it.*

425 *Oh wait only the mechanical energy is conserved. ...*

426 *Er in scenario two ... there is there is a presence of an external applied force which is the force of the engine ...*

427 *thus making the system no longer isolated isolated. OK.*

Another example demonstrating that the learner understood two critical features pertaining to the work done by the gravitational force. Since the gravitational force is a conservative force, the work done by it is independent of the path taken. The independence of the work done by the gravitational force to the path taken is a critical feature. Furthermore, work is not time-dependent. Work is not time-dependent is also a critical feature. Question 2 probed learners' understandings of these two critical features. Blue demonstrated his understanding of these two CFs in lines 8- 9 of his TAP as he answered Question 2.

8 *because whether you move it quickly or slowly the force of gravity acting on it on the object doesn't actually tth affect.*

9 *The speed err which you lift the object doesn't determine the force of gravity, it just that it reduces the time it takes to get to the table. Then ya option number option B. 3 only.*

She had selected the correct option (Option B) on her script.

### 6.2.3. Alternative conceptions about Work

Further analysis of the learners' transcripts that were categorised under the theme Alternative Conceptions about Work Energy Power revealed seven distinct alternative conceptions about work. These alternative conceptions about work are presented in Table 6.4.

**Table 6.4: Alternative conceptions about Work**

NAME	NUMBER OF QUESTIONS TO WHICH LEARNER RESPONSES DEMONSTRATE THIS ALTERNATIVE CONCEPTION
AC W1: Work and Net Work can be used inter-changeably	3
AC W2: WET does not apply to accelerating objects	1
AC W3: Work by gravitational force is dependent on the path taken	4
AC W4: Greater velocity greater work done	1
AC W5: More force more work	4
AC W6: Work must be done on an object to keep it in motion	5
AC W7: Positive force positive work negative force negative work	3

The extracts from the TAPs that are presented below provide evidence of these alternative conceptions about Work.

#### **AC W1: Work and Net Work can be used inter-changeably**

Question 10.2 (Q10.2) required the learner to state whether the net work done on a box is positive, negative or zero when its velocity changes from  $-1 \text{ m}\cdot\text{s}^{-1}$  to  $1 \text{ m}\cdot\text{s}^{-1}$ . Gold attempted to answer this question by looking at the work done on the box to change its velocity from  $-1 \text{ m}\cdot\text{s}^{-1}$  to  $1 \text{ m}\cdot\text{s}^{-1}$  as she explains in lines 246 to 271 of his TAP. In doing this, she demonstrated that she did not discern any difference between the concepts work and net work. In lines 267 and 268 specifically, Gold is demonstrating that she is not distinguishing between work and net work as she looks at the work done to change the

direction of motion of the box which she finds to be negative and therefore concludes that the net work is also negative.

246 *Is the net work done on the box positive or negative?*

247 *I think it is positive*

248 *because I think it is I think it is.*

249 *No I think it is negative work.*

250 *Think it is negative work because the wor the the.*

251 *Because the it oppo.*

252 *Did it oppose? It was.*

253 *Ok the object was moving slower and now it's moving faster.*

254 *I think it was whoohh.*

255 *I think it is nege its positive work.*

256 *Wait but velocity.*

257 *Ok so going back to 10.1.1.*

258 *So er n so er this person.*

259 *Ok. So it was 1 meters per second to the left and now its one meters per second to the right.*

260 *So what can this mean?*

261 *Was the net work positive or negative?*

262 *Taking taking er left taking right as positive and left as negative*

263 *I could say that this person was moving left and therefore this person did negative work on the object and therefore the person started moving to the right.*

267 *Yes. I think its negative work since since the work done the work done on the object.*

268 *Cos thh since the work done on the object caused it to move and in a different direction. In a different direction.*

269 *Yes that's what I think.*

270 *Direction.*

271 *And this one is negative.*

### **AC W2: WET does not apply to accelerating objects**

In her answer to Q7, Jasmine simply dismissed applying the Work Energy Theorem as she believed that it cannot be applied to objects that are accelerating as she states in line 163 of her transcript below:

*163 But work energy theorem does not apply in acceleration.*

### **AC W3: Work done by the gravitational force is dependent on the path taken**

Question 2 was a Multiple-Choice Question (MCQ) that required the learners to select the factors that determine the work done by the gravitational force in lifting a suitcase from the floor to the table. The question provides a choice of three factors and learners had to determine the correct factors. In her answer to this question, Ann said the following in lines 20-21 when she chose the incorrect option: She articulated her understanding that the work done by the gravitational force is dependent on the path taken.

*20 So I think er the work done will be affected by by whether I lift the the the the the the bag up the to to the or along the path.*

*21 So my answer will be A.*

Another example exhibiting this alternative conception is found in lines 154-170 of the TAP of Gold as he answered Q9.1. In this question the learner had to determine which of two people of equal masses will do more work in climbing a mountain. Both people in the question started at the foot of the mountain and climbed to the top. In lines 154-170 Gold explained why the person (called the hiker in Q9.1) who walked around the mountain (having a longer path) did more work: In his response he articulated his understanding that work done by the gravitational force is dependent on the path taken as well as his understanding that displacement is equal to path length.

*154 They both have equal masses so that the same time by foot but easier route.*

*155 Spiralling.*

*156 So the distance is longer. So the distance is longer.*

- 157 *Eh so the work done by this person ah will be the work done by him*
- 158 *but the net the total work done by this person would be great since he took a longer he has a bigger displacement.*
- 159 *And see but the climber would also have to do more work since the road eh.*
- 160 *I think the one who dd who did more work was the was the the hiker.*
- 161 *The hiker oh because he took because he took*
- 162 *because er the work done the work done increases increases with the displacement.*
- 163 *The displacement.*
- 164 *Decreases*
- 165 *increases with the displacement of of the person doing the work.*
- 166 *So the hiker took a longer way took a longer way a longer way.*
- 167 *So his displacement is bigger.*
- 168 *Is bigger and therefore and therefore having and therefore his displacement his displacement is bigger and his er ya his displacement is bigger and therefore meaning he did greater work.*
- 169 *Meaning he displacement greater work.*
- 170 *He did greater work.*

#### **AC W4: Greater velocity greater work done**

Gold demonstrated two alternative conceptions in her response to Q9.1. In the above extract from her TAP in lines 154-170 she demonstrated the alternative conception AC W3: Work done by the gravitational force is dependent on the path taken and in lines 171 to 177 she finds a further reason to justify her understanding that the hiker did more work. This further reason being a second alternative conception about work, namely AC W4: Greater velocity greater work done. Lines 171-177 of the TAP of Gold is provided below:

- 171 *And another one could be that er the total net work by an object is equal to eh ek (Ek)*
- 172 *the net work by an object is equal to ek(Ek) plus mgh*
- 173 *delta e k plus mgh ( $\Delta Ek + mgh$ ).*
- 174 *And so the person so the persons who saw this one the hiker took the longest road but he was able to arrive there first.*

174 *So meaning he had greater speed and*

175 *therefore considering the work energy theorem we I can conclude that this person's velocity was bigger.*

176 *And therefore the one with the more with the highest velocity he is the one who did more work adding on to the for the one for delta  $e k$  ( $Ek$ ).*

177 *He did greater work. I think so.*

### **AC W5: More force more work**

Question 9.1 in the questionnaire elicited three alternative conceptions about work namely AC W3, AC W4 and AC W5. Alternative conceptions AC W3 and AC W4 have been presented in the paragraphs above and AC W5 is presented in this paragraph. In question Q9.1 Jasmine said that the climber does more work in getting to the top of the mountain because he applies more force. Her answer is different from that of Gold who said that the climber did more work because he “took a longer way” and also because he had the “highest velocity”. Jasmine provided her reasoning in lines 205-215 of her TAP. In line 215 Jasmine says “the climber is doing more work because more force”.

205 *I'm going to write formula for work which is work total is equals to force times displacement and then cos the angle o ya.*

206 *In this case eh? Wait. Is this one right?*

207 *Take a longer route but arrives earlier?*

208 *Like if the route is longer it means the displacement will be longer.*

209 *OK. So if the displacement is longer, more time.*

210 *At the same time this one the displacement will be shorter but the force?*

211 *Hai uh. I'm not sure about this one because.*

212 *OK. It's the force the force.*

213 *I think the the the climber is the one who is who is actually doing more work OK,*

214 *and again.*

215 *OK, the climber is doing more work because more force. Uhm Uhm.*

### **AC W6: Work must be done on an object to keep it in motion**

In Q4 a box is moving at constant velocity along a horizontal surface while an applied force directed towards the right and a frictional force directed to the left act on the box. The learners were asked to select the True statement from a choice of five options. Ann said the following in lines 44-45 of her transcript as she selected option C as the correct option: In lines 44-45 Ann articulated her understanding that work must be done on an object to keep it in motion.

*44 Er for option C the total work done on the box by the net force is nonzero.*

*45 So I think it must it can be nonzero because there is the net force is the one that enables the block to move to the right.*

Gold selected a different option as her correct answer to Q4. She selected option E and she rejected option D and explained in lines 41-42 of her TAP as she does so. Although Gold chose a different answer to Q4 from Ann she also displayed her understanding that work must be done on an object to keep it in motion.

*41 The magnitude of the work done on the box by force applied is equal to the net is equal to the magnitude of the force of the work done by  $F_k$ . (He is reading option D of Q4)*

*42 This cannot be possible since the object is moving so one of them must be greater.*

### **AC W7: Positive force positive work and negative force negative work**

In question 10 learners were required to state whether the work done on a box was positive, negative or zero. London was unable to answer the question correctly and he articulated his alternative conception in lines 532-538. London articulated his understanding that a negative force applied to an object will do negative work on the object.

*532 And the net work done we see can be negative.*

*533 No the net work done is positive.*

534 *I don't think value have to change.*

535 *This is confusing ...*

536 *the force applied it is in a negative direction, it is in the opposite direction.*

537 *But I'm confused here*

538 *though the signs negative implies that work is negative*

#### 6.2.4 Alternative conceptions about Energy

Further analysis of the learners' transcripts that were categorised under the theme Alternative Conceptions Work Energy Power revealed four distinct alternative conceptions about energy. These alternative conceptions about energy are presented in Table 6.5.

**Table 6.5: Alternative Conceptions about Energy**

NAME	NUMBER OF QUESTIONS TO WHICH LEARNER RESPONSES DEMONSTRATE THIS ALTERNATIVE CONCEPTION
AC E1: Change in velocity equals change in kinetic energy	3
AC E2: Kinetic Energy and mechanical energy of an object decreases as it falls freely	2
AC E3: Mechanical energy is conserved in the presence of non-conservative forces	1
AC E4: A change in mechanical energy depends only on changes in velocity and not on changes in height	1

The extracts from the TAPs that are discussed below provide evidence of these alternative conceptions about Energy:

#### **AC E1: Change in velocity equals change in kinetic energy**

In attempting to determine the change in kinetic energy in question 10.1.1, Gold (L4) equates this change to the change in velocity as shown in lines 226 to 231 in his transcript:

- 226 *It started from negative one meters to one meters per second.*
- 227 *So it means it increased by 2*
- 228 *so the kinetic energy of the box increased.*
- 229 *Wait its final minus initial.*
- 230 *So its 1 minus negative 1 (1-(-1)).*
- 231 *So then kinetic the change in kinetic energy is 2 so it increased since its positive.*

### **AC E2: Kinetic Energy and mechanical energy of an object decreases as it falls freely**

Patience selected option E as the correct answer for question 6 which is an MCQ. This question required learners to choose the correct option from five options that related to the energy and work done on a ball in free fall. Patience (L2) chose the option E which states, “The total mechanical energy of the ball decreases as it falls”. She reasons in line 133 that “as an object falls velocity decreases meaning that kinetic energy also decreases”. Her detailed reasoning is given in the following lines from her transcript:

- 133 *Oh as an object falls velocity decreases meaning that kinetic energy also decreases.*
- 134 *So I don't, its its negative as it falls.*
- 148 *The total mechanical energy of the ball decreases as it falls.*
- 149 *So the total mechanical energy of the ball,*
- 150 *this is because as as as the the ball gets down the velocity decreases*
- 151 *and thus the total mechanical energy of the ball will decrease.*
- 152 *The height also I thi, the height also decreases,*
- 153 *so I think as it goes down it will be like  $m g h$  plus half  $m v$  squared,*
- 154 *so it will be like the mass will stay constant*
- 155 *because the height will decrease as it falls, so as the height decreases, so as the height decreases the*
- 156 *the velocity also decreases, so it falls as if free fall so that that is why,*
- 157 *let me make it.*
- 158 *The answer maybe E, the total mechanical energy of the ball decreases as it falls.*
- 159 *Ughm ughm.*

**AC E3: Mechanical energy is conserved in the presence of non-conservative forces**

Question 13.3 required the learner to calculate the speed of a 6 kg block when it falls through 1.6m while still attached to a 4 kg block. There is kinetic friction between the 4 kg block and the horizontal surface on which it is moving. Timber (L6) uses the conservation of mechanical energy in the presence of non-conservative forces to calculate the speed of the 6 kg block as evidenced in lines 634 to 640 and he is also very confident of his understanding as he says in lines 641-642:

634 *I use the mechanical energy formula to calculate my velocity.*

635 *Since I knew that my initial velocity was zero*

636 *(Recall that earlier he said that acceleration is zero in line 608).*

637 *The formula says  $m g h$  initial plus*

638 *oh OK*

639 *the potential energy initial plus the kinetic energy initial is equal to the potential energy final plus the final kinetic energy ( $E_{pi} + E_{ki} = E_{pf} + E_{kf}$ ).*

640 *After calculating I found out that my velocity is five point six meters per second ( $v = 5,6 \text{ m}\cdot\text{s}^{-1}$ )*

641 *and I trust that my answers*

642 *I believe I'm right.*

**AC E4: A change in mechanical energy depends only on changes in velocity and not on changes in height**

In Q8 two scenarios are presented in which two cars X and Y are moving uphill. In scenario one, Car X is freewheeling uphill and in scenario two Car Y is driving uphill at constant velocity. The learner was required to state and explain in which of the two scenarios the conservation of mechanical energy is conserved. Gift (L3) chose scenario two and provided the explanation as given in lines 118-122 of his TAP. In lines 118-122 Gift articulated his alternative conception that the mechanical energy of an object remains constant as it moves uphill at constant velocity.

118 so in scenario 2 since the car moves in a constant velocity then the acceleration of the car is zero.

119 The constant velocity in fact is that the initial velocity and the final velocity remains the same throughout which means the change in velocity of the car is zero.

120 Thus the mechanical energy before will be equal to mechanical energy after, since height does not affect.

121 This is not the main factor that could make the mechanical energy not to be conserved.

122 The height will remain unchanged on the hill and I would say the height is constant. It doesn't affect that.

### 6.2.5 Alternative Conceptions about power

Further analysis of the learners' transcripts that were categorised under the theme Alternative Conceptions Work Energy Power revealed three distinct alternative conceptions about power. These alternative conceptions about power are presented in Table 6.6.

**Table 6.6: Alternative conceptions about power**

NAME	NUMBER OF QUESTIONS TO WHICH LEARNER RESPONSES DEMONSTRATE THIS ALTERNATIVE CONCEPTION
AC P1: More Power is expended where more energy or work is needed or where more difficulty is experienced	1
AC P2: Work alone determines power irrespective of time	3
AC P3: Time alone determines power irrespective of work	3

**AC P1: More Power is expended where more energy or work is needed or where more difficulty is experienced**

In Q9.2 learners were required to compare the power expended by two people, a climber and a hiker, of equal masses in getting to the top of a mountain after having started from the foot of the mountain but having travelled different paths. The question further states that the climber took longer than the hiker to reach the top of the mountain. Gold explained why she thought the climber expended more power in lines 194-210 of her TAP. She articulated her alternative conception that more power is expended where more energy or work is needed.

194 *Expends more power.*

195 *So power is the rate of work done.*

196 *Is the the rate of work done on an object.*

197 *Ahh so which one is more power?*

198 *So the one who is going to need more power is probably the one who has who's route is more difficult because er.*

199 *Ya I think is the one who needs more power.*

200 *But because eh I don't know the reason why but I just think he's the one.*

201 *Ah let me think.*

202 *He needs more work he needs more power (In Q9.1 she said that the hiker does more work)*

203 *because his route is more difficult.*

204 *And therefore he requires a lot of energy.*

205 *Yeh he requires a lot of energy in order to be able to do work.*

206 *Yes I think its the the climber.*

207 *Because his road his route er pps was difficult was er his route was difficult.*

208 *His route was difficult and*

209 *therefore and therefore had and therefore required required err lots energy energy to do the work.*

210 *Required a lot of energy to do the work per given time.*

### **AC P2: Work alone determines power irrespective of time**

Although in line 148 of her transcript Blue is aware that power is inversely proportional to time and directly proportional to work, she only considered work when comparing the power expended by the hiker and the climber in Q9.2. She failed to take into account both work done and the duration of the work done when comparing the power expended by the climber and the hiker as shown in lines 148-151 of her TAP.

*148 so meaning power is inversely proportional to time and also power is directly proportional to work being done.*

*149 So if the hiker had a greater work being done and also had to expend more power because*

*150 power and work done directly proportional, ya.*

*151 That's what I think.*

### **AC P3: Time alone determines power irrespective of work**

Gift takes a similar approach to answering Q9.2 as Blue, however, Blue considered only work and ignored time, Gift considered only time and ignored work when determining the power expended. Lines 145-148 of Gift's TAP presents his reasoning when comparing the power expended by the climber and hiker in reaching the top of the mountain.

*145 According to definition it says "Power is the rate at which work is done". (He writes the equation for power on his script)*

$$P = \frac{W}{\Delta t}$$

*146 Yes it means if you have rate then its P is equals to work done over time change in time.*

*147 Hence the more the time you take to get in to the mountain the less power the you expend.*

*148 Thus the inversely proportional I would say and work done is directly proportional to what? (On his script for Q9.1 he says climber does more work. On his script for Q9.2 he says hiker expends more power).*

In section 6.3 a discussion of the alternative conceptions about work, energy and power is presented.

### **6.3 Analysis: Alternative conceptions about Work Energy Power**

The Think Aloud Protocols (TAPs) of the eight learners have provided extensive data on alternative conceptions about work, energy and power held by the learners in the sample and these results were presented in section 6.2. This data is showing the limited number of qualitatively different ways in which learners understand WEP.

In this section, an analysis of this data is conducted using Variation Theory as the theoretical framework. Firstly, in section 6.3.1 the intended object of learning will be discussed followed by section 6.3.2 where the enacted object of learning will be discussed. This will be followed by an analysis of the results that were presented in section 6.2 using Variation Theory as a theoretical framework.

The object of learning in this study are the concepts of work, energy and power in the Physical Sciences curriculum in schools.

#### **6.3.1 The intended object of learning: Work Energy Power**

The intended object of learning is the topic Work Energy Power as it is stated in the Curriculum and Assessment Policy Statement (CAPS). The topic Work, Energy & Power is presented in Grade 12 under the broad knowledge area Mechanics (DBE, 2011, p. 10). The CAPS presents the sub-topics work, work-energy theorem, conservation of energy with non-conservative forces present and power under the topic Work Energy Power. The total annual teaching and assessment time allocated for the subject Physical Sciences is 160 hours. This topic is allocated 10 hours of teaching time in the Grade 12 year of the learner (DBE, 2011, p. 117). Twenty-eight hours of teaching time is allocated to the broad knowledge area Mechanics and 10 hours of these 28 hours are allocated to the topic Work Energy and Power

### **6.3.2 The enacted object of learning: Work Energy Power**

The interactions that occur between teacher and learner, learner and peers and learner and learning materials define the enacted object of learning. Several researchers refer to the enacted object of learning as opportunities to learn which is a broad view of the enacted object of learning (Euler et al., 2020; Ingerman et al., 2007; Sun, 2011). The possibility for learning is dictated by what is actually presented to learners and is co-constructed through the interactions that occur between teacher and learner and among learners within and with the learning environment (Lo, 2012; Lupton, 2011; Marton & Booth, 1997).

In this study the enacted object of learning is not a focus and has not been studied. However, the responses of learners in the NSC examination paper, focus group interviews and think-aloud sessions have provided data on the enacted object of learning by inference. In the process of collecting and analysing the data provided in the lived object of learning, this study has made some assumptions about the enacted object of learning, but these assumptions will not be discussed in any detail in this study as the main focus is the lived object of learning.

### **6.3.3 The lived object of learning: Work Energy Power**

The lived object of learning can be described as the way learners make meaning of the object of learning after the lesson ends and beyond (Ludányi, 2007; Marton & Ling, 2007). In section 6.2 the way in which learners made meaning of work, energy and power was presented. The focus of section 6.2 was to identify the alternative conceptions about work, energy and power demonstrated by learners as they answered the questions in the TAQ. The focus of section 6.3.3 is to analyse the data presented in section 6.2 and discuss this analysis using Variation Theory as a theoretical framework. It has been shown in section 6.2 that learners hold certain alternative conceptions and that learners also have an understanding of certain critical features regarding Work Energy Power that is regarded as correct. Both the ACs and CFs represent a part of the lived object of learning. However, in this analysis the focus will be on the alternative conceptions which will

represent only a part of the lived object of learning. The critical features of the topics work, energy and power from CAPS will represent the intended object of learning.

In section 6.2 it has been shown that in 39% of the learner responses, learners have displayed an understanding of critical features involving WEP that is in line with the intended object of learning. In a smaller percentage of the learner responses, namely 18%, learners displayed ACs. These ACs are a focus of this section.

In Chapter 7, I will discuss research question three of this study where the “why” question will be explored. Research Question three states: Why do Grade 12 Physical Sciences learners hold certain alternative conceptions and problem-solving difficulties in work, energy and power? In this section the data that was presented in Section 6.2 will be analysed further from a VT and phenomenographic perspective.

This object of learning is often the focus of educational research, that is, what did students actually learn? Any discrepancies between this lived object of learning and either the intended or enacted objects of learning can provide insight into how curricula or curriculum materials might be modified in order to help students become aware of the critical features of a given phenomenon, a condition that is necessary for learning. Variation is central to Variation Theory (Åkerlind et al., 2011; Lo, 2012; Marton & Pang, 2006). In this section, the discrepancies between the lived object of learning and the intended object of learning are presented and analysed.

Table 6.7 presents an analysis of the prevalence of alternative conceptions on the intended object of learning Work Energy Power among the eight learners in the sample. All eight learners in the sample have articulated an alternative conception on Work Energy Power. London has articulated 2 ACs which is the least number of alternative conceptions whereas Gold has articulated 6 ACs which is the largest number of ACs from the sample of eight learners. None of the learners demonstrated an absence of ACs in their TAPs.

**Table 6.7: Number of alternative conceptions on work, energy and power per learner**

Learner	Name	Question Number	Number of ACs
Ann	AC W3 Work by gravitational force is dependent on the path taken	2	4
	AC W5 More force more work	9.1	
	AC W6 Work must be done on an object to keep it in motion	4	
	AC P3: Time alone determines power irrespective of work	9.2	
Patience	AC W3 Work by gravitational force is dependent on the path taken	2	4
	AC W7 Work Positive force positive work negative force negative work	6	
	AC E2: Kinetic Energy and mechanical energy of an object decreases as it falls freely	6	
	AC P3: Time alone determines power irrespective of work	9.2	
Gift	AC E2: Kinetic Energy and mechanical energy of an object decreases as it falls freely	6	3
	AC E4: A change in mechanical energy depends only on changes in velocity and not on changes in height	8	
	AC P3: Time alone determines power irrespective of work	9.2	
Gold	AC W1 Work and net work can be used inter-changeably	10.2	6
	AC W3 Work by gravitational force is dependent on the path taken	9.1	
	AC W4 Greater velocity greater work done	9.1	
	AC W6 Work must be done on an object to keep it in motion	4	
	AC E1: Change in velocity equals change in kinetic energy	10.1.1 10.1.2 10.3	
	AC P1: More Power is expended where more energy or work is needed or where more difficulty is experienced	9.2	
London	AC W1 Work and net work can be used inter-changeably	10.2 10.3	2
	AC W7 Positive force positive work negative force negative work	10.1.2	
Timber	AC W3 Work by gravitational force is dependent on the path taken	2	3

Learner	Name	Question Number	Number of ACs
	AC W6 Work must be done on an object to keep it in motion	4	
	AC E3: Mechanical energy is conserved in the presence of non-conservative forces	13.3	
Jasmine	AC W2 WET does not apply to accelerating objects	7	4
	AC W5 More force more work	9.1 9.2	
	AC W6 Work must be done on an object to keep it in motion	4	
	AC P2: Work alone determines power irrespective of time	9.2	
Blue	AC W5 More force more work	9.1	4
	AC W6 Work must be done on an object to keep it in motion	4	
	AC W7 Positive force positive work negative force negative work	10.3	
	AC P2: Work alone determines power irrespective of time	9.2, 9.1	

This analysis also shows that there were 31 learner responses altogether where learners demonstrated alternative conceptions on the topic Work Energy Power. These are 31 responses out of a total of 176 learner responses. This represents 17.61% of the learner responses where alternative conceptions were articulated. This data does not mean that the remaining 145 learner responses were devoid of errors or learner difficulties, but rather that alternative conceptions were not clearly articulated. There were other learner difficulties that emerged from the TAPs, but these will be explored in the following sections.

This data is obtained from the words spoken by the learners and not from any inferences made from learner responses as is sometimes done on learners written calculations. Therefore, this is a significant portion of the 176 responses. However, no generalisations are made from this data as this is a qualitative analysis. The significance of this analysis is in determining whether there are any discrepancies between the intended object of learning and the lived object of learning, and this was informed by the presence of alternative conceptions in the think aloud protocols of the learners. The prevalence of any discrepancies between the intended object of learning and the lived object of learning have been determined by comparing the critical features of the topics in the intended

object of learning with the alternative conceptions articulated by learners in their think aloud protocols.

In the following paragraphs of this section the results presented in section 6.2 have been analysed according to the three objects of learning namely work, energy and power given in sections 6.3.3.1, 6.3.3.2 and 6.3.3.3 respectively.

### **6.3.3.1 Analysis of alternative conceptions about work**

Table 6.8 presents an analysis showing the prevalence of alternative conceptions about work that learners hold. According to Figure 6.9 seven alternative conceptions about work has emerged from the TAPs of the eight learners. Seven of the eight learners (87.5%) in the sample have articulated at least two alternative conceptions about work. Only Gift did not articulate any alternative conceptions on work. This does not indicate that Gift does not hold any alternative conceptions about work, rather that he did not articulate any in his TAP. This may be due to the fact that he did not record his thinking while answering the questions but rather explained his thinking after he had written down his answers on his script.

**Table 6.8: Prevalence of alternative conceptions about work**

Topic	Learner	Question Number for AC	Question Number for CF
Work	Ann	Q2, Q4, Q9.1	Q4, Q6, Q13.2, Q13.3
	Patience	Q2, Q6	Q4, Q12, Q11.3, Q13.2
	Gift		Q10.2, Q11.4, Q12
	Gold	Q4, Q9.1, Q10.2	Q3, Q4, Q6, Q9.1, Q12, Q13.2, Q13.3
	London	Q10.1.2, Q10.2, Q10.3	Q4, Q6, Q8, Q9.1, Q10.1.2, Q11.4, Q12, Q13.2, Q13.3
	Timber	Q2, Q4	Q4, Q6, Q12
	Jasmine	Q4, Q7, Q9.1, Q9.2	Q6, Q7, Q9.1
	Blue	Q4, Q9.1, Q10.3	Q12

Tables 6.9, 6.11 and 6.13 present analyses of the data showing the intended and lived objects of learning on work, energy and power respectively. This analysis shows that all the learners in the sample hold alternative conceptions on at least two of the intended objects of learning work, energy and power. Each learner response to a question was assigned a unique file name, for example the response of learner 3 to Q4 was assigned the file name Q4 L3 Gift. “Gift” is the fictitious name given to learner number 3. All eight learners responded to all twenty-two questions giving a total of 176 responses and thus 176 files.

Table 6.9 shows that seven learners have articulated alternative conceptions about work in their TAPs. Furthermore, seven alternative conceptions about work emerged from the think aloud protocols of the learners.

At the outset, the evidence shows that the critical features of the definition of work and net work in the intended object of learning is at odds with the lived object of learning which is with the meaning that learners have made about these definitions after the lessons ended. This is evidenced by 5 of the 7 alternative conceptions about the definition of work that emerged from their TAPs. These are AC W1, AC W4, AC W5, AC W6 and AC W7. Seven of the eight learners (87.5%) in the sample hold alternative conceptions regarding the definition of work and net work.

Three alternative conceptions about the Work Energy Theorem emerged from the TAPs and are detailed in Table 6.9. These are AC W1, AC W2 and AC W6. Five of the eight learners (62.5%) in the sample hold alternative conceptions about the Work Energy Theorem. Alternative conceptions AC W1 and AC W6 apply to both the definition of work and net work and to the work energy theorem. It must be noted that an alternative conception can speak to more than one critical feature of an object of learning since the critical features that are presented in Table 6.9 are concepts, laws or principles and these are all inter-related. In Physics concepts, laws and principles are generally inter-related. For example, AC W1 is *No distinction between Work and Net Work* is an alternative conception that relates to both the definition of work and net-work and to the work energy theorem.

One alternative conception about work with the critical features speaking to the conservation of energy in the presence of conservative and/or non-conservative forces emerged from the TAPs and is detailed in Table 6.9. This alternative conception is AC W3. There are two more alternative conceptions about conservation of energy in the presence of conservative and/or non-conservative forces that will be analysed in section 6.3.3.2 where the alternative conceptions about energy are analysed. Five of the eight learners (62.5%) in the sample hold alternative conceptions about conservation of energy in the presence of conservative and/or non-conservative forces.

The same process of content analysis and thematic analysis of the CAPS document that was discussed in Section 5.9.1 was employed here to identify the objects of learning and their critical features. This analysis is presented in Tables 6.9, 6.11 and 6.13.

**Table 6.9: Analysis of learner responses on Work based on Variation Theory**

<b>Topics</b> <b>Grade 12:</b> <b>Intended</b> <b>Object of</b> <b>Learning</b> <b>Work</b> <b>Energy</b>	<b>Critical Features of the</b> <b>Intended Object of Learning:</b> <b>Content, Concepts &amp; Skills</b> <b>(DBE, 2011, pp. 117-120)</b>	<b>Lived Object of Learning:</b> <b>Evidence of Alternative Conceptions</b>	
		<b>Alternative Conception</b>	<b>Learners holding this AC</b>
Definition of Work and net work	Define the work done on an object by a force as: $W = F\Delta x \cos\theta$ . Know that work is a scalar quantity and is measured in joules (J)	AC W1 Work and net work can be used interchangeably	Gold London
	Calculate the net work done on an object by applying the definition of work to each force acting on the object while it is being displaced, and then adding up (scalar) each contribution	AC W4 Greater velocity greater work done	Gold
	Positive net work done on a system will increase the energy of the system and negative net work done on the system will decrease the energy of the system	AC W5 More force more work	Ann Jasmine Blue
		AC W6 Work must be done on an object to keep it in motion	Ann Gold Timber Jasmine Blue
		AC W7 Positive force positive work and negative force negative work	Patience London Blue

<b>Topics</b> <b>Grade 12:</b> <b>Intended</b> <b>Object of</b> <b>Learning</b> <b>Work</b> <b>Energy</b>	<b>Critical Features of the</b> <b>Intended Object of Learning:</b> <b>Content, Concepts &amp; Skills</b> <b>(DBE, 2011, pp. 117-120)</b>	<b>Lived Object of Learning:</b> <b>Evidence of Alternative Conceptions</b>	
		<b>Alternative Conception</b>	<b>Learners holding this AC</b>
Work - Energy Theorem	Know that the net work done on an object causes a change in the object's kinetic energy - the <i>work-energy theorem</i> - $W_{\text{net}} = E_{\text{kf}} - E_{\text{ki}}$ Apply the work-energy theorem to objects on horizontal and inclined planes (frictionless and rough)	AC W1 Work and net work can be used interchangeably	Gold London
		AC W2 WET does not apply to accelerating objects	Jasmine
		AC W6 Work must be done on an object to keep it in motion	Ann Gold Timber Jasmine Blue

<b>Topics</b> <b>Grade 12:</b> <b>Intended</b> <b>Object of</b> <b>Learning</b> <b>Work</b> <b>Energy</b>	<b>Critical Features of the</b> <b>Intended Object of Learning:</b> <b>Content, Concepts &amp; Skills</b> <b>(DBE, 2011, pp. 117-120)</b>	<b>Lived Object of Learning:</b> <b>Evidence of Alternative Conceptions</b>	
		<b>Alternative Conception</b>	<b>Learners holding this AC</b>
Conservation of energy with non-conservative forces present.	Define conservative forces and give an example Define non-conservative forces and give examples Know that when only conservative forces are present, mechanical energy is conserved Know that when non-conservative forces are present mechanical energy (sum of kinetic and potential) is not conserved, but total energy (of the system) is still conserved Solve conservation of energy problems (with dissipative forces present) using the equation:	AC W3 Work by gravitational force is dependent on the path taken	Ann Patience Gold Timber
	$W_{nc} = \Delta E_k + \Delta E_p$ Use the above relationship to show that in the absence of non-conservative forces, mechanical energy is conserved	AC E4: A change in mechanical energy depends only on changes in velocity and not on changes in height	Gift

These seven alternative conceptions about work indicate a significant discrepancy between the intended object of learning and the lived object of learning. I will discuss AC W1 and AC W7 in detail as examples. Two out of the eight learners, Gold and London, articulated the alternative conception *AC W1 Work and net work can be used interchangeably*. This AC was articulated as the learners answered questions 10.2 and 10.3.

The question required learners to state whether the net work done on a box was positive, negative or zero when its velocity changed from  $-1\text{m}\cdot\text{s}^{-1}$  to  $1\text{m}\cdot\text{s}^{-1}$ . In line 567 of his TAP London said that work was needed to change the direction of motion of the box, and he is correct. His error was that in lines 575-577 he concludes that the work done being positive meant that the net work done was also positive. He could not distinguish between work done and net work done indicating that he could not discern the critical features that distinguish these two concepts. According to the intended object of learning shown in Table 6.9 he also failed to equate the net work done to the change in kinetic energy.

564 *so it changed from the negative direction to the positive direction*

565 *the work may not be positive,*

566 *the work was done.*

567 *Yes the work was done because work was needed to change direction here*

573 *if my velocity is negative and I go reverse to the right my work is positive (AC about relationship between velocity and work)*

574 *so OK*

575 *having work positive*

576 *net work done.*

577 *It will be a positive net work done*

Three of the eight learners, Patience, London and Blue, articulated the alternative conception *AC W7 Positive force positive work and negative force negative work*. Patience, London and Blue articulated this alternative question as they answered Q6, Q10.1.2 and Q10.3 respectively. It seems like these learners do not understand what is positive work and negative work. They are confusing the direction of the force that is doing the work with the positive and negative nature of work done. This shows that the learners are not aware of the critical feature of work being the angle between the force and the displacement that determines the nature of the work done. As an example, Q6 probed the understanding of work and its dependence on variables like time, distance, displacement and force. Patience chose option D as the correct answer. Option D stated that “The work done on the ball by the gravitational force is negative as it falls”. In her explanation Patience decides that the work done on the falling ball is negative because the gravitational force is negative. She fails to see and apply the critical feature which is

the angle between the force doing the work in the direction of motion and the displacement. This is a requirement in the intended object of learning as shown in Table 6.9. This shows a clear discrepancy between the intended object of learning and the lived object of learning. Patience explained her choice in lines 143-145 of her TAP wherein she articulates this alternative conception:

*143 The work done on the ball, the work done on the ball by the gravitational force, the work done. The work done on the ball by the gravitational force is negative as it falls.*

*144 This is because at at the the the the gravitational force will be negative*

*145 and then you know this means that it's the work. OK let me see.*

Five of the eight learners (62.5%) articulated the alternative conception *AC W6 Work must be done on an object to keep it in motion* in their TAPs. Ann, Gold, Timber, Jasmine, and Blue articulated this alternative conception as they answered Q4. Only one learner, London, was able to answer Q4 correctly. This question probed the learners' understanding of net work done which is a topic in the intended object of learning. The five learners who articulated alternative conception *AC W6* have shown that they do not understand the critical feature of the work energy theorem, namely that the net work done on an object is equal to the change in kinetic energy of that object. One of the given data in the question is "the box moves at constant velocity from position A to position B". This given information implies that the change in kinetic energy of the box is zero which further implies that the net work done on the box is zero. Since there are only two forces frictional force and the applied force that act on the box when it is in motion, the sum of the work done by these two forces should be zero. Hence, the work done by the two forces should be equal in magnitude. Furthermore, since  $F_A$  is acting in the same direction as the displacement it is positive work and since  $F_k$  is acting in the opposite direction to the displacement of the box it is negative work. However, the 7 learners who got this question wrong did not follow the above line of argument. Instead, they expressed a belief that work must be done on the box since it is in motion. Although all five learners expressed this alternative conception about work their choice of option were not the same. Ann and Jasmine chose option C which stated, "The total work done on the box by the net force is nonzero". Gold and Timber chose option E which stated, "The magnitude of  $F_A$  is greater than the magnitude of  $F_k$ ". Line 35 in the TAP of Blue shows that she believes that work

must be done on the box to keep it in motion, and she therefore believes that there must then be a force doing this work. She therefore chooses option E, and she rejects option D which is the correct option.

*36 I'm gonna cross out D because the magnitude of the work done by the applied force cannot (unclear) energy equal to the work done by the  $F_k$ , because the box moving in the direction of the applied force so means that  $F_k$  is virtually ... (unclear) ... mmm the greater work done than  $F_k$ .*

Ann on the other hand selected option C and she articulated her understanding in lines 44-45 of 45:

*44 Er for option C the total work done on the box by the net force is nonzero.*

*45 So I think it must it can be nonzero because there is the net force is the one that enables the block to move to the right.*

Neither Ann nor Blue realised that options C and E referred to the same incorrect point that is: There is a net force acting on the block in the same direction of its displacement therefore the total (net) work done on the box is non-zero. Both the options C and E are incorrect.

### **6.3.3.2 Analysis of alternative conceptions about energy**

Table 6.10 presents an analysis showing the prevalence of alternative conceptions about energy that learners hold. According to Table 6.11 four alternative conceptions about energy has emerged from the TAPs of the eight learners. The four alternative conceptions about energy are AC E1, AC E2, AC E3 and AC E4. Four of the eight learners (50%) in the sample have articulated at least one alternative conception about energy as shown in Table 6.12. These alternative conceptions are about kinetic energy, mechanical energy which is the sum of kinetic and potential energy and the conservation of mechanical energy.

**Table 6.10: Prevalence of alternative conceptions about energy**

Topic	Learner	Question Number for AC	Question Number for CF
Energy	Ann		Q6, Q10.1.1, Q10.1.2, Q10.3, Q13.3
	Patience	Q6	Q3, Q8
	Gift	Q6, Q8	Q4, Q10.1.1, Q10.2
	Gold	Q10.1.1, Q10.1.2, Q10.3	Q3, Q4, Q6, Q9.1, Q12, Q13.2, Q13.3
	London		Q3, Q5, Q6, Q8, Q9.1, Q12, Q10.1.2, Q13.3
	Timber	Q13.3	Q6, Q10.1.2
	Jasmine		Q6, Q8, Q10.1.1
	Blue		Q6, Q8, Q10.1.1, Q10.1.2

Table 6.11 presents a further analysis of this prevalence of alternative conceptions about energy based on Variation Theory as a Theoretical Framework. The topics and critical features of concepts relevant to mechanical energy have been lifted from DBE (2011, pp. 58, 59, 117-119) and presented as the intended object of learning in Table 6.11.

The alternative conceptions of learners that emerged from the TAPs of the eight learners in the sample were tabled as the lived object of learning and analysed against the intended object of learning.

The topics kinetic energy, potential energy, mechanical energy and the conservation of mechanical energy were first introduced in Physical Sciences in Grade 10 (DBE, 2011, pp. 58, 59). The conservation of mechanical energy that was in the Grade 10 curriculum excluded non-conservative forces, but in Grade 12 it included non-conservative forces. Mechanical work and the work energy theorem were introduced for the first time in Grade 12 (DBE, 2011, pp. 58, 59, 117-119).

Four of the eight learners (50%) expressed alternative conceptions about energy as shown in Table 6.11. Patience, Gift, Gold and Timber expressed alternative conceptions about

energy. One learner, Gold, articulated the alternative conception *AC E1: Change in velocity equals change in kinetic energy* as she answered Q10 in her TAP. Two learners, Patience and Gift, stated the alternative conception *AC E2: Kinetic Energy and mechanical energy of an object decreases as it falls freely* as they answered Q6 in their TAPs. One learner, Timber, believed that *AC E3: Mechanical energy is conserved in the presence of non-conservative forces*, and he used this belief as he answered Q13.3. One learner, Gift, inferred that *AC E4: A change in mechanical energy depends only on changes in velocity and not on changes in height*, as he answered Q8.

**Table 6.11: Analysis of learner responses on Energy based on Variation Theory**

Topics Grade 12: Intended Object of Learning Work Energy	Critical Features of the Intended Object of Learning: Content, Concepts & Skills (DBE, 2011, pp. 117-120)	Lived Object of Learning: Evidence of Alternative Conceptions	
		Alternative Conception	Learners holding this AC
Work - Energy Theorem	<p>Know that the net work done on an object causes a change in the object's kinetic energy</p> <p>- the <i>work-energy theorem</i> -</p> $W_{\text{net}} = E_{\text{kf}} - E_{\text{ki}}$ <p>Apply the work-energy theorem to objects on horizontal and inclined planes (frictionless and rough)</p>	AC E1: Change in velocity equals change in kinetic energy	Gold
Conservation of energy with non-conservative forces present.	<p>Define conservative forces and give an example</p> <p>Define non-conservative forces and give examples</p> <p>Know that when only conservative forces are present, mechanical energy is conserved</p> <p>Know that when non-conservative forces are present mechanical energy (sum of kinetic and potential) is not</p>	AC E2: Kinetic Energy and mechanical energy of an object decreases as it falls freely	Patience Gift
		AC E3: Mechanical energy is conserved in the presence of non-conservative forces	Timber

Topics Grade 12: Intended Object of Learning Work Energy	Critical Features of the Intended Object of Learning: Content, Concepts & Skills (DBE, 2011, pp. 117-120)	Lived Object of Learning: Evidence of Alternative Conceptions	
		Alternative Conception	Learners holding this AC
	<p>conserved, but total energy (of the system) is still conserved</p> <p>Solve conservation of energy problems (with dissipative forces present) using the equation:</p> $W_{nc} = \Delta E_k + \Delta E_p$ <p>Use the above relationship to show that in the absence of non-conservative forces, mechanical energy is conserved</p>	<p>AC E4: A change in mechanical energy depends only on changes in velocity and not on changes in height</p>	<p>Gift</p>

One of the critical features of the object of learning Energy presented in Table 6.11 is that the net work done on an object is equal to its change in kinetic energy. One of the eight learners, Gold, articulated the alternative conception *AC E1: Change in velocity equals change in kinetic energy* as she answered Q10. Gold demonstrated in Q10 that she believes that the change in velocity equals change in kinetic energy. This clearly shows that at least for this learner there is a discrepancy between the intended object of learning and her lived object of learning. This is what she said in lines 233-238 of her TAP, as she answered Q10.1.2 where she was required to state whether the work done on a box was positive, negative or zero as its velocity changed from  $-4\text{m}\cdot\text{s}^{-1}$  to  $-1\text{m}\cdot\text{s}^{-1}$ :

233 *So from 4 minus 4 meters per second to 1 meters so initial think it increased by*

234 *its minus 1 minus 4 (-1-4)*

235 *so final - initial.*

236 *So minus negative 4. Minus negative 4.*

237 *So it increased by three.*

238 *Yes it increased.*

Another critical feature of the intended object of learning Energy, is that the mechanical energy of an object in free fall is conserved and this is presented in Table 6.11. Furthermore, in Table 6.11 the critical feature “Know that when only conservative forces are present, mechanical energy is conserved” is stated in the object of learning which is Energy (DBE, 2011, p. 119). When an object is in free fall  $\Delta E_p = -\Delta E_k$  which is stating that the loss in kinetic energy is equal to the gain in potential energy. This results in  $E_m = E_p + E_k$  being conserved. Patience and Gift have demonstrated a discrepancy between this intended object of learning with their lived object of learning. Patience demonstrates in lines 131-134 of her TAP that she is not even considering this transformation of energy from potential to kinetic as the object is in free-fall.

131 *You drop a ball from a higher tower as it falls freely under the influence of the gravitational force. Which one of the following statements is true?*

132 *Kinetic energy of the ball, kinetic as it falls.*

133 *Oh as an object falls velocity decreases meaning that kinetic energy also decreases.*

134 *So I don't, it's it's negative as it falls.*

In lines 148 to 159 Patience goes on to say that the velocity of the ball decreases as it falls and therefore the mechanical energy decreases. She is not applying the principle of conservation of mechanical energy to solve this problem showing a clear mismatch between the intended object of learning and her lived experience of this object. She also does not mention anything about the potential energy of the ball and its relationship with the kinetic energy of the ball.

148 *The total mechanical energy of the ball decreases as it falls.*

149 *So the total mechanical energy of the ball,*

- 150 *this is because as as as the the ball gets down the velocity decreases*
- 151 *and thus the total mechanical energy of the ball will decrease.*
- 152 *The height also I thi, the height also decreases,*
- 153 *so I think as it goes down it will be like  $m g h$  plus half  $m v$  squared,*
- 154 *so it will be like the mass will stay constant*
- 155 *because the height will decrease as it falls, so as the height decreases, so as the height decreases the*
- 156 *the velocity also decreases, so it falls as if free fall so that that is why,*
- 157 *let me make it.*
- 158 *The answer maybe  $E$ , the total mechanical energy of the ball decreases as it falls.*
- 159 *Ughm ughm.*

One learner, Timber, used the principle conservation of mechanical energy where non-conservative forces were present suggesting AC E3: *Mechanical energy is conserved in the presence of non-conservative forces*. In Q13.3 learners were asked to use energy principles to calculate the speed of a 6 kg block when it fell through 1.6m while still attached to a 4 kg block that was placed on a rough horizontal surface. The two blocks were attached by a light inextensible string passing over a pulley. In this question there were two non-conservative forces Tension and friction, but Timber still decided to use the principle of conservation of mechanical energy to solve the problem. This shows a clear discrepancy between the intended object of learning and the lived object of learning at least for Timber. Lines 631-642 of his TAP shows this discrepancy.

- 631 *So I'm going to use the mechanical energy to find the velocity at which the block drops to the ground.*
- 632 *Yep.*
- 633 *So after finding my tension*
- 634 *I use the mechanical energy formula to calculate my velocity.*
- 635 *Since I knew that my initial velocity was zero*
- 636 *(Recall that earlier he said that acceleration is zero in line 608).*
- 637 *The formula says  $m g h$  initial plus*
- 638 *oh OK*

639 *the potential energy initial plus the kinetic energy initial is equal to the potential energy final plus the final kinetic energy ( $E_{pi} + E_{ki} = E_{pf} + E_{kf}$ ).*

640 *After calculating I found out that my velocity is five point six meters per second ( $v = 5,6 \text{ m}\cdot\text{s}^{-1}$ )*

641 *and I trust that my answers*

642 *I believe I'm right.*

Gift showed in his TAP as he answered Q8 that he believes that AC E4: *A change in mechanical energy depends only on changes in velocity and not on changes in height.* This shows that he does not understand the critical features of energy especially those pertaining to gravitational potential energy of an object. He seems to indicate in lines 118 to 122 of his TAP that since the height of the hill is constant then it does not affect the mechanical energy of the car that is driving uphill. He fails to see that there is a change in the potential energy of the car as it drives uphill because its height is changing. There is a mismatch between the intended understanding of potential energy as shown in Table 6.11 and the lived object as experienced by Gift.

118 *so en in scenario 2 since the car moves in a constant velocity then the acceleration of the car its zero.*

119 *The constant velocity in fact is that the initial velocity and the final velocity remains the same throughout which means the change in velocity of the car its zero.*

120 *Thus the mechanical energy before will be equal to mechanical energy after, since height does not affect.*

121 *The is not the main factor that could make err the mechanical energy not to be conserved.*

122 *The height will remain unchanged of the hill and I would say the height is constant. It doesn't affect that.*

### **6.3.3.3 Analysis of alternative conceptions about power**

Table 6.12 presents an analysis showing the prevalence of alternative conceptions about power that learners hold. According to Table 6.13 three alternative conceptions about power has emerged from the TAPs of the eight learners. The three alternative conceptions

about are AC P1, AC P2 and AC P3. Six of the eight learners (75%) in the sample have articulated at least one alternative conception about power as shown in Table 6.12. Alternative conception is recorded as AC P1: *More Power is expended where more energy or work is needed or where more difficulty is experienced*. This alternative conception about power is about how much power is required. The remaining two of these alternative conceptions are about the relationship between power and work (AC P2) and between power and time (AC P1).

**Table 6.12: Prevalence of alternative conceptions about power**

Power	Ann	Q9.2	Q11.1
	Patience	Q9.2	Q11.1
	Gift	Q9.2	Q2, Q9.2, Q11.1
	Gold	Q9.2	Q9.2, Q11.1
	London		Q2, Q9.2, Q11.1
	Timber		Q11.1
	Jasmine	Q9.2	Q11.1
	Blue	Q9.1, Q9.2	Q2, Q9.2, Q11.1

Table 6.13 presents a further analysis of this prevalence of alternative conceptions about Power based on Variation Theory as a Theoretical Framework. The topics and critical features of concepts relevant to power have been lifted from DBE (2011, p. 120) and presented as the intended object of learning in Table 6.13. The alternative conceptions of learners about power that emerged from the TAPs of the eight learners in the sample were tabled as the lived object of learning and analysed against the intended object of learning.

The topic power was first introduced in Physical Sciences in Grade 11 (DBE, 2011, p. 89) in the broad knowledge area Electricity and Magnetism. Electrical power was discussed in Grade 11. Mechanical power was first introduced in Physical Sciences in Grade 12 (DBE, 2011, p. 120). I have not included electrical power in this analysis as the focus of this study is Work Energy and Power in the broad knowledge area Mechanics.

The analysis presented in Table 6.13 shows that all the alternative conceptions about power that emerged from the TAPs were articulated by the learners as they answered Q9.2. Only Blue articulated this alternative conception as she answered both Q9.1 and Q9.2. Q9.2 required the learners to state which of two people of equal masses, a climber and hiker, expended more power in climbing to the top of a mountain after having started from the foot of the mountain and having travelled different routes.

Six of the eight learners (75%) expressed alternative conceptions about power that is presented in Table 6.13. Ann, Patience, Gift, Gold, Jasmine and Blue expressed alternative conceptions about power in their TAPs. One learner (12.5%), Gold, articulated the alternative conception *AC P1: More Power is expended where more energy or work is needed or where more difficulty is experienced*, as she answered Q9.2 in her TAP. Two learners (25%), Jasmine and Blue, stated the alternative conception *AC P2: Work alone determines power irrespective of time*, as they answered Q9.2 in their TAPs. Blue also articulated alternative conception *AC P2* as she answered Q9.1. Three learners (37.5%), Ann, Patience and Gift believed that *AC P3: Time alone determines power irrespective of work*, and they used this belief as they answered Q9.2.

**Table 6.13: Analysis of learner responses on Power based on Variation Theory**

Topics Grade 12: Intended Object of Learning Power	Critical Features of the Intended Object of Learning: Power Content, Concepts & Skills (DBE, 2011, p. 120)	Lived Object of Learning: Evidence of Alternative Conceptions	
		Alternative Conception	Learners holding this AC
Power	Define power as the rate at which work is done Calculate the power involved when work is done Understand the average power required to keep an object moving at a constant speed along a rough horizontal surface or a rough inclined plane and do calculations using $P_{av}=Fv_{av}$ Calculate the minimum power required of an electric motor to pump water from a borehole of a particular depth at a particular rate using $W_{nc}=\Delta E_k + \Delta E_p$ Recommended practical investigation for informal assessment: Perform simple experiments to determine the work done in walking up (or running up a flight of stairs). By timing the run and walk (same flight of stairs) one can enrich the concept of power Materials for practical activity: Flight of stairs, stopwatch, measuring tape (5m) or meter stick.	AC P1: More Power is expended where more energy or work is needed or where more difficulty is experienced	Gold
		AC P2: Work alone determines power irrespective of time	Jasmine' Blue
		AC P3: Time alone determines power irrespective of work	Ann Patience Gift

Gold articulated the alternative conception *AC P1 More Power is expended where more energy or work is needed or where more difficulty is experienced*, as she answered Q9.2. She was the only learner out of the eight learners who articulated this alternative conception about power. On analysing her TAP, it is observed that although she states the definition of power in lines 195 to 196, she does not apply this definition as she finds her

solution to the question, her solution being incorrect. Instead, she articulates her belief that since the climber took a harder route, he needed more power and therefore she chose the climber as having expended more power. She does not consider the work done, and the time taken as is required by the definition of work which she articulated while answering this question. This evidence shows clearly that there is a discrepancy between the intended object of learning and Gold's lived object of learning.

195 *So power is the rate of work done.*

196 *Is the the rate of work done on an object.*

...

202 *He needs more work he needs more power (In Q9.1 she said that the hiker does more work)*

203 *because his route is more difficult.*

204 *And therefore he requires a lot of energy.*

205 *Yeh he requires a lot of energy in order to be able to do work.*

206 *Yes I think its the the climber.*

207 *Because his road his route er pps was difficult was er his route was difficult.*

208 *His route was difficult and*

209 *therefore and therefore had and therefore required required err lots energy energy to do the work.*

210 *Required a lot of energy to do the work per given time.*

Five learners, Jasmine, Blue, Ann, Patience and Gift articulated alternative conceptions about power that relate to understanding the relationship between power and both work done, and time taken. On the one hand, Jasmine and Blue articulated the alternative conception *AC P2: Work alone determines power irrespective of time*. Jasmine and Blue only considered the work done and did not consider the effect of the duration of the work done when comparing the power expended by the hiker and the climber. On the other hand, Ann, Patience and Gift articulated the alternative conception *AC P3: Time alone determines power irrespective of work*. Ann, Patience and Gift only considered the time taken and did not consider the effect of the work done when comparing the power expended by the hiker and the climber. Both the alternative conceptions AC P2 and AC P3 involve the equation for power:  $P = \frac{\text{Work done}}{\text{time taken}}$ . When comparing the power expended

by the hiker and the climber, all five learners did not consider the effect of both variables, work done, and time taken on power.

## **6.4 Results and Analysis: Focus Group Interview**

The focus group interview was conducted with 30 learners using a semi-structured interview schedule that was discussed in Chapter 4. During the focus group interview learners displayed both a good understanding and ACs regarding concepts involving WEP. The focus group interview also provided data on learners PSADs. Both the focus group transcription and my field notes were used as a source of data. One of the observations in my field notes was the “shaking of heads” in agreement or disagreement with another learner who was speaking. Shaking of the head from side-to-side was interpreted as a disagreement and the up-and-down shaking of the head was interpreted as an agreement. The sound “mm” was interpreted as an agreement and “ah ah” was interpreted as a disagreement with the learner who was speaking. This had been noted quite frequently in my field notes. The researcher interpreted these two body movements and sounds as an indication that the learner either agreed or disagreed with the learners who were verbalising their responses. The focus group transcript will be referred to as FGT. In the FGT the researcher is referred to as the interviewer. In Section 6.4.1 the results of the focus group interview are discussed. This is followed by section 6.4.2 where an analysis of the focus group interview is discussed.

### **6.4.1 Results: Focus Group Interview**

In the results that follow, the learners were referred to as Focus Group Learner 1, 2, 3, etcetera. As an example FGL1 refers to Focus Group Learner 1. The results are highlighted in bold in the paragraphs that follow.

**The topic WEP is difficult for a few learners but not so difficult for most learners in the focus group**

QB.2 required the learners to say whether they find the topic WEP easy or not. Some learners in the focus group interview said that they find the topic WEP difficult because

they have difficulty in applying it. This is articulated by FGL1 in lines 21 – 23 of the FGT given below:

19 *Interviewer: Okay, I want to ask you if you liked the topic work energy and power. Now those of you who don't like this topic work energy and power. You just don't like it. put up your hands. Okay* (Interviewer walks to one learner who had put her hand up).

20 *Interviewer: Yes. Why don't you like it?*

21 *FGL1: I fail to* (not clear)

22 *Interviewer: Speak loudly?*

23 *FGL 1: I I fail to understand to apply*

FGL2 who had her hand up indicating that she found the topic difficult says “*the whole thing*” is difficult in line 30 of the FGT.

Most of the learners had not put up their hands which was an indication that they did not find the topic WEP insurmountable. However at least a third of the learners had put their hand up indicating that they found the topic WEP difficult. Many of these learners shook their heads in agreement as FGL1 indicated that she found the topic difficult and she gave her reason in line 23 of the FGT: “I fail to understand to apply”.

### **Work is defined by the formula $W = F\Delta x \cos\theta$**

Question B.3 required the learners to state what is work. In response, the learners in the focus group identified work with the formula  $W = F\Delta x \cos\theta$  in answering the question “What is work”. In response to this question “What is work” some of the learners immediately focus on the formula for work and not on any qualitative description of the concept. This is evidenced by learner FGL11 in lines 96-106 of the FGT.

96 *FGL11: Okay. I think work is the force that's appl that's applied to an object*

97 *Interviewer: Mm*

98 *FGL11: and causes it to move in a in a in a same direction.*

99 *Interviewer: Yes in what direction?*

100 FGL11: *the direction of the force*

101 Interviewer: *direction of the force*

102 FGL11: *yes*

103 Interviewer: *Yes. So you want to define work as er an equation*

104 FGL11: *I think its work equals to the force that's applied times the distance*

105 Interviewer: *Mm*

106 FGL11: *or the direction times cos and theta which is the angle and then the negative or the positive work that's done on the object*

### **Work and Energy are equivalent concepts**

Question B.4 required learners to state whether work and energy are equivalent concepts. In response, all the learners in the focus group indicated that work and energy are equivalent concepts as shown in lines 112-123 of the FGT given below:

112 Interviewer: *Okay. But we'll go on to the next question. Do you think work and energy are related concepts?*

113 Chorus (learners): *Mmm (meaning "yes")*

114 Interviewer: *Yes.*

115 Chorus (learners): *Mmm. Yes*

116 Interviewer: *Mm. Why? Why would you say its related? Put your hands up. What makes you think its related? Or how is it related? Mm?*

117 FGL11: *It's like when you apply force to an object you actually need energy to be able to to move that object, so they are related.*

118 Interviewer: *Okay*

119 FGL11: *Ya*

120 Interviewer: *Okay. Yes?*

121 FGL16: *And also er mm for you to understand er mm energy you have to understand work because er mm when you define energy you say the ability to do work. So you need to def to like understand the concept of work*

122 Interviewer: *Mm*

123 FGL16: *like there are more related, yes*

**Work is done by a force if there is displacement in the direction of the force**

Question B.5 required learners to explain how they would know that work is being done on an object. In response some of the learners indicated that work is done by a force on an object if there is displacement of the object in the direction of the force.

129 FGL17: *Change in position of the object. Change in position of the object.*

130 Interviewer: *Change in position of the object. So the object must move*

131 FGL17 and Chorus (learners): *Yes*

132 Interviewer: *But how?*

133 FGL17 and Chorus (learners): *In the direction of the force*

134 Interviewer: *Say it*

135 FGL17: *In the direction of the force*

**Work done by your hand on the ball after you throw it up in the air and the ball has left your hand: Some learners believe it is zero while others it is not zero.**

Question B.8 required learners to state whether the thrower's hand does any work on a ball that he throws upwards into the air, after the ball has left his hand. Some learners correctly stated that the work done on the ball by the hand after the ball has left the thrower's hand is zero, while others stated that work was being done by the thrower's hand. FGL11 clearly states this in line 151 of the FGT given below:

146 Interviewer: *Okay. Now, let's say I er throw something into the air mm? I throw a ball. Now I don't have a ball. Right. So I'm going to make a ball. (Interviewer squashes an A4 page into the shape of a ball). I have a ball right. I'm going to throw it in the air. You have this question in front of you (Each learner had been given a hardcopy of the semi-structured interview schedule). So what is the work done by your hand on the ball when the ball is in the air and moving upwards? In other words I throw the ball (Interviewer throws the paper ball vertically upwards in the air). Can you see the ball in the air?*

147 Chorus (learners): *Yes mam*

148 Interviewer: *Right. So when the ball is in the air and moving upwards*

149 FGL11: Mm

150 Interviewer: What is the work done by my hand on the ball?

151 FGL11: Zero

However, the reasoning provided by FGL11 for his correct answer that the work done is zero, is flawed as shown in line 155 of the FGT given in the paragraphs below.

**The applied force (exerted by the hand) on the ball is at  $90^{\circ}$  to the displacement**

In their response to QB.8 some learners also indicated that the angle between the applied force exerted by the thrower is at  $90^{\circ}$  to the displacement of the ball. FGL8 and FGL11 articulate this in lines 155 and 161 of the FGT given below:

152 Interviewer: Yes you said? You said zero?

153 FGL11: Mm (meaning yes)

154 Interviewer: Mm? You said?

155 FGL11: I said. I think its zero because the force that is applied on the ball its in the same direction as its displacement. So it means the angle between the force and the the force applied and the displacement of the of the ball is ninety degrees. So when using the formula to calculate the work done then its zero.

156 Interviewer: Then its zero. Okay that's what she says that the angle is ninety degrees between the force and the

157 FGL8: 11

158 Interviewer: motion

159 FGL8: I also think that its zero.

160 Interviewer: Why would you think its zero?

161 FGL8: Er. As she said like they they are acting in the same direction, so the angle between will be ninety degrees

**The only force acting on the ball after it has been thrown upwards into the air is the gravitational force**

Included in their response to QB.8 some learners, but not all, correctly stated that the only force acting on the ball after it has been thrown and has left the thrower's hand is the gravitational force in the absence of friction. FGL10 clearly states this in lines 171-173 of the FGT:

*171 FGL10: I think no work is done on the ball.*

*172 Interviewer: Yes? Why?*

*173 Learner 10: Since when the ball is in the air the only force acting on it is in the gravitational force*

It seemed like only nine learners confidently agreed with FGL10 that the only force acting on the ball after it has left the thrower's hand is the gravitational force as shown in lines 178-180 of the FGT.

*178 Interviewer: So the force is zero by your hand, it's not in contact. So the work is zero (Interviewer summarises what FGL10 has said). How many of you agree with him? Put your hands up. Okay. Just one two three four five six okay seven eight nine. So the rest of you disagree with him. You think that there is work done by my hand. When the ball is in the air, is my hand exerting a force on the ball?*

*179 Chorus (learners): No. No*

*180 FGL15: They do. When you say direction like when you throw it in the air*

FGL15 explains why she thinks that the only force acting on the ball after it has left the thrower's hand and is in the air is that "it's in free fall" and "it becomes a projectile", as shown in lines 188 and 190 of the FGT.

*184 FGL15: Zero*

*185 Interviewer: Why zero?*

*186 FGL15: Because like as he said aikere (word in Sepedi) like when the ball is in the air*

187 Interviewer: *Uhhh*

188 FGL15: *Like it's it's in free fall*

189 Interviewer: *Mmm*

190 FGL15: *I think it becomes a projectile immediately you you throw it in the air so your hand I think It's just non-existent towards the ball*

### **Force of gravity does negative work on an object as it is moving vertically upwards**

QB.13 required the learners to state whether the force of gravity does work on a ball that is moving vertically upwards in the air, after it has been thrown. It also required learners to state whether this work is positive or negative. Most of the learners in the focus group seem to agree that the force of gravity does negative work on an object as it moves upwards as shown in lines 316 to 327 of the FGT given below:

316 Interviewer: *Do you think gravity is doing any work on this ball if I throw it in the air as its moving upwards? (Interviewer throws the paper ball vertically upwards into the air).*

317 Chorus (learners): *yes*

318 Interviewer: *Why would you say gravity is doing work on it? Yes?*

319 FGL21: *Because the ball will eventually stop when it reaches the top, its maximum point*

320 Interviewer: *Repeat that. Because the ball*

321 FGL21: *the ball will eventually stop when it reaches the top, its maximum point*

322 Interviewer: *And then?*

323 FGL21: *and then it goes down again*

324 Interviewer: *And what's bringing it down?*

325 FGL21: *the force of gravity.*

326 Interviewer: *Force of gravity okay. Because the ball will eventually stop (Interviewer summarises what FGL21 has said). So when the ball is moving up is the work done by gravity positive or negative on the ball, when it is moving upwards?*

327 Chorus (learners): *negative*

### **Kinetic Energy is always positive**

QB.14 required the learners to state whether kinetic energy can ever be negative or not. Most of the learners seemed to agree correctly that kinetic energy is always positive as shown in lines 337-350 of the FGT given below:

337. *Interviewer: Do you think kinetic energy can ever be negative?*

338. *Chorus No (unclear)*

339. *Interviewer: Eh? No?*

340. *FGL14: No*

341. *Interviewer: Why no?*

342. *Chorus (learners): (unclear)*

343. *Interviewer: Why would you say no?*

344. *FGL13: No. I think maybe if you take it as a as a formula, because*

345. *Interviewer: Ya*

346. *FGL13: its half  $m v$  squared*

347. *Interviewer: Mm*

348. *FGL13: So when you you you substitute, there is a squared there so eventually there won't be a negative. You will never get a negative.*

349. *Interviewer: Mm. She says if you look at the formula its half  $m v$  squared.*

350. *FGL13 and chorus (learners): Mm (meaning "yes")*

### **Potential Energy is always positive**

QB.15 required the learners to state whether potential energy can ever be negative or not. Most of the learners incorrectly stated that potential energy is always positive. Some learners don't believe this but they were unable to explain why. This is shown in lines 352-364 of the FGT given below:

352. *Interviewer: Can potential energy ever be negative?*

353. *FGL13 and Learner 24: No mam. No*

354. *Interviewer: No. Why?*

355. *FGL24: I. First. I think because er aikere (word in Sepedi) for the potential energy is mgh mass and gravitational and height. So there is, height will never be negative*
356. *Interviewer: Mm*
357. *FGL24: and also*
358. *Interviewer: Mm*
359. *FGL24: the the the gravitational force I think its since its constant is positive ne, and ai there mass obviously is always positive. So I will I wouldn't think hore (word in Sepedi) er the the potential energy will ever be negative.*
360. *Interviewer: You agree with him that potential energy can never be negative?*
361. *FGL9: [00:29:14] No*
362. *FGL6: [00:29:16] yes yes*
363. *FGL9: [00:29:17] like*
364. *Interviewer: [00:29:18] Mm (but Learner 9 doesn't say more)*

**Problem Solving: Work done on object moving at constant velocity on frictionless horizontal floor**

The interviewer added the following question to QB.17.1: A box of 20kg is sliding across a frictionless horizontal floor at a constant velocity. Will the box continue moving like this forever?

Some learners stated that the box will continue moving forever at constant velocity under frictionless conditions on the horizontal floor while others said no, as shown in lines 448-457 of the FGT given below:

449. *Chorus (learners): no*
450. *Interviewer: [00:40:11] if there is no friction? I pushed it and I left it. Will it continue moving forever?*
451. *FGL8 and chorus: yes no (some say yes and some say no)*
452. *Interviewer: under frictionless conditions?*
453. *Chorus (learners): yes*
454. *Interviewer: [00:40:20] mm?*
455. *FGL6: yes*

456. *Interviewer: yes or no?*

457. *FGL5 and learner 11: yes. definitely yes.*

**Problem Solving: Work done is zero if there are no forces acting on an object**

Question B.17 stated: A box of mass 20 kg is sliding across a frictionless horizontal floor at a constant velocity of  $1\text{m}\cdot\text{s}^{-1}$ . Question B17.1 stated: Is any work being done on the box? Some of the learners in the focus group correctly stated that the work done on the box is zero since there are no forces acting on it as demonstrated in lines 469-475 of the FGT given below:

469. *FGL11: [00:41:11] no*

470. *Interviewer: [00:41:14] Yes?*

471. *FGL5: [00:41:15] No*

472. *Interviewer: [00:41:16] No. Why would you say no?*

473. *FGL5: [00:41:17] There is no force will be applying*

474. *Interviewer: [00:41:19] There's no forces acting on it.*

475. *FGL5: [00:41:21] Ya and its moving*

**Problem Solving: Calculating work done when force and displacement are not given: Some learner's try to use the plug-and-chug-trial.**

Question B.17.2 stated: A box of mass 20 kg is sliding across a frictionless horizontal floor at a constant velocity of  $1\text{m}\cdot\text{s}^{-1}$ . Question 17.2 stated: Thato now exerts a constant horizontal force of magnitude  $x$  on the box in the direction opposite to its motion, stopping the box. Is the work done by Thato on the box positive or negative? Can you tell what amount of work done by Thato is? Explain your answer.

None of the leaners in the focus group could answer this question. Only FGL8 offered an attempt at a solution as shown in lines 488-498 of the FGT given below:

488 *FGL8: Right. Yes.*

489 *Interviewer: If, yes?*

490 FGL8: *Ughm. The amount of work done by Thato*

491 Interviewer: *Mm*

492 FGL8: *will be equal to the force applied by Thato which is x*

493 Interviewer: *Mm*

494 FGL8: *multiply by the distance it takes for the box to stop*

495 Interviewer: *Mm*

496 FGL8: *multiply by the cos of one hundred and eighty degrees since it is in the opposite direction*

497 Interviewer: *Mm*

498 FGL8: *of motion.*

But FGL8 could not complete the problem and reach a solution indicating that she got “stuck” in the problem-solving process. Her plug and chug (PACT) approach required the values for force and displacement which are not given in the question. None of the learners in the focus group could provide a solution to the problem. One approach to solving this problem is in applying the WET. The net work done on the box to bring it to a stop equals the change in its kinetic energy:  $W_{net} = \Delta E_k$ . All the learners failed to be aware of this at the time of answering this question.

#### **6.4.2 Analysis and Discussion: Focus Group Interview**

There was a total of 17 questions in the semi-structured interview schedule. For QB.1 and QB.2 there were no right or wrong answers as these questions focused on how learners felt about the topic WEP. Some of the learners stated that they don’t like the topic WEP because it is very difficult. However, about a third of the learners had indicated that they like the topic WEP but that they find difficulty in applying the concepts to problems. The remaining responses to questions were categorized as correct or incorrect responses. Table 6.14 presents an analysis of the learners’ responses to questions in the semi-structured focus group interview schedule.

**Table 6.14: Correct and incorrect responses in focus group interview**

Grade 12: Intended Object of Learning Work Energy	Critical Features of the Intended Object of Learning: Content, Concepts & Skills (DBE, 2011, pp. 117-120)	Lived Object of Learning: Evidence of Understandings		
		Quest	Correct	Not Correct
Definition of Work and net work	Define the work done on an object by a force as: $W=F\Delta x\cos\theta$ . Know that work is a scalar quantity and is measured in joules (J) Calculate the net work done on an object by applying the definition of work to each force acting on the object while it is being displaced, and then adding up (scalar) each contribution Positive net work done on a system will increase the energy of the system and negative net work done on the system will decrease the energy of the system	3, 4, 5, 6, 7, 9, 11, 16, 13	√	
		8, 12	√	√
		17		√
Work - Energy Theorem	Know that the net work done on an object causes a change in the object's kinetic energy - the <i>work-energy theorem</i> - $W_{\text{net}} = E_{\text{kf}} - E_{\text{ki}}$ Apply the work-energy theorem to objects on horizontal and inclined planes (frictionless and rough)	4, 10, 11, 14	√	
		15	√	√
		17		√
Energy	Define Kinetic Energy. Define Potential Energy. Define conservative forces and give an example. Define non-conservative	8, 13,15	√	√

Grade 12: Intended Object of Learning Work Energy	Critical Features of the Intended Object of Learning: Content, Concepts & Skills (DBE, 2011, pp. 117-120)	Lived Object of Learning: Evidence of Understandings		
		Quest	Correct	Not Correct
Conservation of energy with non-conservative forces present.	forces and give examples. Know that when only conservative forces are present, mechanical energy is conserved. Know that when non-conservative forces are present mechanical energy (sum of kinetic and potential) is not conserved, but total energy (of the system) is still conserved. Solve conservation of energy problems (with dissipative forces present) using the equation: $W_{nc} = \Delta E_k + \Delta E_p$ Use the above relationship to show that in the absence of non-conservative forces, mechanical energy is conserved	10, 14, 16	√	
		17		√

According to the analysis presented in Table 6.14 some of the questions in the semi-structured interview schedule elicited only correct responses from the learners in the focus group. These were Questions B3, B4, B5, B6, B7, B9, B10, B11, B14 and B16. Questions B.8, B.12, B.13 and B.15 had elicited correct responses from some learners and incorrect responses from some learners. Question 17 elicited no correct response from any learner. It is also shown in the analysis in Table 6.14 that the responses to most of the questions during the focus group interview were correct.

The responses to 10 of the questions indicated that at least some of the learners have an understanding of some concepts on WEP that is in line with the intended object of learning. Some learners displayed an acceptable understanding of the concept of work, work done by the gravitational force, and kinetic energy. However, the responses to the remaining questions show that learners don't have a good understanding of some of the concepts involving WEP.

Question 8 dealt with a very common question regarding the work done by the thrower's hand on a ball after the ball has left the thrower's hand and is moving vertically upwards in the air. Some learners indicated that the work done by the thrower's hand is zero but their reasoning was incorrect. The reason given was that the angle between the force acting on the ball and the displacement of the ball was  $90^\circ$  and therefore  $W = F\Delta x \cos 90^\circ = 0$ , since  $\cos 90^\circ = 0$ . This was incorrect. This response is similar to the ACW1: Angle between force of gravity and displacement as an object falls downwards is  $180^\circ$  or  $90^\circ$  displayed by some learners in the sample of NSC scripts, discussed in Chapter 5. Some of the remaining learners correctly stated that the work done by the thrower's hand is zero, since the only force acting on the ball while it is moving vertically upwards in the absence of friction is the gravitational force. However, only 9 of the 30 learners indicated that they agreed with this reasoning. This finding is in line with Neidorf et al. (2020) who found that 25% of the learners in their sample "demonstrated a related misconception by not identifying gravity as a force that acts on a stone after it is thrown straight up in the air". It has been found that some learners still believe that the thrower's hand is doing work on the ball after it has left the thrower's hand.

When faced with unfamiliar questions some learners resort to the PACT problem solving approach that fails to reach a solution, as was demonstrated by FGL8 as she answered Question 17.2 of the focus group interview schedule.

Many learners in the focus group believed that potential energy is always positive while some did not believe this but they could not explain why. This belief probably stems from the curriculum that does not include the point of reference in the section that deals with potential energy (DBE, 2011).

## **6.5 Discussion: Alternative conceptions about Work Energy Power**

This study has found that all learners display a good understanding of some of the critical features of concepts involving WEP as well as alternative conceptions regarding some critical features. However, the focus of this section is on alternative conceptions and these are discussed further here. The findings about alternative conceptions in this study add support to the notion that many learners hold alternative conceptions about physics concepts (Arons, 1999; Dega & Govender, 2016; Govender, 2007; Jewett, 2008a; Lehrman, 1973; Mchunu & Imenda, 2013; Singh & Rosengrant, 2003; Singh & Rosengrant, 2016; Singh & Schunn, 2009). The findings show that there were 31 learner responses out of a total of 176 learner responses where learners demonstrated alternative conceptions on the topic Work Energy Power. This represents 17.61% of the learner responses where alternative conceptions were articulated. This finding does not necessarily mean that the remaining 145 learner responses were devoid of errors or learner difficulties. There were other learner difficulties that emerged from the TAPs, but these will be explored in sections 6.5 and 6.6.

The significance of this analysis as stated previously in this study, is in determining whether there are any discrepancies between the intended object of learning and the lived object of learning, and this was informed by the presence of alternative conceptions in the think aloud protocols of the learners. The prevalence of any discrepancies between the intended object of learning and the lived object of learning have been determined by comparing the critical features of the topics in the intended object of learning with the alternative conceptions articulated by learners in their think aloud protocols.

The findings presented seven alternative conceptions about work that were articulated by learners in their think aloud protocols. I will discuss some of these alternative conceptions in more detail. The physics concept work is a scalar quantity, and it can be either positive or negative. The alternative conception that a positive force does positive work and a negative force does negative work is supported by other research about algebraic signs (Govender, 2007). The interpretation of the algebraic signs is not well understood by learners as they at times confuse their understandings of these signs as they relate to scalar and vector quantities (Govender, 2007). Learners do not understand the meaning of the positive and negative signs that define the scalar quantity work. “Positive work done on a system increases the energy content of that system, and negative work done on a system decrease its energy content” (Hecht, 2019, p. 498). Some learners also demonstrated the alternative conception that the gravitational force always does negative work. This finding resonates well with Singh and Rosengrant (2003, p. 610) who reported that more than 28% of students believed that the work done by gravitational force is negative in the pre-test and 23% in the post-test. One potential reason for this misconception is that students consider work as a vector quantity (Liu & Fang, 2017, p. 5). Work is one of several ways in which the energy content of matter can be changed (Hecht, 2019, p. 498) but this finding is showing that learners are probably not attaching this meaning to the concept work, but are rather focusing on the formula that is used to calculate work. Even when focusing on the formula, learners are not understanding work as a scalar product (dot product) of force and displacement and the possible reason for this is that the dot product is not part of the school curriculum although the formula  $W = F\Delta x \cos\theta$  is. This formula is used to calculate the work done by a force  $F$  on an object that undergoes a displacement of  $\Delta x$  while the force  $F$  is acting on it.

Newton’s first law is about force and motion and accordingly it is understood that an object can remain in uniform motion even if there are no forces acting on it or it can remain in uniform motion if the resultant force acting on it is zero. Closely related to motion is work. The alternative conception that work must be done on an object to keep it in motion was articulated by five of the eight learners in this study. This shows a high prevalence of this alternative conception among the sample of eight learners. This alternative conception is closely linked to and adds support to the alternative conception

that force is needed to keep an object moving at all times (Mchunu & Imenda, 2013, p. 8).

Energy is one of the most fundamental and far reaching of all science concepts (Jewett, 2008a, p. 38; Liu & Fang, 2017, p. 3; Nordine et al., 2011, p. 671; Swackhamer, 2005, p. 1). Energy as presented in school science is not taught as a single coherent concept. Energy is not taught in a consistent way from one grade to the next and from one subject to the next in schools (Swackhamer, 2005, p. 1). These are probably some of the reasons why learners still hold alternative conceptions about energy. Four alternative conceptions about energy have been identified in this study. One of these alternative conceptions is that the change in velocity of an object equals its change in kinetic energy. The learner having this alternative conception cannot discern the difference between  $\Delta v$  and  $\Delta E_k$  that is between  $v_f - v_i$  and  $\frac{1}{2}m(v_f^2 - v_i^2)$ . This appears to be due to learners having poor mathematical skills. Another alternative conception that emerged from the TAPs was that the potential energy of an object remains constant when an object moves uphill. In order to arrive at this conclusion, the learner had reasoned that since the height of the hill remained constant then the potential energy of the object moving up the hill should also be constant. The learner here is not displaying any knowledge of any relationship between kinetic energy and potential energy or of any energy transformation. His reasoning focuses purely on the formula to calculate potential energy. The critical features of energy, namely energy transformation and forms of energy are not in his focal awareness. This finding echoes what Swackhamer (2005, p. 3) says about the teaching of energy in school science. In school, energy is taught simply as a quantity that needs to be calculated and not as a coherent concept across grades and subjects (Swackhamer, 2005, pp. 1-2). “There is only one kind of energy” so when one speaks of energy transformation or different forms of energy, one is talking about the different ways in which energy is stored or is manifested (Swackhamer, 2005, p. 3).

One of the critical features of the intended object of learning in Table 6.11 is that when non-conservative forces are present, mechanical energy (sum of kinetic and potential) is not conserved, but total energy (of the system) is still conserved (DBE, 2011, p. 119). Since the frictional force is a non-conservative force, mechanical energy will not be conserved in the presence of friction. Notwithstanding this, the alternative conception that

mechanical energy is conserved in the presence of non-conservative forces emerged in the TAP of Timber as he answered Q13.3 in the questionnaire. This finding is closely related to the finding that students experience difficulty in understanding the relationship between potential energy, kinetic energy and mechanical energy when influenced or not influenced by non-conservative forces (Wijayanti et al., 2018, p. 4). Timber is aware that there is frictional force present as he stated in line 623 “So I will have to calculate the frictional force” and he goes ahead to calculate the frictional force acting on the 4 kg block correctly. However, he does not use this frictional force anywhere in his calculation to calculate the velocity of the 6 kg block. He probably cannot see that since the 6 kg block is attached to the 4 kg block, the presence of friction between the 4 kg block and the surface has an effect on the motion of the 6 kg block. Or put differently, the motion of the 6 kg block will be different if there was no friction between the 4 kg block and the surface. Another possibility is that he believes (however incorrectly) that he can apply the principle of conservation of mechanical energy to the 6 kg block since the frictional force is acting on the 4 kg block and not on the 6 kg block. Although the two blocks are attached with a light inextensible string, he is looking at them as if they are in complete isolation to each other and not forming part of a system. In his perception, applying the conservation of mechanical energy to the 6 kg block is correct as he stated in lines 641 and 642

*641 and I trust that my answers*

*642 I believe I'm right.*

“Two-body systems such as two masses joined by a light (negligible mass) string” as stated in (DBE, 2011, p. 41) is a critical feature of the intended object of learning Work. Timber has not looked at the two masses connected by a light inextensible string in this question as a system and this could possibly be the reason he believed that he could apply the conservation of mechanical energy to the 6 kg block only. The following statement explains the importance of being aware of the “system” on which a force is doing work:

In any discussion of work, it is important to state that work is done on a system by a force. This phrasing has two important components: (1) the identification of the force that is doing the work and (2) the identification of the recipient of the work as a system (Jewett, 2008b, p. 81).

It is possibly a lack of awareness of the critical features about two-body systems that could have contributed to this alternative conception about the conservation of mechanical energy. Perhaps what is observed as an alternative conception is simply a lack of awareness of critical features of the object of learning.

There is not much research done about the alternative conceptions surrounding the concept power. There is a high prevalence of alternative conceptions about power that has been articulated by learners in their TAPs. Six of the eight learners articulated alternative conceptions about power. The three alternative conceptions that were articulated are: AC P1: More Power is expended where more energy or work is needed or where more difficulty is experienced, AC P2: Work alone determines power irrespective of time and AC P3: Time alone determines power irrespective of work. This finding is indicating that learners do not have a scientific understanding of the relationship between the concepts work, energy, time and power. This finding resonates with the findings in a study conducted by Sağlam-Arslan and Kurnaz (2009, pp. 15-16) that student teachers did not have a scientific understanding of and relationships between the concepts energy, power and force. In articulating AC P1, more power is expended where more energy or work is needed or where more difficulty is experienced, the learner is aware that power as the rate at which work is done (line 210 of his TAP) but is probably not discerning the difference between power and energy as is evidenced in lines 198 and 209 of his TAP.

*198 So the one who is going to need more power is probably the one who has who's route is more difficult because er.*

*209 therefore and therefore had and therefore required required err lots energy energy to do the work.*

*210 Required a lot of energy to do the work per given time.*

The mathematical relationship between power, work and the duration during which the work is done is not adequately understood as is shown by the emergence of the alternative conceptions AC P2 and AC P3 in the TAPs. When comparing the power expended by the two people (hiker and climber) in Q9.2 some learners only considered the work done and ignored the time taken to do the work as one learner said in lines 149-150:

149 *So if the hiker had a greater work being done and also had to expend more power because”*

150 *power and work done directly proportional, ya. said that*

Other learners only considered the time taken and concluded that more time less power. Learners articulating these two alternative conceptions about power may have other difficulties, namely understanding the concept of rate and understanding the relationships between variables in a formula. In the power formula  $P = \frac{\text{Work done}}{\Delta t}$  the changes in both the work done and  $\Delta t$  need to be considered when deciding how the power is affected. If both the numerator and denominator on the right hand side of the formula increase/decrease by the same factor, then P will not change. Similarly, if the numerator does not change but the denominator increases then P will decrease. Learners were unable to discern the effect of both the variables work done and  $\Delta t$  on power.

There are alternative conceptions about work, energy and power that learners harbour. Some of these alternative conceptions may be due to a lack of awareness and discernment of critical features of work, energy and power as found in the intended object of learning in the school curriculum. This idea will be explored further in Chapter 7.

## **6.6 Overview of Data: Problem-solving approaches and problem-solving difficulties**

This section presents the data that was obtained in this study, and it focuses on the problem-solving approaches and problem-solving difficulties of Grade 12 Physical Sciences learners on work energy and power. This section is also addressing research question two of this study as did section 6.3.

*Research Question Two: What are the alternative conceptions, problem-solving approaches and problem-solving difficulties of Grade 12 Physical Sciences learners on work, energy and power?*

*Coding and recording of data*

The TAPs were recorded according to a broad category namely Problem-Solving Approaches and Difficulties (PSADs). Two of the sub-questions that research question two focusing on are what are the problem-solving approaches and problem-solving difficulties that learners display on work energy and power.

In this study, 21 of the 22 questions given in the TAQ are problems. Question 11.3 was not coded according to problem-solving approach because it is a pure recall question. This question had asked the learners to state the work-energy theorem. The first six questions were Multiple Choice Questions (MCQs), and the remaining seven questions were structured questions each comprising of at least two sub-questions. The long questions together with their sub-questions made up a total of 16 questions. All the questions were based on the topic Work Energy Power.

The learners' spoken words which are verbalisations of their knowledge, thoughts conceptions, ideas, difficulties and approaches were recorded as data under specific themes. The learners' written answers to the 21 questions on their scripts were also used as sources of data. The problem-solving approaches that emerged from the TAPs were initially coded into 16 categories. These 16 categories were later reduced into 7 categories as similar problem-solving approaches were grouped into one category. For example, problem-solving approaches that exhibited different limitations like having conceptual errors or lack of awareness were initially categorised separately but were later grouped together into the category labelled PSAD Limited. This process was iterative and was repeated three times to check for accuracy. Each iteration was separated by a period of three weeks in order to give the researcher an opportunity to take a fresh look at each learner response. Initially, the PSAs and PSDs were coded separately, but as the coding process progressed one found that this was a duplication as the categories for the PSAs included PSDs. The PSA and PSD categories were subsequently merged into seven Problem-Solving Approaches and Difficulties (PSADs) categories. These seven PSADs categories spoke to both problem-solving approaches and problem-solving difficulties. Hence, the problem-solving difficulties were embedded in the problem-solving approach. The categorisation was done one question at a time. To illustrate this for example Q1 was categorised for all 8 learners before proceeding to categorise Q2. This process was also

iterative since during categorisation of question x of Gold for example, the researcher often went back to re-categorise question x of Ann as new insights emerged. Each learner had responded to all 21 questions. Table 6.15 presents this data.

**Table 6.15: Number of questions categorised according to Problem-Solving Approach and difficulties**

Learner	Ann	Patience	Gift	Gold	London	Timber	Jasmine	Blue	Total
Number of Questions	21	21	21	21	21	21	21	21	168

### 6.6.1 Results: Problem Solving Approach and Difficulties

Each of the 168 learner responses was coded according to the 7 PSADs as shown in Table 6.16. These problem-solving approaches had not been categorised prior to reading through the TAPs. The categories emerged from the TAPs. The learner responses to 21 of the 22 questions provided in the TAQ were coded according to the 7 categories of problem-solving approaches as indicated in Table 6.16. The TAPs provided more information on the problem solving approaches and difficulties of the learners compared to the information provided in the NSC examination scripts. This resulted in more categories being identified in the analysis of the TAPs (7 categories) compared to the categories identified in the analysis of the NSC scripts (4 categories). Three of the categories that were identified during the analysis of the TAPs overlapped with three of the categories that were identified during the analysis of the NSC scripts. These were MPS, L and LIS. The category DSR that was found in the analysis of the NSC did not appear as such in the analysis of the TAPs. However, four other categories namely Plug and Chug Trial and Error (PACT), Layman's approach (LAY), By Elimination (BE) and Not Shown (NS) were identified during the analysis of the TAPs. The data provided by the learners in their TAPs as they thought aloud while answering the questions provided more data on their thinking process when compared to the written answers to questions in the NSC scripts, hence the number of categories that were identified differed.

**Table 6.16: Problem-Solving approaches and difficulties of learners on Work Energy Power**

PROBLEM SOLVING APPROACH (PSADs)	DESCRIPTION	LEARNER	QUESTION NUMBER
PSAD 1: MPS Jumbled and confused	Missed the Point State. Jumbled and confused. Does not have any clear direction as to how to arrive at the solution.	L1: Ann	Q3
		L3: Gift	Q8, Q10.1.2, Q9.1
		L4: Gold	Q10.3, Q10.1.1, Q10.1.2, Q10.2
		L6: Timber	Q3, Q12
		L7: Jasmine	Q1, Q9.1, Q9.2, Q12, Q13.3, Q2
PSAD 2: Limited (L)	<p>The approach is limited/constrained by different factors like:</p> <ul style="list-style-type: none"> <li>• lack of awareness of critical features of a concept</li> <li>• ACs</li> <li>• Mathematical errors/shortcomings</li> <li>• Memory based. Bases the solution on previous examples and tries to "fit" the current situation to those examples</li> </ul>	L1: Ann	Q8, Q4, Q7, Q9.1, Q11.4, Q12
		L2: Patience	Q4, Q11.4, Q12, Q3, Q7, Q9.2, Q11.4
		L3: Gift	Q7, Q12, Q11.4, Q9.2
		L4: Gold	Q4, Q7, Q8, Q9.1, Q11.4, Q12
		L5: London	Q10.1.1, Q10.1.2, Q13.3, Q10.2, Q10.3, Q7
		L6: Timber	Q4, Q7, Q9.1, Q11.4, Q13.3
		L7: Jasmine	Q4, Q7, Q11.2, Q11.4, Q3
		L8: Blue	Q4, Q6, Q9.2, Q10.2, Q10.3, Q7, Q11.4, Q12
PSAD 3: PACT		L1: Ann	Q9.2, Q11.1

PROBLEM SOLVING APPROACH (PSADs)	DESCRIPTION	LEARNER	QUESTION NUMBER
	Plug and Chug Trial and Error. Not sure of where this is leading.	L2: Patience	Q6, Q8, Q10.1.1, Q10.1.2, Q10.3
		L3: Gift	Q13.3
		L5: London	Q6
		L6: Timber	Q8, Q9.2, Q10.1.1, Q10.3
		L7: Jasmine	Q5, Q8, Q10.1.1
		L8: Blue	Q3, Q5, Q9.1, Q10.1.2
PSAD 4: LAY	Layman's approach: Trying to explain or provide an answer without theories, laws, formulae and/or scientific facts/definitions.	L1: Ann	Q2, Q5, Q6
		L2: Patience	Q2, Q5
		L3: Gift	Q3, Q5, Q6
		L4: Gold	Q5, Q9.2
		L6: Timber	Q2, Q5, Q10.2
PSAD 5: LIS	Linked and Integrated State: Qualitatively analyses the problem. Displays awareness and discernment regarding the critical features of the concepts pertaining to the problem. Plans a solution (selects laws, theorems, formulae and/or scientific facts). Executes the plan by substituting and calculating or qualitatively reasoning to arrive at the numerical and/or non-numerical answer.	L1: Ann	Q1, Q10.1.1, Q10.1.2, Q10.2, Q10.3, Q11.2, Q13.1, Q13.2, Q13.3
		L2: Patience	Q1, Q10.2, Q11.1, Q11.2, Q13.1, Q13.2, Q13.3
		L3: Gift	Q1, Q2, Q4, Q10.1.1, Q10.2, Q10.3, Q11.1, Q11.2, Q13.2
		L4: Gold	Q1, Q3, Q11.1, Q11.2, Q13.1, Q13.2, Q13.3

PROBLEM SOLVING APPROACH (PSADs)	DESCRIPTION	LEARNER	QUESTION NUMBER
		L5: London	Q1, Q2, Q3, Q4, Q5, Q8, Q9.1, Q9.2, Q11.1, Q11.2, Q11.4, Q12, Q13.1, Q13.2
		L6: Timber	Q1, Q10.1.1, Q11.1, Q11.2, Q13.1, Q13.2
		L7: Jasmine	Q11.1, Q13.1, Q13.2
		L8: Blue	Q1, Q2, Q8, Q10.1.1, Q13.1, Q13.2, Q13.3, Q11.1, Q11.2
PSAD 6: By elimination (BE)	Eliminates what he/she believes is incorrect and takes what is left as correct	L4: Gold	Q6
		L6: Timber	Q6
PSAD 7: Not Shown (NS)	No clear approach is discernible, but an answer is provided.	L3: Gift	Q13.1
		L4: Gold	Q2
		L7: Jasmine	Q6, Q10.1.2, Q10.2, Q10.3

In the paragraphs below I will illustrate each of the 7 PSADs indicated in Table 6.16 by discussing examples of these approaches from the TAPs of the learners in this study.

The problem-solving category Missed the Point State (MPS) emerged from the think aloud protocols of the learners. This category describes a problem-solving approach that is jumbled and confused. In this approach, the learner has no clear direction as to how to arrive at a solution as well as no clear idea of the goal of the problem. Sixteen of the 168 learner responses were categorised as having the MPS problem solving approach. This represents 9.52% of all the learner responses. Five of the eight learners exhibited this

problem-solving approach in at least one of their responses to the 21 questions in the TAQ.

I will illustrate the MPS problem-solving approach and difficulties by discussing Jasmine's response to Q12 as illustrated in her TAP and her written response on her script. Question 12 required the learner to determine the change in kinetic energy of a minibus that is being pulled from a point A that is 5m above the ground to a point B that is 20m above the ground. The work done by friction and the chain mechanism are given. Jasmine clearly has not been able to decipher exactly what the given information is as she indicated in line 312 of her TAP:

*312 Oh if we have work done? I think these things are forces or something.*

It seems as though she had started calculating work done (in line 307 of her TAP) but later realised that this is given in the question. Then she gets more confused by thinking that perhaps the given information are forces as she states in line 312 of her TAP.

*307 Eh work done, why am I still calculating?*

*308 Then why they gave it six marks, like I totally don't know.*

*309 Because if we have er friction and work done, just have to find ... (unclear) total work, but we just have to add them.*

*310 Er um it does not even make any sense to me.*

*311 OK. The one minus.*

*312 Oh if we have work done? I think these things are forces or something.*

*313 Let me think here.*

Jasmine stops answering Q12 at this point and proceeds to answer Q13. After that she goes back to Q12 and her TAP regarding Q12 is given below:

*342 I don't have time so how I'm going to calculate it?*

*343 Oh ya so, what is the change in kinetic energy?*

*344 Just taking the risk.*

*345 Oh ya all I'm going to write is that  $E_k$  ( $E_k$ ), delta  $E_k$  ( $\Delta E_k$ ) is equals to, is there any formula here?*

346 *Umm. Seems like there is no other formula except for this one so I'm just going to use it, umm which is W net (Wnet) and then.*

347 *Unless there is any other formula which statement include.*

348 *I actually feel like uh, I don't feel like, like we should calculate it, like I will calculate it.*

349 *Plus two times ten to the exponent five.*

350 *Ehhh.*

351 *Ya it's positive direction.*

352 *So so its two hundred and twenty Joules (but she writes 220 000 J).*

353 *So I'm going to do it in parts. Uhm. Just a new part next.*

In lines 345 to 347 of her TAP, Jasmine is looking for a formula. It seems like she settled on the formula for the work energy theorem as shown on her script. On her script, Jasmine writes the following:

$$\Delta Ek = W_{net} = 2 \times 104 + 2 \times 105 = 220\,000\,J.$$

$$W = F \Delta x \cos\theta = (1200)(9,8)(20)\cos 1800 = -235200\,J.$$

In her calculation, she takes the work done by friction to be positive instead of negative. She correctly writes down that the net work done is equal to the change in kinetic energy of the minibus, but she fails to see that the work done by friction is negative and that the force of gravity is also doing work on the minibus. She calculates the work done by gravity but does not use this information to find the solution to the question. It is just a calculation left hanging. Her calculation of the work done by the force of gravity is also incorrect as she takes the height to be 20m instead of 15m. She also fails to use this work done to determine the change in kinetic energy of the minibus. These lines on her TAP show that her problem-solving approach is jumbled and confused as she finally looks for a formula to get out of this confusion but is still unable to solve the problem. She does a calculation (that of work done by the force of gravity) that could be used to solve the problem but does it incorrectly and also does not see its relevance as she does not use it.

The PSAD category Limited (L) emerged from the think aloud protocols of the learners. This category describes a problem-solving approach that is constrained by different

factors like lack of awareness of critical features of a concept, ACs, Mathematical errors/shortcomings and reliance on memorised information without understanding. Forty seven of the 168 learner responses were categorised as having the Limited problem-solving approach. This represents 28.0% of all the learner responses. All eight learners exhibited this problem-solving approach in at least five of their responses to the 21 questions in the TAQ.

I will illustrate the Limited problem-solving approach by discussing Patience's response to Q4 as illustrated in her TAP lines 83-97. Question 4 is an MCQ, and it required the learner to select the correct choice given five distractors. Question 4 is about a box that is being pulled via a rope of negligible mass at constant velocity on a horizontal surface where friction cannot be ignored. The learner was required to choose the correct option concerning the motion of the box from five distractors. Patience chooses option E as the correct option where option E states "the magnitude of  $F_A$  is greater than the magnitude of  $F_k$ ". Patience verbalises her thinking through this problem in her TAP lines 83-97. In her problem-solving approach, Patience is not jumbled and confused but rather she is systematically looking at the distractors and explaining why she thinks they are incorrect. In lines 85 and 86 she correctly reasons and concludes that options A and B are false. In lines 88-89 she displayed the alternative conception AC W6 Work must be done on an object to keep it in motion to conclude that Option C is correct. However, she failed to discern that both options C and option D are referring to the same point that is that there is a resultant net force acting on the box which is not true since the box is moving at constant velocity. In lines 89-91 she reveals her conceptual mis-understanding about the relationships between force, acceleration and velocity where she believes that a constant force implies zero acceleration which implies constant velocity. This is showing that she makes disjointed relationships among different physical quantities like force, velocity and acceleration. Her problem-solving approach is limited by her alternative conceptions and inability to make correct relationships between different physical quantities hence, this problem-solving approach was categorised as Limited. Lines 83-97 of Patience's TAP is presented below:

83 *OK. It moves at a constant velocity.*

84 *So in this case as it moves*

- 85 *the ughm ughm the work done on the box by  $F_k$  ( $F_k$ ) is positive, no it's not positive.*
- 86 *So the the work done by the gravitational force is non-zero. The work done by the gravitational force, no the height is zero so work done must be zero.*
- 87 *Total work done by the box is nonzero. Mmm. (says "by" instead of "on").*
- 88 *The magnitude of the total work done on the box by the net force is non-zero.*
- 89 *Ya, because pull a box a horizontal force,*
- 90 *so if it's constant horizontal force it means the acceleration will be zero*
- 91 *and constant velocity from A to B.*
- 92 *The total net work done, net work done as you know it's not quite.*
- 93 *It has to be the magnitude of the the  $F_A$  ( $F_A$ ) is equals to the magnitude done by  $F_k$  ( $F_k$ ). work done by  $F_k$ .*
- 94  *$F_A$  ( $F_A$ ) is greater than the magnitude of  $F_k$ .*
- 95 *The magnitude done by  $F_k$  ( $F_k$ ). No it's not true.*
- 96  *$F_A$  ( $F_A$ ) is greater than. I think I think ( $F_A$ ) is greater than, I think  $F_A$  ( $F_A$ ) is going to be greater than the magnitude of  $F_k$  ( $F_k$ )  $F_k$  since it moved to the right.*
- 97 *So it's the answer is number E. ughm ughm.*

The PSAD category Plug and Chug Trial (PACT) emerged from the think aloud protocols of the learners. This category describes a problem-solving approach where the primary aim is to look for a formula and to see if it works or somehow provides an answer. In this approach the choice of the formula is a "let's see if the formula works" approach or where the learner plugs in fictitious values to solve a problem. It depicts the use of a formula in a trial-and-error manner without clearly having a scientific understanding of the problem at hand. Twenty of the 168 learner responses were categorised as having the PACT problem-solving approach. This represents 11.9% of all the learner responses. Seven of the eight learners exhibited this problem-solving approach in at least one of their responses to the 21 questions in the TAQ. Only Gold did not display this problem-solving approach.

I will illustrate the PACT problem-solving approach and difficulties by discussing Gift's response to Q13.3 as illustrated in his TAP lines 234-242 and his written answer on his script. Question 13.3 is a structured problem, and it required the learner to use energy principles to calculate the speed of a 6 kg block when it falls through 1.6m while attached to a 4 kg block that is lying on a horizontal surface. On his script, Gift initially tried to

use the formula  $W_{nc} = \Delta E_k + \Delta E_p$  to answer the question, but he discarded this formula as he says in line 234 because “it was not working”. If this formula was used with correct scientific understanding it could have led him to a correct solution, however, he discarded it for the formula  $W_{net} = \Delta E_k$  but was still unable to arrive at the correct answer and he seemed quite pleased with his answer as he says “thank you very much” in line 242. Lines 234-242 are the Think Aloud of Gift’s thinking as he responds to Q13.3 and are presented below:

234 *So from mm I tried to use the non-conservative force but it was not working*

235 *because I was not sure*

236 *and I used the one for work energy theorem.*

237 *I was able to get er eh five comma five meters eh eh*

238 *of the block the the speed of the block at eh*

239 *so I will use the work net because to E k ( $E_k$ ) er delta E k ( $\Delta E_k$ ).*

240 *So I was able to get er the to the components er wer er g plus F g.*

241 *So I was able to get er thirty comma five from my calculations.*

242 *Thank you very much.*

Lines 264-273 of Patience’s TAP as she answers Q10.1.1 also illustrates The PACT approach where she substitutes an arbitrary value of 5 in order to determine whether the kinetic energy of a box increases, decreases or remains the same when its velocity changes from  $-1 \text{ m}\cdot\text{s}^{-1}$  to  $1 \text{ m}\cdot\text{s}^{-1}$ . This shows that she did not qualitatively analyse the question but relied on numerical values and calculations to answer the question. This is not necessary to answer this question. If she had analysed the question qualitatively and had a correct understanding of kinetic energy, she could have seen that the kinetic energy does not change as only the direction of the velocity was changing and also that energy is a scalar quantity that depends on the mass and the magnitude of the velocity.

264 *So it’s a small box moving.*

265 *Does the kinetic energy of the ball (she says ball instead of box) increase, decrease.*

266 *A small box is moving along a horizontal floor.*

267 *So as it moves along a horizontal floor, does the kinetic energy of the box increase.*

*Does the kinetic energy of the box increase, decrease or remain the same is*

268 *if the velocity of the ball (again she says ball instead of box) changes from negative one to one (  $-1 \text{ m}\cdot\text{s}^{-1}$  to  $1 \text{ m}\cdot\text{s}^{-1}$ ).*

269 *Does the kinetic of the ball energy of the ball increase, decrease. If. OK.*

270 *If it increase let's say the mass is five here. If the mass is five the kinetic energy is like half mass which is  $5 m v$ .*

271 *Velocity it will be negative one and the product will be one over two and it changes from one.*

272 *So it will remain the same. Remain the same. Ughm. Ughm.*

273 *The kinetic energy of the ball is changes from, it will remain the same.*

The PSAD Layman's Approach (LAY) emerged from the think aloud protocols of the learners. This category describes a problem-solving approach where the learner tries to explain or provide an answer without scientific theories, laws, formulae, definitions and other scientific facts. In this approach the use of scientific knowledge is not the focus. Thirteen of the 168 learner responses were categorised as having the Laymans problem-solving approach. This represents 7.7% of all the learner responses. Five of the eight learners exhibited this problem-solving approach in at least two of their responses to the 21 questions in the TAQ.

I will illustrate the LAY problem-solving approach and difficulties by discussing Ann's response to Q6 as illustrated in her TAP lines 86-91. Question 6 is an MCQ with five distractors. Question 6 requires the learners to select which one of the five distractors is true regarding the work done and mechanical energy of a ball that is dropped from a high tower and that falls freely under the influence of the gravitational force. In making her choice Ann stated correctly that the kinetic energy of the ball increases as it falls, but she failed to use any scientific knowledge to make her choice between options A and B. This question can be answered correctly by applying the principle of conservation of mechanical energy to the ball since it is in free fall and concluding that the increase in kinetic energy is equal to the decrease in potential energy. Since  $\Delta E_p = mg\Delta h$  where  $h$  is the height one can therefore conclude that the kinetic energy increases by equal amounts over equal distances. However, Ann does not use this or any other scientific knowledge like equations of motion to arrive at her answer. Lines 86-91 of Ann's TAP follows:

86 *But then I think the options lies, the answer lies between A and B.*

87 *Why the kinetic energy of the ball increases by equal amounts in equal times.*

88 *So I think A is the correct answer because kinetic energy increases due to an increase in the velocity of the book, in the velocity of the the book She says "book" instead of "ball").*

89 *I think the velocity the eish tai as the ball moves down the velocity increases and if the velocity increases it means that the the kinetic energy will also increase.*

90 *So this shows er a good result of er change in position of the ball per unit time.*

91 *That is why I think my answer will be A.*

In her TAP Jasmine also displays the LAY problem-solving approach as she answers question three. Question three is an MCQ that has five distractors. Question three requires the learners to select the correct factors that determine the work done by the gravitational force when a suitcase is lifted from the floor to the table. Jasmine shows that she is not using any relevant scientific knowledge when she chooses the incorrect option as shown in line 66 of her TAP.

66 *So I I honestly think that at at my at my friend because his slide has a constant slope so if he have the con the the slope is constant you will have more er mm what not to to to like you will have more opportunity to accelerate so I go with C this time around.*

The problem-solving approach titled Linked and Integrated State (LIS) emerged from the think aloud protocols of the learners. Of the seven PSAD categories this is the only category where the learner does not display any problem-solving difficulties. This category describes a problem-solving approach where the learner qualitatively analyses the problem, displays awareness and discernment regarding the critical features of the concepts pertaining to the problem, plans a solution (selects laws, theorems, formulae and/or scientific facts), executes the plan by substituting and calculating or qualitatively reasoning to arrive at the numerical and/or non-numerical answer. Sixty four of the 168 learner responses were categorised as having the LIS problem-solving approach. This represents 38.1% of all the learner responses. All eight learners exhibited this problem-solving approach in at least three of their responses to the 21 questions in the TAQ.

I will illustrate the LIS problem-solving approach by discussing London's response to Q12 as illustrated in his TAP lines 673-692. Question 12 is a structured question about a minibus that is being pulled up from a point that is 5m above the ground to a point that is 20m above the ground. The work done by friction and the chain mechanism that is pulling the minibus are given. No mention of the gravitational force is given. The learner is required to find the change in kinetic energy of the minibus. In his TAP London shows in lines 673-684 that he is qualitatively analysing the problem. He shows in line 673 that he has a plan to solve the problem by selecting the work energy theorem which applies in this question, to calculate the change in kinetic energy of the minibus. He also displays that he is aware of the critical feature "gravitational force acting on the mini bus" pertaining to this problem and of which no mention was made in the question (line 678). He displays that he is aware of the critical features about work done by the gravitational force (line 678) and of the work done by friction (line 679) and the chain mechanism (line 680). He then executes his plan by doing the calculations and substitutions as shown in lines 685- 692 of his TAP and on his script and he also shows in line 692 that he gets the correct answer of 3600 J for the change in kinetic energy. Lines 673-692 of London's TAP follows:

673 *Net work done is equals to er the change in its kinetic energy from the work energy theorem.*

674 *So I have ...*

675 *if its pulled up there are two forces,*

676 *the work done by the pulling,*

677 *oh there are no (unclear).*

678 *So I have the work done by the the gravitational force which is the work done by the gravity*

679 *which is summed by the work done by the frictional*

680 *plus the work by the applied force which is the chain mechanism,*

681 *equals to kinetic, final kinetic er minus initial kinetic energy.*

682 *OK, I do not get to do that because they said to me what is its its change in kinetic energy.*

683 *OK so never mind.*

684 *Gravitational force*

685 *it will be one thousand two hundred multiply by the displacement, displacement it will be final minus initial (unclear) multiply by cos of hundred and eighty degrees (cos 1800 )* (He writes on his script  $(9,8)(1200)(20-5)\cos 180$ )

686 *plus work done by the frictional,*

687 *it will be two multiply by ten to the power four, negative four er negative two* (On his script he writes  $-2 \times 10^4$  ),

688 *so in the calculation*

689 *plus two times ten to the power five* (On his script he writes  $2 \times 10^5$  ),

690 *the change in kinetic energy therefore err change in kinetic energy is equal to*

691 *(plugging values in calculator) (long silence with voicing out some numbers incoherently)*

692 *three thousand six hundred joules (3600 J).*

The PSAD titled By Elimination (BE) emerged from the think aloud protocols of the learners. This category describes a problem-solving approach where the learner eliminates what he/she believes is incorrect and takes what is left as correct. Two of the 168 learner responses were categorised as having the BE problem-solving approach. This represents 1.2% of all the learner responses. Only two learners exhibited this problem-solving approach in only one of their responses to the 21 questions in the TAQ. Both learners, Gold and Timber, displayed this approach when answering Q6 in the TAQ.

I will illustrate the BE problem-solving approach by discussing Gold's response to Q6 as illustrated in his TAP lines 66-90. Question 6 is an MCQ with five distractors. Question 6 requires the learners to select which one of the five distractors is true regarding the work done and mechanical energy of a ball that is dropped from a high tower and that falls freely under the influence of the gravitational force. In making her choice, Ann initially discards option A as is evidenced in lines 66-69 without stating any reason. Later in lines 87-90 she chooses this same option after eliminating options B-E in lines 71-86 of her TAP. In line 87-88 she chooses option A but does not have a reason for this choice as she says in line 88 "Though I don't know why but". This choice is most probably because she eliminated options B-D. This question could have been answered correctly by applying the conservation of mechanical energy to the ball as the ball was in free fall. Lines 66-90 of Gold's TAP follows:

- 66 *The kinetic energy of the ball increases by equal amounts in equal times.*
- 67 *The kinetic energy of the ball increases by equal amounts in equal times (emphasised "equal times").*
- 68 *This is very wrong. (But she chooses this option in lines 87 -88)*
- 69 *Wrong.*
- 70 *Er B.*
- 71 *The kinetic energy of the ball increases by equal amounts over equal distances.*
- 72 *There is zero work done on the ball by the gravitational force as it falls.*
- 73 *This one is not true.*
- 74 *The work done on the ball by gravitational force is negative as it falls.*
- 75 *This is not true since the ball is falling in the same direction as the nn gravitational force so the work done is positive.*
- 76 *Er the total mechanical energy of the ball decreases as it falls.*
- 77 *No er D.*
- 78 *No this forc this this ball is under free fall so the mechanical energy of the ball as if the system is conserved so mechanical energy is not changed.*
- 79 *So err which one?*
- 80 *Between A and B.*
- 81 *Equal amounts over equal distances.*
- 82 *Ohhh. But the.*
- 83 *But irrespective but when we talk about gravitational force we never talk about distance.*
- 84 *Eh distance?*
- 85 *The path?*
- 86 *No its the path.*
- 87 *But I think its gonna be option A.*
- 88 *Though I don't know why but.*
- 89 *Think option A suits it best.*
- 90 *Time.*

Timber on the other hand used the BE problem-solving approach and arrived at the correct answer although he probably did not have a scientific understanding of why. In lines 199-

221 of his TAP, he shows that he is eliminating options A, C, D, and E. He does not have a scientific understanding of why he is eliminating option A as he says in line 203-204 and he probably also does not have a scientific understanding of why option B is correct as is evidenced in lines 222-227 of his TAP except that it is the only option that is left after he had eliminated the other options.

- 199 *So A says the kinetic energy of the ball increases by equal amounts in equal times.*
- 200 *By equal amounts*
- 201 *Er mmmmmm.*
- 202 *Velocity by equal amounts in equal times.*
- 203 *I don't think so.*
- 204 *Well I just I just don't think so.*
- 205 *So B says the kinetic energy of the ball increases by equal amounts over equal distances.*
- 206 *I'll come back to it.*
- 207 *C says there is a zero work done on the ball by the gravitational force as it falls.*
- 208 *That's false.*
- 209 *C is out because the gravitational force pulls the ball downwards.*
- 210 *As it goes downwards the displacement and the gravitational force are in the same direction, so it means that the cos of theta will be one ( $\cos \theta = 1$ ), because theta ( $\theta$ ) will be zero (0) and the cos of theta is one (1).*
- 211 *So C is definitely out.*
- 212 *The gravitational force does do work on the on the ball as it falls.*
- 213 *So let me go to D.*
- 214 *D says the work done on the ball by the gravitational force is negative as it falls.*
- 215 *That's not true, because it's going in the same direction as the ball.*
- 216 *So D is also out.*
- 217 *Then E. It says the total mechanical energy of the ball decreases as it falls.*
- 218 *The total mechanical energy of the ball decreases as it falls.*
- 219 *Mmmmm.*
- 220 *No.*
- 221 *The velocity will be increasing, so E is out.*
- 222 *So if, I think the answer is*

223 *ummm.*

224 *Can I say*

225 *mmmm mmmm*

226 *I go with B. Sounds more seems to be more relevant.*

227 *Mm.*

The final PSAD in this study titled Not Shown (NS) emerged from the think aloud protocols of the learners. This category describes a problem-solving approach where no clear approach is discernible, but an answer is provided by the learner. Six of the 168 learner responses were categorised as having the NS problem-solving approach. This represents 3.6% of all the learner responses. Three learners exhibited this problem-solving approach. Gift exhibited this approach in one question, Gold in one question and Jasmine in four questions.

I will illustrate the NS problem-solving approach by discussing Jasmine's response to Q10.3 as illustrated in her TAP line 254. In Q10.3, the learner was required to state whether the net work done on a box that moving on a horizontal surface is positive, negative or zero when the velocity of the box changes from  $-4 \text{ m}\cdot\text{s}^{-1}$  to  $-1 \text{ m}\cdot\text{s}^{-1}$ . Jasmine provides the correct answer without saying how she arrived at the answer. Therefore, her problem-solving approach for this question was categorised as NS. Line 254 of Jasmine's TAP is provided below:

254 *Negative.*

## **6.7 Analysis: Problem-solving approaches and problem-solving difficulties**

The think aloud protocols of the eight learners were coded into two broad categories, Problem-Solving Approaches (PSAs) and Problem-Solving Difficulties (PSDs). The Think Aloud Protocols (TAPs) of the eight learners have provided extensive data on Problem-Solving Approaches and Problem-Solving Difficulties regarding problems based on work, energy and power displayed by the learners in the sample and these results were presented in section 6.5.

An analysis of this data is conducted using Variation Theory as the theoretical framework. In section 6.6.1 an analysis of the results on Problem-Solving Approaches and Difficulties that was presented in section 6.5.1 will be discussed. This will be followed by a discussion about these problem-solving approaches and difficulties.

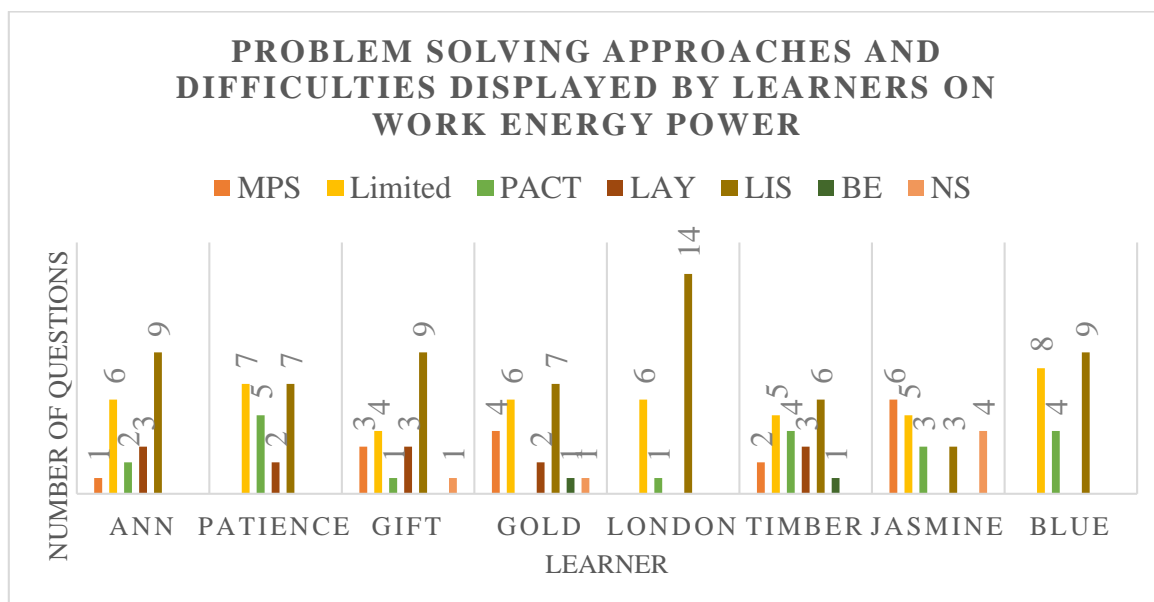
### **6.7.1 Analysis: Problem-Solving Approaches and Difficulties through the lens of VT**

Table 6.17 presents an analysis showing the prevalence of problem-solving approaches and difficulties involving problems based on Work Energy Power displayed by learners. According to Table 6.17, each learner displays several different PSADs however, a particular PSAD may be more prevalent for a learner when compared to other PSADs. The PSADs displayed by London and Gold will be discussed further as examples that explain this finding. London displays three of the seven PSADs namely L, PACT and LIS. He displayed the Linked and Integrated State PSAD in fourteen of his responses, PACT in one of his responses and L in six of his responses. He did not display the Missed the Point State PSAD in any of his responses showing that he was never jumbled and confused while solving any of the 21 problems in the TAQ. The PSADs displayed by Gold present a different picture from that of London. Gold displayed six of the seven PSADs namely MPS, L, LAY, LIS, BE and NS. Gold displayed the MPS in four of his responses, L in six responses, LAY in two responses, LIS in seven responses, BE in one response and NS in one response. According to this analysis, Gold displayed for example that while he could solve seven problems successfully, he was jumbled and confused while trying to solve four of the 21 problems in the TAQ. Table 6.17 shows that the PSAD displayed by the learners vary depending on the question that is presented to them. It is also evident that all learners displayed the Linked and Integrated problem-solving approach in at least three of their responses. This shows that all the learners in the sample have the capacity to link and integrate concepts when solving some problems but that this ability may depend on other factors like the type of question or the critical features of the concepts that pertain to the problem that is presented to the learners.

**Table 6.17: Problem-Solving Approaches and Difficulties Displayed by Learners**

	PSAD 1	PSAD 2	PSAD 3	PSAD 4	PSAD 5	PSAD 6	PSAD 7	
	MPS	L	PACT	LAY	LIS	BE	NS	Total
Ann	1	6	2	3	9			21
Patience		7	5	2	7			21
Gift	3	4	1	3	9		1	21
Gold	4	6		2	7	1	1	21
London		6	1		14			21
Timber	2	5	4	3	6	1		21
Jasmine	6	5	3		3		4	21
Blue		8	4		9			21
Total	16	47	20	13	64	2	6	168

Graph 6.1 is a graphical presentation of the data presented in Table 6.17 to show clearly that the PSADs of the learners vary, that is, learners display different problem-solving approaches and difficulties when confronted with problems that differ according to their focus on different critical features of Work Energy Power.

**Graph 6-1: Problem-Solving Approaches Displayed by Learners on Work Energy Power**

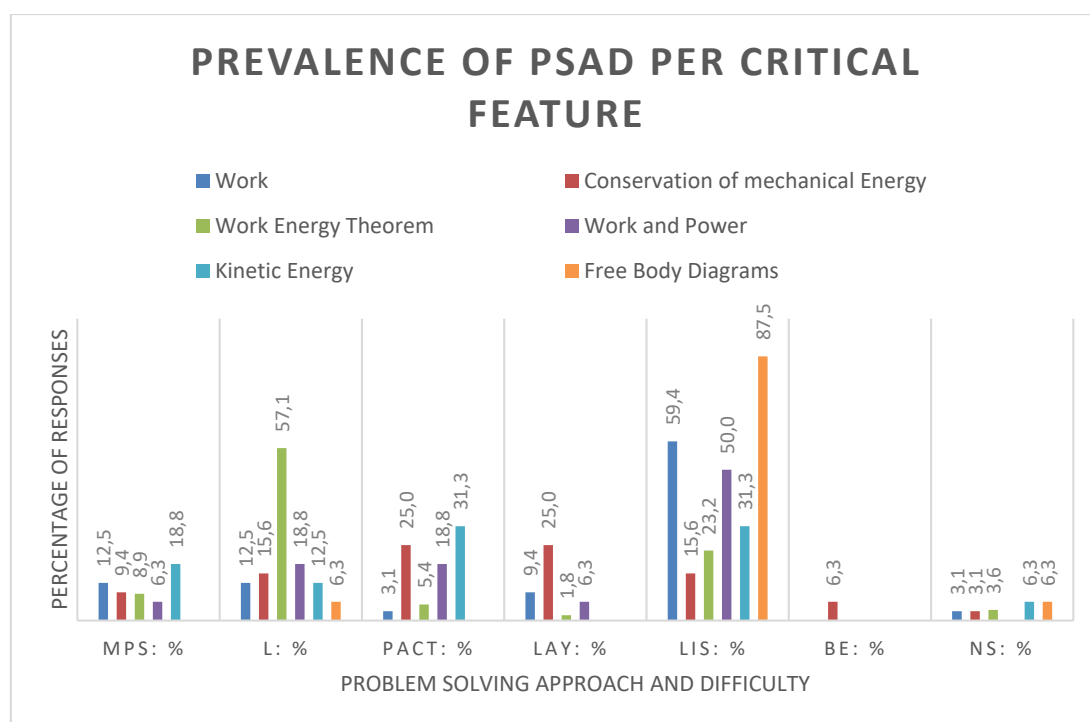
The TAQ was composed of questions that focused on different critical features of Physics namely work, conservation of mechanical energy, work energy theorem, work and power,

kinetic energy and free body diagrams. Table 6.18 provides an analysis of each question showing the critical feature that is the focus of each question in the TAQ. I will explain the analysis in Table 6.18 by explaining column 2. The critical feature work was the focus of four questions and the number of learner responses that were analysed for this critical feature was given by the number of questions (4) multiplied by the number of learners (8) given a total of 32 learner responses.

The prevalence of the different PSAs per critical feature is presented in Graph 6.2. I will explain the percentages reflected on the bar graph in Graph 6.2 by explaining the brown bar at LIS % on the x-axis. The brown bar refers to the critical feature “Conservation of Mechanical Energy” and the value 15.6% on the y-axis refers to 15.6% of 32 learner responses (for this critical feature) which equals 5 responses. Another example would be the grey bar that corresponds to L% on the x-axis. The grey bar refers to the critical feature “Work Energy Theorem” and the value 57.1% on the y-axis refers to 57.1% of 56 learner responses (for this critical feature) which equals 32 responses. The total number of learner responses for each critical feature is provided in Table 6.18.

**Table 6.18: Critical Features per question**

Question	1, 2, 9.1, 13.2	3, 5, 6, 8	4, 7, 10.2, 10.3, 11.4, 12, 13.3	9.2, 11.1	10.1.1, 10.1.2	11.2	13.1
<b>Critical Feature</b>	Work	Conservation of Mechanical Energy	Work Energy Theorem	Work and Power	Kinetic Energy	FBD	
<b>Description of critical feature</b>	Applying the formula $W = F \Delta x \cos\theta$ in the presence or absence of dissipative forces	Applying the principle of conservation of Mechanical Energy in the presence or absence of dissipative forces	Applying the Work Energy Theorem in the presence or absence of dissipative forces	Determining Power dissipated	Determining kinetic energy qualitatively	Drawing free body diagrams	
<b>Details of Critical Feature</b>	Force, displacement, angle	mechanical energy, kinetic energy, work done by gravitational energy, conservative and non-conservative forces	work, energy, friction, conservative forces and non-conservative forces	Work, duration, time	Mass, velocity, vectors, scalars, number line	Applied force, friction, tension, weight, normal, force of gravity	
Number of responses	32	32	56	16	16	16	
Total Number of responses	21 questions x 8 learners = 168 responses						

**Graph 6-2: Prevalence of PSADs per Critical Feature**

According to Graph 6.2, most of the learner responses on all the critical features of Work Energy and Power provided information on the problem-solving approach and difficulties that the learner displayed since the NS% is very low for all the critical features. This shows that mostly the learners in this sample are able to “talk” about the science concepts that they are engaging with. This finding is significant as it most probably indicates that learners were “Thinking Aloud” while they were answering the questions. Another significance of this finding is that it indicates that learners are actively engaging with the content of science, rightly or wrongly, and that they are confident enough to talk about how they are engaging with it.

Most of the learner responses are showing that learners display the LIS problem-solving approach when drawing free body diagrams (FBDs). This finding is significant in that it is showing that most learners are able to draw FBDs and that they can also explain what they are doing in a scientifically correct manner as they are drawing the FBDs.

Only 23.2% of the learner responses that focus on the critical feature Work Energy Theorem (WET) are displaying the LIS problem-solving approach. This is showing that many learners in the sample cannot link and integrate the concepts work, energy, friction,

conservative forces and non-conservative forces when solving problems. Most of the learner responses (57.1%) on problems involving the WET display the L PSAD. This is indicating that learners have limitations like lack of awareness of critical features pertaining to the problem or the presence of alternative conceptions, when attempting to solve problems involving the Work Energy Theorem. The significance of this finding is that it is not the inability to solve problems that is critical, but rather the lack of awareness of critical features or the presence of ACs that is critical in terms of improving learners' performance in problem-solving. Some learners' approach (8.9% of responses) to solving problems that focus on this critical feature is jumbled and confused (MPS). These responses show that the learners do not have any clear direction to solving problems based on the Work Energy Theorem.

Applying the principle of conservation of Mechanical Energy in the presence or absence of dissipative forces is a critical feature of solving problems on Work Energy Power. Graph 3 shows that the PSADs that involve this principle being displayed by learners are mostly Layman's Approach (LAY: 25%), Plug and Chug Trial (PACT: 25%) and Limited (L: 15.6%). Only 15.6% (LIS) of the responses show that the learners can link and integrate the concepts mechanical energy, kinetic energy, work done by gravitational force, conservative and non-conservative forces when approaching problems as shown by Graph 6.2. Learners are clearly facing difficulties in approaching problems that involve the conservation of mechanical energy.

In contrast to their problem-solving approaches involving the critical features Work Energy Theorem and the Conservation of Mechanical Energy, a greater percentage (59.4%) of learner responses show that learners display the linked and integrated approach when solving problems whose focus is the critical feature Work. This is a significant finding as it most probably is showing that as the problems begin to include a greater number of inter-related concepts and scientific principles, the more learners are unable to link and integrate them.

## **6.8 Discussion: Problem-Solving approaches and Problem-Solving difficulties**

One major finding in this study are the seven problem-solving approaches displayed by the sample of eight learners, namely Linked and Integrated State (LIS), Missed the Point State (MPS), Limited (L), Plug and Chug Trial (PACT), Layman's Approach (LAY), By Elimination (BE) and Not Shown (NS). These problem-solving approaches include problem-solving difficulties except for the LIS approach. These problem-solving approaches have been presented and analysed in sections 6.5 and 6.6 respectively. This finding shows the qualitatively different ways in which several learners approach the same problem as well as the qualitatively different ways in which one learner approaches different problems. Several researchers have found that many learners experience problem-solving difficulties and display different problem-solving approaches when solving problems (Bing & Redish, 2009; Chen & Bradshaw, 2007; Chi & Glaser, 1983; DBE, 2015a; Docktor et al., 2016; Docktor et al., 2015; Holyoak, 1995; Kim & Pak, 2002; Schultz & Lochhead, 1988; Walsh et al., 2007).

There are four categories of PSADs in this study that resonate well with four categories of problem-solving discussed in (Walsh et al., 2007). Walsh et al. (2007, p. 9) placed the problem-solving approaches in four main hierarchical categories namely scientific, plug and chug, memory based and no clear approach. The LIS approach that I have described in this study is similar to the scientific approach of Walsh et al. (2007), but is not identical in the sense that in the LIS approach the learner does not have any conceptual or mathematical errors as in the category described as the scientific approach in Walsh et al. (2007, p. 4). In my study I placed the learner problem-solving approach that displayed conceptual and mathematical errors in the category described as Limited (L). The PACT problem-solving approach and difficulties in my study is similar to the combination Plug and Chug Structured and Plug and Chug Unstructured in Walsh et al. (2007, pp. 5-6). In both the structured and unstructured plug and chug approaches discussed in Walsh et al. (2007) the learners start with the formulae and variables that could be used to solve the problem and in both approaches they may experience difficulties and may or may not arrive at the correct answer. Initially I also separated the plug and chug approach into two categories but found that the responses of the learners could fall into both categories

described by Walsh et al. (2007) hence, I combined the two categories into one category that I named PACT. The significance of this finding is that it supports and is supported by the finding that there is a problem-solving approach displayed by learners where they focus on finding a formula to solve the problem and that in this approach learners do at times experience problem-solving difficulties. The ideal problem-solving approach as alluded to by many research studies is that described in the LIS approach in this study and which is the scientific approach in Walsh et al. (2007) (Biggs & Collis, 1982; Bing & Redish, 2009; Chen & Bradshaw, 2007; Chi & Glaser, 1983; Govender, 2007).

## 6.9 Conclusion

This chapter is the second of four chapters that presented the data analysis and findings of this study. It focused on the second research question.

*Research Question Two: What are the alternative conceptions, problem-solving approaches and problem-solving difficulties of Grade 12 Physical Sciences learners on work, energy and power?*

This part of the study employed two methods to obtain data. Firstly, a focus group interview was used to obtain data about the alternative conceptions, problem-solving approaches and problem-solving difficulties of the learners in the sample of 30 learners. Secondly, the TA method was used to gain a deeper insight into the “thinking” of learners as they grappled with concepts and solved problems involving WEP. The sample for the TA session consisted of eight learners who were purposively selected from the same group of 30 learners who had participated in the focus group interview. The focus group interview was recorded for audio. This audio recording was transcribed to provide the FGT. The TA session was also recorded for audio. Eight audio recordings were obtained, one from each of the eight learners in the sample. The eight audio recordings were transcribed to provide eight Think Aloud Protocols (TAPs). The TAPs were obtained by administering the TAQ that consisted of 13 questions based on the topics work, energy and power. The FGT was obtained by administering the semi-structured interview schedule that consisted of 17 questions.

All learners in this study demonstrated a good understanding of some of the critical features pertaining to WEP, however all these learners also demonstrated poor understanding of some of the concepts pertaining to WEP. This study found that all learners in the sample demonstrated the presence of ACs about WEP as they worked their way through the questions in the TAQ. The following seven ACs about work were displayed by learners: AC W1: Work and Net Work can be used inter-changeably, AC W2: WET does not apply to accelerating objects, AC W3: Work by gravitational force is dependent on the path taken, AC W4: Greater velocity greater work done, AC W5: More force more work, AC W6: Work must be done on an object to keep it in motion and AC W7: Positive force positive work negative force negative work. The following four ACs about energy were displayed by learners: AC E1: Change in velocity equals change in kinetic energy, AC E2: Kinetic Energy and mechanical energy of an object decreases as it falls freely, AC E3: Mechanical energy is conserved in the presence of non-conservative forces and AC E4: A change in mechanical energy depends only on changes in velocity and not on changes in height. The following three ACs were displayed by learners about power: AC P1: More Power is expended where more energy or work is needed or where more difficulty is experienced, AC P2: Work alone determines power irrespective of time and AC P3: Time alone determines power irrespective of work.

Another major finding in this study were the seven problem-solving approaches that have been identified namely Linked and Integrated State (LIS), Missed the Point State (MPS), Limited (L), Plug and Chug Trial (PACT), Layman's Approach (LAY), By Elimination (BE) and Not Shown (NS). These problem-solving approaches include problem-solving difficulties except for the LIS approach. This finding shows the "qualitatively different" ways in which several learners approach the same problem as well as the "qualitatively different" ways in which one learner approaches different problems (Marton & Pang, 2006, p. 203). Several researchers have found that many learners experience problem-solving difficulties and display different problem-solving approaches when solving problems (Bing & Redish, 2009; Chen & Bradshaw, 2007; Chi & Glaser, 1983; DBE, 2015a; Docktor et al., 2016; Docktor et al., 2015; Holyoak, 1995; Kim & Pak, 2002; Schultz & Lochhead, 1988; Walsh et al., 2007). The finding that a single learner displays a variety of problem-solving approaches when confronted with different problems can be explained by using VT. When a learner is faced with a problem, the learner proceeds in a

manner that is informed by his/her “awareness, discernment and simultaneity” regarding the concepts pertinent to the problem at that particular time (Marton & Booth, 1997, pp. 100-103). This aspect has been investigated further in Chapter 7 where other possible conditions that influence a learners’ understanding and problem-solving approach are discussed.

The PSDs among Grade 12 learners in Physical Sciences were found to be as follows: Missed the Point (MPS), Limited (L), Plug-And-Chug Trial (PACT), Layman’s Approach, By Elimination (BE) and Not Shown (NS).

This chapter had focused on research question two. The next chapter will present the data analysis and findings pertaining to research question three.

## Chapter 7 - **LOOKING AT THE REASONS FOR PROBLEM-SOLVING DIFFICULTIES AND ALTERNATIVE CONCEPTIONS**

### **7.1 Introduction**

This section presents my results, findings and analysis of the Think Aloud protocol data regarding research question three of this study.

*Research Question Three: Why do Grade 12 Physical Sciences learners hold certain alternative conceptions and problem-solving difficulties on work, energy and power?*

In Chapter 6, the alternative conceptions, problem-solving approaches and problem-solving difficulties on work, energy and power displayed by a small sample of eight Grade 12 Physical Sciences learners from one school in South Africa were discussed. In this chapter, the possible reasons for these learners to hold these alternative conceptions and problem-solving difficulties on work energy and power will be discussed. This process of explaining why learners display these qualitatively different ways of experiencing WEP will be underpinned by VT.

### **7.2 Unpacking the themes**

The TAPs were coded utilising thematic analysis underpinned by the phenomenographic approach and VT, according to categories that emerged from them. The categories were not pre-determined. The coding process was similar to the coding process that was undertaken for the ACs and PSAs in Chapter 6 and it is described in detail in the methodology chapter. In this chapter, the coding process regarding possible reasons for learners to hold alternative conceptions and problem-solving difficulties will be described briefly.

The responses of the learners were read with an analytical lens that searched for possible reasons for the learners to hold the alternative conceptions and problem-solving difficulties that were discussed in Chapter 6. For example, a response that did not articulate anything about or did not use the conservation of mechanical energy in a problem where this knowledge was necessary to solve the problem, was coded under the category Lack of Awareness (LOA). All responses that indicated a lack of awareness of a critical feature necessary to solve a problem were coded under the category LOA. Similarly, responses that showed a lack of discernment between concepts like work and net-work for example were coded under the category Lack of Discernment (LOD). Responses where learners gave an answer that was more-or-less like a gut feeling without any scientific reasoning were recorded as Lack of Reason (LOR). This category did not include incorrect reasoning, but rather a lack of it. Another interesting category that emerged from the TAPs was an incorrect understanding of proportionality and these were categorised as a lack of logic (LOL). Finally, in some responses, learners expressed confusion. Responses that included any words that spoke to confusion or where learners expressed that they were not sure were categorised as Lack of Clarity (LOC). The choice of these five categories stemmed from research question three of this research and was designed to answer this research question. Initially the transcripts were read while listening to the recordings. The reason for this was twofold. Firstly, this process assisted in checking the transcripts for accuracy of transcription. Secondly, it assisted in developing the first set of categories (open-coding) which were subsequently reduced to the five categories mentioned above.

In section 7.2.1 I will present the overall data showing the prevalence of each of the five categories of possible reasons why learners hold alternative conceptions and experience problem-solving difficulties. This will be followed by a more detailed presentation and discussion of the data for each of the five categories in sections 7.2.2 to 7.2.6.

### **7.2.1 Why do learners hold alternative conceptions and experience problem-solving difficulties**

Each of the 168 learner responses was coded according to the 5 categories: Lack of Awareness (LOA), Lack of Discernment (LOD), Lack of Reason (LOR), Lack of Logic

(LOL) and Lack of Clarity (LOC). The number of learner responses that displayed each of these categories as possible reasons for the prevalence of alternative conceptions and problem-solving difficulties is presented in Table 7.1. The reasons provided in Table 7.1 had not been categorised prior to reading through the TAPs. The categories emerged from the TAPs.

**Table 7.1: Reasons for prevalence of alternative conceptions and problem-solving difficulties**

<b>Reason</b>	<b>LOA</b>	<b>LOD</b>	<b>LOR</b>	<b>LOL</b>	<b>LOC</b>	<b>TOTAL</b>
<b>Number of responses</b>	66	21	9	10	13	119

It is shown in Table 7.1 that in 119 of the 168 responses of learners in this sample there is a demonstration of a lack of awareness, discernment, reason, logic or clarity. The number of learner responses demonstrating a particular reason like LOA for example is not significant in this study as this is not a quantitative study. The numbers here provide data about the prevalence of a particular reason and not the degree of prevalence of that reason. Therefore, even if the number of learner responses demonstrating a particular reason is small as is the case with LOR, it is significant in this qualitative study.

### **7.2.2 Lack of Awareness**

Lack of Awareness (LOA) as a possible reason for learners holding alternative conceptions and problem-solving difficulties emerged from the think aloud protocols of the learners. This category describes a situation where a critical feature of Work Energy Power that is pertinent to the question that a learner is attempting to understand and solve, is absent from the learner's focal awareness. This category does not in any way imply that the learner does not understand this critical feature but rather that this critical feature is not in the learner's area of focal awareness while he/she is attempting to understand and solve the problem. Sixty-six of the 168 learner responses were categorised as displaying this lack of awareness of critical features. This represents 39.28% of all the

learner responses. All eight learners displayed the LOA in at least five questions in their TAPs.

Table 7.2 presents the questions to which the learner responses displayed that there was a lack of awareness of critical features of Work Energy Power necessary to understand and solve the problem at hand. For example, Ann displayed the LOA in her responses to questions 2, 4, 5, 6, 7, 8 9.1, 11.4 and 12 and London displayed the LOA in his responses to questions 6, 7, 10.2, 10.3 and 13.3.

**Table 7.2: Prevalence of Lack of Awareness**

Learner	LOA							
	L1 Ann	L2 Patience	L3 Gift	L4 Gold	L5 London	L6 Timber	L7 Jasmine	L8 Blue
Questions showing Evidence of LOA on WEP	2, 4, 5, 6, 7, 8, 9.1, 11.4, 12	3, 4, 5, 6, 8, 9.1, 11.4, 12	3, 5, 6, 7, 8, 9.1, 11.4, 12	4, 5, 7, 8, 9.1, 10.2, 11.4, 12	6, 7, 10.2, 10.3, 13.3	3, 4, 5, 6, 7, 8, 9.1, 9.2, 10.2, 10.3, 11.4, 12	3, 4, 5, 7, 8, 9.1, 9.2, 13.3	5, 6, 7, 9.1, 10.2, 10.3, 11.4, 12

I will illustrate the LOA category by discussing Jasmine's response to Q8 as illustrated in her TAP lines 186-198. Question 8 is a structured question that presents a learner with two scenarios and requires the learner to state and explain in which scenario the conservation of mechanical energy will be observed. A critical feature of the principle of conservation of mechanical energy is that mechanical energy is conserved in an isolated system. In line 188 of her TAP, Jasmine states the principle of conservation of mechanical energy correctly and she also uses the term "isolated" in her statement, but this critical feature is not in her area of focal awareness as she attempts to solve the problem. She does not pay any attention to this critical feature and to apply this test to each of the two cars. Car X is free-wheeling up the hill (in the absence of dissipative forces) and Car Y has its engine running as it is driving up the hill. She fails to see that the engine is transferring energy to the Car Y - earth system and is therefore not isolated. Another critical feature that is not in her area of focal awareness is that the mechanical energy of an object is the sum of the kinetic and potential energies of the object. The critical feature is "sum". In lines 193-194 she concludes that since the kinetic energy of car Y is constant (because its velocity is constant) its mechanical energy is constant. These two critical

features of the principle of conservation of mechanical energy are not in her area of focal awareness. For a learner to be aware of a critical feature of an object of learning the learner needs to be aware of the absence of that critical feature. According to the Variation Theory framework, a learner must experience variation in order to be aware of a critical feature (or dimension) of a particular object of learning which in this case is Work Energy Power (Marton & Pang, 2006, p. 207). For example, to understand the colour blue, the learner needs to know what is not blue. Lines 186-198 of Jasmine's TAP are presented below:

186 *OK firstly I'm going to start by stating er what the principle of conservation of mechanical energy states, right.*

187 *Ughughm.*

188 *Principle of conservation of mechanical energy energy. It says, says, states not says, states that in an isolated system total mechanical mechanical energy er which is kinetic and potential energy eish constant.*

189 *So in this case scenario two this principle is observed. Ughughm.*

190 *Umm scenario two this principle is observed is observed in such a way a way that, in such a way that when we look at the formulas, the formulae of kinetic and potential energy*

191 *which is um  $E_k$  equals to half  $m \cdot v^2$  (  $E_k = \frac{1}{2} m \cdot v^2$  ) and  $E_p$  equals to  $m \cdot g \cdot h$  ( $E_p = mgh$ ) and mass is constant,*

192 *gravitational acceleration is constant*

193 *and it is given on scenario two that that velocity is constant*

194 *so total mechanical energy mechanical energy, it should be therefore, therefore total mechanical energy is constant.*

195 *Actually so scenario two one.*

196 *Scenario I'm going to say something about scenario one. Ughm.*

197 *OK I am going to say in scenario one, velocity is not constant therefore kinetic energy energy will not be constant,*

198 *meaning total mechanical energy will not be conserved.*

An example that illustrates that LOA is a possible reason for learners to hold alternative conceptions is the response of Blue to Q10.3. Blue had displayed the AC W7 Positive

force positive work negative force negative work. Q10.3 is a follow-up to question 10.1.2 where the learner had to state whether the kinetic energy of a box increases, decreases or remains the same when its velocity changes from  $-4 \text{ m}\cdot\text{s}^{-1}$  to  $-1 \text{ m}\cdot\text{s}^{-1}$ . Blue was able to answer Q10.1.2 correctly as he stated that the kinetic energy decreases. In Q10.3 learners were required to state whether the net work done on the box in Q10.1.2 was positive, negative or zero. The Work Energy Theorem states that the net work done on an object is equal to the change in kinetic energy of that object. The two critical features are “net-work” and “change in kinetic energy”. This problem in Q10.3 can be solved by reasoning that the kinetic energy of the box has decreased, making the change in kinetic energy negative and therefore resulting in the net work done being negative. However, in lines 184-189 of his TAP given below, Blue shows that these critical features of the work energy theorem are not in his area of focal awareness as he is answering this question. Instead, he concentrates on the force that would have brought about this change in velocity, which possibly resulted in his AC W7. He reasons that since the force is positive the work done will be positive. His reasoning also shows that there is a lack of discernment (LOD) between “work” and “net work” since the question required him to state whether the net work done was positive, negative or zero and he reasoned about the work done instead of net work done. Furthermore, in his understanding of the positive and negative sign of velocity he is also displaying an alternative conception about velocity which seems to be based on his understanding of the number line. According to the number line  $-4 < -1$ , meaning that  $-4$  is a smaller integer when compared to  $-1$ . However, the “ $-4$ ” and “ $-1$ ” in “ $-4 \text{ m}\cdot\text{s}^{-1}$ ” and “ $-1 \text{ m}\cdot\text{s}^{-1}$ ” refer to the directions and magnitudes of the velocity. The negative sign specifically refers to the direction. Hence, it will be illogical to state that “it moves to a greater speed” as he states in line 185 of his TAP. Lines 184-185 are also displaying a LOL. These aspects of LOD and LOL will be discussed further under the discussion on LOD and LOL.

182 (Q10.3) (Q10.1.2). And in 10.1.2 above

183 is the net work done being, net work being done on the box positive, negative or zero?

184 Well what I think is because it it moved from a less big to a greater one.

185 Because it had to be because of a positive force that made it move at a greater speed

186 so that so it can't have the same as the one above.

- 187 *Its positive,*  
 188 *its a positive force*  
 189 *it should result in a positive work being done.*

Another example showing that learners are displaying LOA as a possible reason for experiencing difficulty in solving problems correctly, is that of Gold as she is responding to Q11.4 in her TAP lines 357-359 where she shows that the work done by the gravitational force on the rider-motorbike system is not in her area of focal awareness as she is attempting to solve the problem. Work done by the gravitational force is a critical feature of the Work Energy Theorem for any object that is on the earth. It is not that Gold does not know of the presence of the gravitational force as she had shown in her response to Q11.2 that she is aware of it. She also knows how to calculate the work done by the gravitational force and to use it to solve problems if she is made aware of it as she demonstrated in Q13.2 and Q13.3. In Q13.2 learners were asked to calculate the work done by the gravitational force and in Q13.3 they were asked to calculate the velocity of the falling block. Gold was able to solve the problems in Q13.2 and Q13.3 using the work done by the gravitational force correctly, perhaps because she was made aware of the work done by the gravitational force. In both Q11.4 and Q12 where no mention was made of the gravitational force, she failed to include the work done by the gravitational force in her attempt to solve the problems. The reason for her experiencing this difficulty to solve the problems correctly is most probably her LOA of this critical feature of the work energy theorem.

- 357 *So the net work done is the work done by the frictional force plus the work done by the by the force applied.*  
 358 *Ok so the net work done is equal to the work done by, the work done by*  
 359 *the frictional force plus the work done by the force applied.*

### **7.2.3 Lack of Discernment**

Lack of Discernment (LOD) as a reason for learners holding alternative conceptions and problem-solving difficulties emerged from the think aloud protocols of the learners. This category describes a situation where the learners fail to discern differences in one or more

critical features of Work Energy Power that is pertinent to the question that a learner is attempting to understand and solve. Twenty-one of the 168 learner responses were categorised as displaying this lack of discernment of critical features. This represents 12.5% of all the learner responses. All eight learners displayed the LOD in at least one question in their TAPs.

Table 7.3 presents the questions to which the learner responses displayed that there was a lack of discernment between critical features of Work Energy Power necessary to understand and solve the problem at hand. For example, Gold displayed the LOD in her responses to questions 7, 9.2, and 11.4, and Timber displayed the LOD in his responses to questions 9.1 and 13.3.

**Table 7.3: Prevalence of Lack of Discernment**

LOD								
Learner	L1 Ann	L2 Patience	L3 Gift	L4 Gold	L5 London	L6 Timber	L7 Jasmine	L8 Blue
Questions showing Evidence of LOD on WEP	9.2	7, 9.2	7, 9.2, 11.4	9.1, 9.2, 10.2	7, 10.1, 10.2, 10.3	7, 9.1, 9.2, 13.3	9.1, 9.2, 13.3	10.3

I will illustrate the LOD category by discussing Timber's response to Q13.3 as illustrated in his TAP lines 623-630 that are presented at the end of this paragraph. This question had been sourced from the National Senior Certificate Examinations as explained in Chapter 4 (DBE, 2017c). Question 13.3 is a structured question that requires the learner to use energy principles to calculate the speed of a 6 kg block when it falls through a vertical distance of 1.6m while attached by a light inextensible string to a 4 kg block that is lying on a rough horizontal surface. Two critical features of this problem are the tension in the string and the force of kinetic friction. In lines 623-626 Timber correctly calculates the frictional force by using the coefficient of kinetic friction that was given in the question. However, he incorrectly then equates this frictional force (which is the force of kinetic friction) to the tension as he reasons in line 629 that "my four kilogram's block is at rest". This reasoning is showing that he has a lack of discernment between kinetic friction and static friction. If the block was at rest, then he would have needed to calculate the force of static friction (which has a range of values) by using the coefficient of static

friction. However, the block is in motion and therefore the force of kinetic friction (on the 4 kg block) cannot be equal and opposite in direction to the tension on it. Lines 623-630 of Timber's TAP are presented below:

623 *So I will have to calculate the frictional force*

624 *which will be coefficient of kinetic friction*

625 *which is been given which is zero point four times normal force ( $F_k = 0,4 N$ ).*

626 *So I'm going to say zero point four times thirty-nine point two which is going to give me fifteen point six eight ( $0,4 \times 39,2 = 15,68$ ).*

627 *So my tension is also going to be fifteen point eight (lack of awareness that kinetic friction acts when the object is in motion and lack of discernment regarding motion)*

628 *since* ( $T = 15,8$ . It seems he made a mistake here - said point eight instead of point six eight. He also wrote 15,8 instead of 15,68 on his script.)

629 *my four kilograms block is at rest*

630 *and don't forget that is in newtons.*

Another example showing that LOD can be a possible reason for learners holding ACs, is that of Ann, as she attempted to solve the problem in Q9.2. In Q9 a climber and a hiker (having equal masses) both started off at the same time at the foot of a mountain to climb it. The hiker took a longer but easier route and was the first to arrive at the top of the mountain. The climber took a shorter route and arrived later at the top of the mountain. In Q9.1 learners were asked to state which of the two people expended more power in climbing the mountain. More time less power expended (AC P3) is the alternative conception about power that Ann displayed as she attempted to solve the problem in Q9.2 as indicated in her TAP line 150 that is presented below. Ann recalls the equation for power as  $P = \frac{\Delta W}{\Delta t}$  correctly as indicated in line 138 of her TAP and she is aware of the relationship between power and work done and between power and duration, but she is showing a lack of discernment (LOD) regarding the simultaneous effect of each of the variables work and time when comparing the power expended by the hiker and the climber. Lines 150-153 of her TAP indicate that she is only considering the effect of time on the power expended by the two people. This would be correct reasoning if she had stated that the work done by both climber and hiker are the same, but in Q9.1 she had

stated that the climber does more work and she completely ignored this as she attempted to answer Q9.2.

138 *So from the equations that I have, it says that power, power is equal to the work done divided by time.*

139 *So I think that expends more power in getting to the top.*

140 *So having to take into consideration two things: the hiker takes longer but easier route, takes a longer but easier route to get to the mountain (she is only comparing the times and not the work done by the hiker and climber)*

141 *and arrives first.*

142 *So it means that the hiker spends less time to move from the, to move from the er from the foot of the mountain to the top.*

143 *And then the climber took a longer time so because it is.*

144 *In this case the formula of power divided by time it will er is er*

145 *power is being equivalent to work done divided by time.*

146 *It means that power it's directly proportional to work done ( $P \propto W$ )*

147 *but inversely proportional to the time that is spent ( $P \propto 1/\Delta t$ ).*

148 *So because because the the the the the climber, the climber spends more time,*

149 *it means that which one expends more power in getting to the top of the mountain.*

150 *So because the the climber takes more time to get to the mountain, it means that the power that he expends its less,*

151 *but because the the the the hiker spends a short period of time to get to top of the mountain, it means that he uh he expends more power.*

152 *Therefore hiker expends more power. Hiker expends more power.*

153 *Hiker expends more power as he takes the shortest time to reach the top of the mountain.*

#### **7.2.4 Lack of Reason**

Lack of Reason (LOR) as a possible reason for learners holding alternative conceptions and problem-solving difficulties emerged from the think aloud protocols of the learners. This category describes a situation where a learner does not display scientific reasoning that is pertinent to the question that he/she is attempting to understand and solve, but

rather displays a “gut-feeling” kind of reasoning. It also includes those responses of learners where they verbalise that they do not know why they have a particular solution/answer to a problem. This category does not in any way state that there is anything particularly wrong with “gut-feeling” but rather that the learners are unable to provide any reasoning for their particular solutions to problems. Nine of the 168 learner responses were categorised as displaying this lack of reason (LOR). This represents 5.3% of all the learner responses. Five of the eight learners displayed the LOR in at least one question in their TAPs.

Table 7.4 presents the questions to which the learner responses displayed that there was a lack of reason behind their particular solution to a problem. For example, Jasmine displayed the LOR in her responses to questions 6 and 9.1, and Blue displayed the LOR in his responses to questions 4 and 5.

**Table 7.4: Prevalence of Lack of Reason**

Learner	LOR							
	L1 Ann	L2 Patience	L3 Gift	L4 Gold	L5 London	L6 Timber	L7 Jasmine	L8 Blue
Questions showing Evidence of LOR on WEP			8	6	3, 5, 6	6, 9.1	4	5

I will illustrate the LOR category by discussing Timber’s response to Q3 as illustrated in his TAP lines 99-108 that are presented at the end of this paragraph. Q3 is a Multiple-Choice Question that has five distractors, and Timber states quite clearly in line 102 that he does not know why he is selecting option C. Option C is the incorrect response. He does however state that he does not understand the distractors in line 103. In lines 101 and 107 of his TAP he seems to have a “gut feeling” that the answer must be his friend and not him. Lines 99-108 of Timber’s TAP are presented below:

99 *So I won't go with C,*

100 *I'd rather go with A than C.*

101 *But I think it's it's supposed to be my friend,*

102 *but I don't know the reason,*

103 *I don't understand the given explanations.*

104 *Mmm.*

105 *Ah its C,*

106 *I think its C.*

107 *Because it has to be my friend, can't be me.*

108Ya. *Ya. I think its C.*

### 7.2.5 Lack of Logic

Lack of Logic (LOL) as a possible reason for learners holding alternative conceptions and problem-solving difficulties emerged from the think aloud protocols of the learners. This category describes learner responses that display a lack of logic involving critical features of Work Energy Power that is pertinent to the question that a learner is attempting to understand and solve. Nineteen of the 168 learner responses were categorised as displaying this lack of logic (LOL) involving critical features of Work Energy Power. This represents 11.3% of all the learner responses. Seven of the eight learners in the sample displayed the LOL in at least two questions in their TAPs.

Table 7.5 presents the questions to which the learner responses displayed that there was a lack of logic (LOL) involving critical features of Work Energy Power necessary to understand and solve the problem at hand. For example, Blue displayed the LOL in her responses to questions 3, 9.1, 9.2, 10.2 and 10.3 and Gift displayed the LOL in his response to questions 6, 7, 9.2 and 10.1.2.

**Table 7.5: Prevalence of Lack of Logic**

LOL								
Learner	L1 Ann	L2 Patience	L3 Gift	L4 Gold	L5 London	L6 Timber	L7 Jasmine	L8 Blue
Questions showing Evidence of LOL on WEP	5, 9.1	5, 6	6, 7, 9.2, 10.1.2	10.1.1, 10.2	10.1.1, 10.1.2		5, 9.2	3, 9.1, 9.2, 10.2, 10.3

I will illustrate the LOL category by discussing Gift's response to Q6 as illustrated in his TAP lines 88-92 that is presented at the end of this paragraph. Question 6 is an MCQ with

five distractors. In question six a ball is dropped from a high tower, and it falls freely under the influence of the gravitational force. Learners are required to choose the option that is true from the five distractors. Gift chooses option E as evidenced in line 92 of his TAP which states that the total mechanical energy of the ball decreases as it falls, as the correct option. This option is incorrect. Gift is displaying an incorrect understanding of the positive and negative signs associated with velocity. In his understanding of the positive and negative sign of velocity he is also displaying an alternative conception about velocity which seems to be based on his understanding of the number line. According to the number line  $-n < 0$  (where  $n$  is a natural number), meaning that all negative integers are less than zero. This is a correct understanding of integers. Gift seems to be applying this understanding of integers to velocity and he is interpreting the negative velocity of the ball as it is falling freely as being smaller than zero velocity as he stated in line 88. He further concludes (as evidenced in line 91 of his TAP) from this understanding of velocity that the kinetic energy of the ball is decreasing as it falls freely. This does not make any mathematically logical sense. How can a ball that has a velocity of  $-2 \text{ m}\cdot\text{s}^{-1}$  for example be moving slower than when its velocity was zero? This is the logical sense that Gift seems to be missing. Gift also makes another mathematical error by saying that the kinetic energy is negative as he is unaware at this point that the square of a negative value is always positive and therefore the kinetic energy cannot be negative. This LOL that Gift displays is similar to the LOL that Blue displayed as he answered Q10.3 that I have already discussed in section 7.2.2. The AC about velocity that Gift is displaying in Q6 is the same as the AC that Blue displayed in Q 10.3. Lines 88-92 of Gift's TAP are presented below:

88 *So basically when the ball is in free fall I would say at the when er the ball was dropped its bec er I think the the velocity decreases because it's like reversing.*

89 *I'm not sure*

90 *but according to er vertical projectile motion we know that initially when the ball is dropped from the the the the highest point the maximum point the the initial velocity will be zero.*

91 *So the kinetic energy on will be decreasing and becoming negative cos if you take upwards as pos er upwards as positive ne.*

92 *So I would say the total mechanical energy of the ball decreases as it falls cos as the ball falls the height also decreases.*

### 7.2.6 Lack of Clarity

Lack of Clarity (LOC) as a possible reason for learners holding alternative conceptions and problem-solving difficulties emerged from the think aloud protocols of the learners. This category describes a learner response that displays confusion about critical features of Work Energy Power that are pertinent to the question that he/she is attempting to understand and solve. This category also includes learner responses where the learner states that he/she is unsure about any critical features pertinent to Work Energy Power. Thirteen of the 168 learner responses were categorised as displaying this lack of clarity pertaining to critical features of Work Energy Power. This represents 7.7% of all the learner responses. Seven of the eight learners in the sample displayed the LOC in at least one question in their TAPs.

Table 7.6 presents the questions to which the learner responses displayed that there was a lack of clarity regarding critical features of Work Energy Power necessary to understand and solve the problem at hand. For example, Jasmine displayed the LOC in her responses to questions 7, 9.1 and 12 and Gold displayed the LOC in her response to question 10.2.

**Table 7.6: Prevalence of Lack of Clarity**

LOC								
Learner	L1 Ann	L2 Patience	L3 Gift	L4 Gold	L5 London	L6 Timber	L7 Jasmine	L8 Blue
Questions showing Evidence of LOC on WEP	6, 7, 12	4	7	10.2	10.1.2	2, 3, 9.2	7, 9.1, 12	

I will illustrate the LOC category by discussing London's response to Q10.1.2 as illustrated in his TAP lines 529-540. Question 10.1.2 is a structured question that required the learner to state whether the kinetic energy of a small box that is moving along a horizontal floor increases, decreases or remains the same when its velocity changes from  $-4\text{m}\cdot\text{s}^{-1}$  to  $-1\text{m}\cdot\text{s}^{-1}$ . London states in lines 535 and 537 of his TAP that he is confused.

He does not seem to have any clarity about the net work that is done on the box as he reasons in lines 532-540 of his TAP. Furthermore, he states the relationship between the net work done to the change in kinetic energy which is a critical feature of the Work Energy Theorem, but he does not use this knowledge to solve the problem, which would have been a quick way to solve the problem qualitatively. He is also displaying the AC W7 Positive Force Positive Work Negative Force Negative Work. London is displaying a LOC about the sign of the net work done because he is not relating this to the energy of the box in terms of whether the box is gaining or losing energy. Instead, he is relating the sign of the net work done to the sign of the force. London also seems to be displaying a LOC about the scalar nature of work and the vector nature of force.

528 *Net work done is equals to my change in the kine in the object's kinetic energy.*

529 *So the final velocity is negative one, the final velocity is negative one.*

530 *Negative one minus squared is a positive value which is ...mmm.*

531 *Net work done, net work done.*

532 *And the net work done we see can be negative.*

533 *No the net work done is positive.*

534 *I don't think value have to change.*

535 *This is confusing ...*

536 *the force applied it is in a negative direction, it is in the opposite direction.*

537 *But I'm confused here*

538 *though the signs negative implies that work is negative*

439 *or we get by the negative velocity squared.*

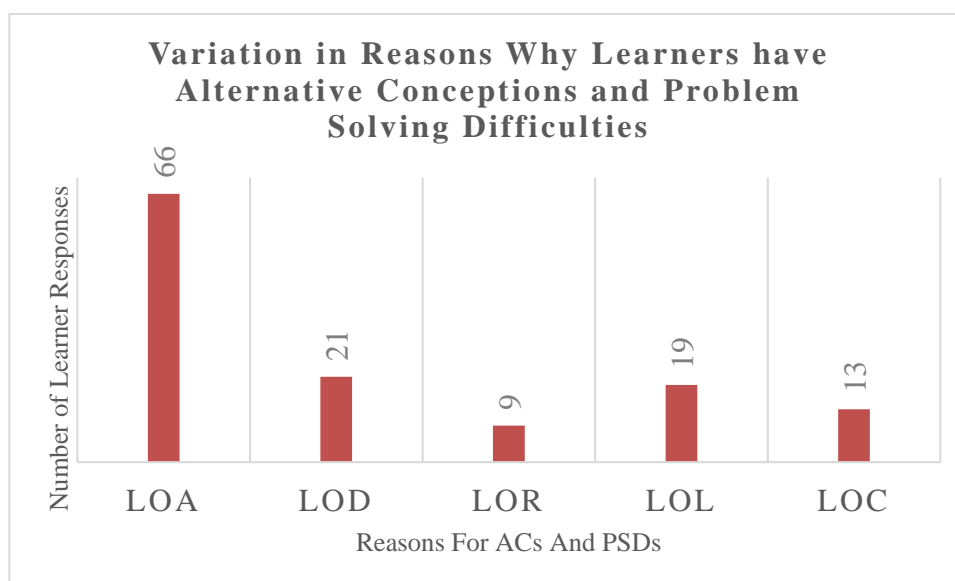
538 *But no.*

### **7.3 Analysis: why alternative conceptions and problem-solving difficulties**

In section 7.2 the results showing the possible reasons for learners holding alternative conceptions were presented. In this section, these results will be analysed using VT as an analytical lens. An analysis of the reasons why learners have alternative conceptions and problem-solving difficulties on Work Energy Power is presented in Graph 7-1. There are five qualitatively different ways in which the learners experienced the problems presented

on Work Energy and Power which, in this study, is the intended object of learning. The analysis reveals that not all learners experienced all the dimensions of variation of the object of learning in the same way.

**Graph 7-1: Variation in Reasons Why Learners have Alternative Conceptions and Problem-Solving Difficulties**



Lack of Awareness (LOA), Lack of Discernment (LOD), Lack of Logic (LOL), Lack of Clarity (LOC) and Lack of Reason (LOR) are the five different ways in which the learners experienced the object of learning that accounted for their problem-solving difficulties (PSDs) and alternative conceptions (ACs). Lack of awareness (66 responses) was the most prevalent reason for their PSDs and ACs followed by LOD, (21 responses), LOL (19 responses), LOC (13 responses) and LOR (9 responses). It must be noted that the LOA, LOD, LOL, LOC and LOR do not represent the entire spectrum of the learners' experiences as they worked through the questions in the TAQ. Learners had also displayed an understanding of CFs of WEP that is in line with the intended object of learning as discussed in sections 6.2 and 6.3. However, the focus of this chapter is on research question three which is probing why Grade 12 Physical Sciences learners hold certain alternative conceptions and problem-solving difficulties on work, energy and power. Hence the focus is on those factors that contribute to learners displaying ACs and PSDs.

“To learn something, the learner must discern what is to be learned (the object of learning). Discerning the object of learning amounts to discerning its critical aspects” (Marton & Pang, 2006, p. 193). According to this definition of learning provided by Marton and Pang (2006), a study of how the learners experience the different dimensions of variation of the critical features of the object of learning will provide insights into the reasons why learners can or cannot understand or do problem-solving involving that object of learning. Table 7.7 provides an analysis of how the learners experienced the problem-solving exercises on the critical features of Work Energy Power.

A further analysis of the data presented in section 7.2 was done. This analysis took into account the dimensions of variation of the intended object of learning and are presented in Table 7.7. This analysis revealed how the learners experienced the dimensions of variation of Work Energy Power and this is presented in Table 7.7.

**Table 7.7: Variation in lived object of learning**

Work Energy Power	Dimensions of Variation in Lived Object of Learning					TOTAL
	LOA	LOD	LOR	LOL	LOC	
Critical Features of the intended object of learning	Number of learner responses (%)	Number of learner responses (%)	Number of learner responses (%)	Number of learner responses (%)	Number of learner responses (%)	
Calculation of Work (4x8=32)	8 (25%)	3 (9%)	1 (3%)	2 (6%)	2 (6%)	16
Conservation of mechanical Energy (4x8=32)	23 ((72%)	0	7 (22%)	6 (19%)	2 (6%)	38
Work Energy Theorem (7x8=56)	33 (59%)	11 (20%)	1 (2%)	4 (7%)	7 (13%)	56
Work and Power (2x8=16)	2 (13%)	6 (38%)	0	3 (19%)	1 (6%)	12
Kinetic Energy (2x8=16)	0	1 (6%)	0	4 (25%)	1 (6%)	6
Free Body Diagrams (2x8=16)	0	0	0	0	0	0
Total	66 (52%)	21 (16%)	9 (7%)	19 (15%)	13 (10%)	128

I will explain the analysis in Table 7.7 by discussing the value “8” (25%) in column 3 and row 3. The value “8” refers to the number of learner responses that displayed LOA. The 25% refers to the percentage of learner responses out of the total number of learner responses on Calculation of Work ( $25\% = 8/32 \times 100\%$ ). There were four questions on Calculation of Work in the TAQ and therefore 32 learner responses ( $4 \times 8 = 32$ ).

According to Table 7.7, LOA and LOD are the most prevalent reasons for most of the problem-solving difficulties and alternative conceptions held by learners in this sample. This finding lends support to the current thinking on learning from a VT theory

perspective that awareness and discernment are necessary conditions of learning (Bussey et al., 2013; Lo, 2012; Marton & Pang, 2006).

The analysis shows that the learners in this sample can identify all the forces acting on objects and draw the free body diagrams correctly. They also did not display PSDs regarding the drawing of the free body diagrams.

Conservation of mechanical energy is a critical feature of WEP (object of learning) that elicited the worst experience of the learners. This was mainly due to a lack of awareness (LOA), lack of reason (LOR) and lack of logic (LOL). The Work Energy Theorem takes second place in terms of “difficult” experiences of learners. This was mainly due to a lack of awareness (LOA), lack of clarity (LOC) and lack of discernment (LOD). Most of the learner responses on Calculating Work Done showed that the learners experience was better when compared to that with conservation of mechanical energy and the work energy theorem. However, some learner responses showed a lack of awareness. The most prevalent reasons for ACs and PSDs on the critical feature Work and Power was lack of discernment (LOD), lack of logic (LOL) and lack of awareness (LOA). Finally, lack of logic was the most prevalent reason that learners experienced PSDs and ACs on Kinetic Energy.

This analysis overall shows that learners most probably are holding alternative conceptions and experiencing problem-solving difficulties because of a lack of awareness of critical features of the object of learning, lack of discernment of the dimensions of variation and a lack of mathematical logic in some situations. Furthermore, one may argue that Conservation of Mechanical Energy requires a learner to be simultaneously aware of several dimensions of variation like conservative and non-conservative forces, friction and net work done, which in themselves require simultaneous awareness of their own dimensions of variation. Thus, Conservation of Mechanical Energy can be regarded as a critical feature of WEP that is deep when compared to simple Calculation of Work done for example. Based on this argument, the analysis shows that learners experience PSDs and hold ACs because they cannot take several critical features into account simultaneously (Bussey et al., 2013; Lo, 2012; Marton & Pang, 2006). This pattern of variation has been named as “Fusion” and defined by Marton and Pang (2006, p. 199).

“The simultaneity of two dimensions of variation cannot be experienced without experiencing the two dimensions varying simultaneously” (Marton & Pang, 2006, p. 199).

### **7.3.1 Discussion: Reasons for Alternative Conceptions and Problem-Solving Difficulties**

This chapter explored possible reasons that explain why learners display ACs and PSDs. Five possible reasons have been identified. These are lack of awareness (LOA), lack of discernment (LOD), lack of logic (LOL), lack of clarity (LOC) and lack of Reason (LOR). These reasons show the limited number of qualitatively different ways in which the learners experienced the object of learning. These reasons can account for their problem-solving difficulties (PSDs) and alternative conceptions (ACs). Lack of awareness was the most prevalent reason for their PSDs and ACs followed by LOD, LOL, LOC and LOR.

52% of the learner responses showed that there was a LOA of critical features while 10% of all the learner responses showed that there was a LOC. It is important to note that these percentages are only provided as descriptive statistics to show the prevalence of these reasons. They do not have any further statistical significance as this is a phenomenographic study in which only a small sample has been analysed. Even a small percentage is significant as it would be indicating that a particular reason has been observed in this small sample. The reader could conduct further studies in order to check the prevalence of any of the reasons provided here in other studies that he/she may conduct, as suggested by Lincoln and Guba (1985). There is no attempt in this study to generalise the findings.

Another finding is that the more complex the concepts, theorems and principles, the more prevalent is LOA. In other words, one needs to be simultaneously aware of multiple features of a phenomenon in order to fully understand and experience it. The phenomenon here refers a concept, problem, event, etc.

These findings indicate that for a learner to fully understand and experience a phenomenon and be able to tackle problems regarding that phenomenon, there should be

awareness, simultaneity, discernment, reason, logic and clarity. The concept of awareness and simultaneity describe a condition where critical features that are pertinent to the problem that a learner is attempting to understand and solve, are simultaneously present in the learner's focal awareness. The learner is able to grapple with these critical features simultaneously and see them as parts of a whole.

Discernment is a concept that describes a situation where the learners are able to discern differences in one or more critical features that are pertinent to the problem that a learner is attempting to understand and solve. The concept of reason is a condition that is important in understanding and problem-solving. This condition of reason highlights that learners should always look for scientific reasoning in problem-solving. There should also be a state of clarity regarding the phenomenon that is being experienced.

Confusion about aspects of the phenomenon need to be cleared so that successful solutions can be found. The condition of logic is also important for phenomena to be understood and for successful problem-solving. For example, saying that a body moving at a velocity of  $-5 \text{ m}\cdot\text{s}^{-1}$  is travelling faster than a body moving at  $-10 \text{ m}\cdot\text{s}^{-1}$  because " $-5 > -10$ " shows a lack of logic notwithstanding the lack understanding of vectors and scalars.

Marton and Booth (1997) have suggested that awareness, simultaneity and discernment are necessary conditions of learning. This study proposes additions to this discourse but relating specifically to understanding and problem-solving in physics as shown in Figure 7.6.

**Figure 7.1: Necessary conditions for understanding and problem-solving in Physics**



These additions are reason, logic and clarity. This study has shown that these concepts, awareness, simultaneity, discernment, reason, logic and clarity are important conditions for learners to fully understand scientific phenomena and successfully solve problems in physics by showing that in their absence learners hold ACs and PSDs.

## 7.4 Conclusion

This chapter presented the results, findings and analysis pertaining to research question three of this study.

*Research Question Three: Why do Grade 12 Physical Sciences learners hold certain alternative conceptions and problem-solving difficulties on work, energy and power?*

In Chapter 6, the alternative conceptions, problem-solving approaches and problem-solving difficulties on work, energy and power displayed by a small sample of eight Grade 12 Physical Sciences learners from one school in South Africa were discussed. In this chapter, the possible reasons for these learners to hold these alternative conceptions and problem-solving difficulties on work energy and power have been discussed. This process of explaining why the learners in the sample displayed these qualitatively different ways of experiencing WEP has been underpinned by VT.

Five possible reasons that explain why learners display ACs and PSDs have been identified in this study. These are Lack of Awareness (LOA), Lack of Discernment (LOD), Lack of Logic (LOL), Lack of Clarity (LOC) and Lack of Reason (LOR). These reasons show the “limited number of qualitatively different ways” (Marton & Booth, 1997) in which the learners “experienced” the object of learning (p. 100). These reasons can explain why learners experience problem-solving difficulties (PSDs) and display alternative conceptions (ACs). LOA was the most prevalent reason for their PSDs and ACs followed by LOD, LOL, LOC and LOR.

52% of the learner responses showed that there was a LOA of critical features, while 10% of all the learner responses showed that there was a LOC. It is important to note that these percentages are only provided as descriptive statistics to show the prevalence of these reasons. They do not have any further statistical significance as this is a phenomenographic study in which only a small sample has been analysed. Even a small percentage is significant as it indicates that a particular reason has been observed in this small sample. The reader could conduct further studies in order to check the prevalence of any of the reasons provided here in other studies that he/she may conduct, as suggested by Lincoln and Guba (1985). There is no attempt in this study to generalise the findings.

Another finding is that the more complex the concepts, theorems and principles, the more prevalent LOA. In other words, one needs to be simultaneously aware of multiple features of a phenomenon in order to fully understand and experience it (Marton & Booth, 1997; Marton & Pang, 2006, 2013). The phenomenon here refers to a concept, problem or event. The focus of Chapter 7 was on research question 3. In the next chapter, the focus will be on research question 4.

## Chapter 8 - A PERSPECTIVE ON ALTERNATIVE CONCEPTIONS AND PROBLEM-SOLVING DIFFICULTIES FROM VARIATION THEORY

### 8.1 Introduction

The fourth objective of this study was to account for Grade 12 Physical Sciences learners' alternative conceptions and problem-solving difficulties using the variation theory of learning. This chapter focuses on the fourth Research question in this study:

*How can the Grade 12 Physical Sciences learners' alternative conceptions and problem-solving difficulties on work, energy and power be explained, using the variation theory of learning?*

In Chapter 7, the reasons for learners holding alternative conceptions and experiencing problem-solving difficulties were discussed. Five reasons, LOA, LOD, LOR, LOL, and LOC had emerged from the think aloud protocols of the learners. In this chapter, patterns of variation are taken into consideration as a possible explanation for the prevalence of these reasons.

### 8.2 Patterns of Variation

The questions in the TAQ (Appendix 10) were categorised according to the four patterns of variation that were identified by Marton et al. (2004, p. 16). These four patterns of variation are contrast, generalisation, separation and fusion.

#### 8.2.1 Contrast

In the TAQ Question 8 focuses on the conservation of mechanical energy. Q8 was chosen to illustrate the contrast pattern of variation because learners needed to contrast two situations, one where mechanical energy was conserved and one where mechanical energy was not conserved. In order to fully understand the principle of conservation of

mechanical energy learners need to compare situations where it is demonstrated and where it is not. This is the pattern of variation titled contrast. There are two conditions that need to be satisfied for mechanical energy to be conserved. One condition is that the system must be isolated, and the other is that there should be no friction. These two conditions can be regarded as critical features of the conservation of mechanical energy. The pattern of variation evident in Question 8 was Contrast and this is presented in Table 8.1.

**Table 8.1: Pattern of Variation: Contrast**

Learners				L1	L2	L3	L4	L5	L6	L7	L8
Q8: Critical Features	Invariant	Dimensions of Variation	Pattern of Variation	Ann	Patience	Gift	Gold	London	Timber	Jasmine	Blue
Work Energy Theorem	No friction, inclined plane, force of gravity acting on both cars	Car X has no external force applied while Car Y has an external force applied	Contrast	LIMITED, LOA	PACT, LOA	MPS, LOR, LOA, ACE4	LIMITED, LOA	LIS	PACT, LOA	PACT, LOA	PACT
Variation in learner responses				Unable to solve the problem	Solves the problem	Unable to solve the problem	Gets scenario one correct. Says nothing about scenario two	Solves the problem	Unable to solve the problem	Unable to solve the problem	Gets scenario one correct. Says nothing about scenario two
Evidence of contrast				No	No	No	No	Yes	No	No	No

The learner is presented with two scenarios. In Scenario One, a car, Car X, is freewheeling uphill while its engine is switched off and in the Scenario Two, a car, Car Y, is driving uphill at a constant velocity. In both scenarios the learner is asked to ignore friction. The contrast between the two scenarios is that one is isolated while the other is not. A simple way to approach this question is to state that the mechanical energy is conserved where the condition that the system be isolated is met. That is saying that the learners must be able to see the contrast between the two situations in terms of the critical features of the principle of conservation of mechanical energy. Only three learners were able to state that mechanical energy is conserved in Scenario One. In only one of these three responses there was an awareness of this contrast, and this fact was used to arrive at a solution. The other two “correct responses” used the PACT (plug-and-chug-trial) approach to arrive at an answer. The remaining five responses chose Scenario Two, which is incorrect, as the option where mechanical energy is conserved. In all five responses, learners were unable to see this contrast between the two scenarios indicating that this critical feature of the conservation of mechanical energy was not in their focal awareness at the time of answering this question. It was only London who articulated awareness of this contrast which he used to arrive at the correct solution as shown in lines 413-427 of his TAP:

413 *So when car X approaches the hill the driver turns off the engine at the bottom of the hill and the car freewheels up the hill.*

414 *It is observing scenario one. ... (silence)*

415 *OK.*

416 *The conservation of the mechanical energy is observed in scenario one o*

417 *because according to this principle there has to be no effect of external forces.*

418 *In scenario one the car the car's engine is switched off so and so it freewheels it freewheels upwards up up up the hill up the hill I'm basing backwards up the hill*

419 *and therefore when it freewheels it has no ... it has no applied force ...*

420 *we have been told we have been told to ignore friction,*

421 *therefore ...*

422 *ughm*

423 *(suddenly from slow speaking his speech gets back to a faster pace)*

424 *therefore only gravitational force acts on it.*

425 *Oh wait only the mechanical energy is conserved. ...*

426 *Er in scenario two ... there is there is a presence of an external applied force which is the force of the engine ...*

427 *thus making the system no longer isolated isolated. OK.*

### **8.2.2 Generalisation**

In order to explore whether learners have a fuller understanding of the Work Energy Theorem, learners had been presented with two different situations in questions 11.4 and 13.3. These two questions required the learners to solve problems by applying the work energy theorem in different situations that had some critical features kept invariant and others varied as discussed in the paragraph below. The pattern of variation between these two questions was categorised as generalisation.

In both Q11.4 and Q13.3 the questions required the learners to use energy principles to calculate the velocity of an object. In Q11.4, the object was a motorbike driving up an incline in the presence of friction. In Q13.3, the object was a block falling vertically downwards while attached via a light inextensible string to another block that was lying on a rough horizontal surface. The critical features that are kept invariant between the two questions were: apply Work Energy Theorem, friction present and calculate velocity. The dimension of variation between the two questions was that in Q11.4 the motion was on an inclined plane and in Q13.3 the motion involved both the horizontal plane and the vertical plane. The pattern of variation between these two questions is generalisation: that is how the learners experience the WET in different situations. The data pertaining to the alternative conceptions, problem-solving approaches and problem-solving difficulties displayed by learners in their TAPS were coded and recorded using NVIVO. This data has already been presented, analysed and discussed in Chapters 6 and 7, but it has been included here for purposes of further analysis with respect to patterns of variation. The final velocity that each learner calculated for each of questions 11.4 and 13.3 were also recorded. This data is presented in Table 8.2.

**Table 8.2: Pattern of Variation: Generalisation**

Critical Features	Invariant	Dimensions of Variation	Pattern of Variation	Ann	Patience	Gift	Gold	London	Timber	Jasmine	Blue
Calculating net work done. Calculating work done by friction, applied force and gravitational force.	Apply Work Energy Theorem, friction present, Calculate velocity	Motion on single Inclined Plane	Generalisation	LIMITED, LOA (12,96)	LIMITED, LOA (but is able to solve the problem using a longer solution path)	LIMITED, LOD, LOA (12,96)	LIMITED, LOA	LIS	LIMITED, LOA (12,96)	LIMITED	LIMITED, LOA
Conservation of mechanical energy in the presence of non-conservative forces – not conserved.	Apply Work Energy Theorem, friction present, Calculate velocity	Motion on both horizontal and vertical planes	Generalisation	LIS	LIS	PACT	LIS	LIMITED, LOA	LIMITED, LOD, ACE3	MPS, LOD, LOA	LIS
Final Answers for Q11.4				12,96	8.37	12,96	12,96	8,37	12,96	0,74	12,96
Final Answers for Q13.3				3,71	3,71	5,5	3,71	2,66	5,6	5,6	3,71

Critical Features	Invariant	Dimensions of Variation	Pattern of Variation	Ann	Patience	Gift	Gold	London	Timber	Jasmine	Blue
Variation of learner responses				In Q11.4 fails to take work done by gravitational force into account. Solves Q13.3 correctly.	Solves Q11.4 correctly. Solves Q13.3 correctly. Uses a long-winded approach to calculate work done by gravitational force in Q11.4 because she fails to see that work done by it is independent of the path taken.	Does not solve both problems	In Q11.4 fails to take work done by gravitational force into account. Solves Q13.3 correctly.	Solves Q11.4 correctly. In Q13.3 - fails to take friction into account. Calculates Work done by gravitational force incorrectly.	Does not solve both problems	Does not solve both problems	In Q11.4 fails to take work done by gravitational force into account. Solves Q13.3 correctly.
Evidence of Generalisation				No	Yes	No	No	No	No	No	No

It is evident from the data presented in Table 8.2 that only one learner, Patience, was able to solve the problems in Q11.4 and Q13.3. She did not display any problem-solving difficulties or alternative conceptions when answering Q13.3. However, she did display a lack of awareness of the conservative nature of the gravitational force when she was answering Q11.4 and she therefore used a long-winded approach to calculate the work done by the gravitational force. Only five learners could solve at least one of the two problems and two learners could not solve any of the problems. These seven learners displayed problem-solving difficulties and one of them also displayed an alternative conception about energy. One highly prevalent PSD that is revealed by looking at the generalisation pattern of variation is that five of the eight learners Ann, Gift, Gold, Timber and Blue, arrived at the same incorrect value for velocity in Q11.4 and this was due to their LOA of the work done by the gravitational force. Three of these five learners Ann, Gold and Blue arrived at the correct value for velocity in Q13.3. In both Q11.4 and Q13.3, learners needed to include the work done by the gravitational force in their calculation of the net work done. One of the reasons that these three learners displayed an LOA as a problem-solving difficulty in Q11.4 and not in Q13.3 is that in Q11 the question did not draw their attention to the work done by the gravitational force whereas in Q13 their attention was drawn to this as they were told to calculate the work done by the gravitational force in the earlier question Q13.2. This analysis is thus indicating that there is evidence of generalisation only in the response of one learner.

One can therefore conclude that seven of the eight learners do not fully understand the work energy theorem. This possibly accounts for their display of problem-solving difficulties and alternative conceptions. These learners are not able to apply their knowledge of the work energy theorem when exposed to different dimensions of variation of the critical features of this theorem. In the case of the single learner who was able to solve both questions albeit with LOA in one of them, this data is insufficient to prove that this learner fully understands the work energy theorem as more variations in the critical features need to be applied in order to come to this conclusion. This could be the research agenda of another study.

The utilisation of the generalisation pattern of variation as explained by Marton et al. (2004) in understanding learner responses to problem-solving exercises has been used to

account for learners holding alternative conceptions and problem-solving difficulties. This has shown that while some learners can successfully solve a problem based on certain concepts on Work Energy Power, they may not necessarily be able to solve other problems based on the same concepts. This leads one to conclude that the learners do not fully understand the concepts that are being assessed and perhaps greater exposure to such problems with carefully thought-out dimensions and patterns of variation could contribute towards deeper and fuller understanding of concepts.

### 8.2.3 Separation

The work done by a force on an object can be positive, negative or zero. This magnitude and sign of work taken together is a critical feature of work. This is the amount of work done on an object. Since work is a scalar quantity these quantities of work done on an object by different forces can be added algebraically. Learners need to be able to identify whether the work done by a force or several forces on an object that is moving a displacement  $\Delta x$  is positive, negative or zero. Questions 1 and 4 were designed to test the understanding of a learner regarding the amount of work done by the applied force acting on an object that is moving on a horizontal plane in the presence of friction. The pattern of variation between these two questions was categorised as separation.

Both Q1 and Q4 were MCQs. In both Q1 and Q4 the learners were required to qualitatively determine the work done by friction and an applied force in order to choose the correct option in the MCQ. In Q1 the object was a box that was pulled along a straight horizontal road in the presence of friction by an applied force that was acting at an angle to the horizontal. In Q4 the object was a box that was pulled along a horizontal surface in the presence of friction by a horizontal applied force. The critical features that are kept invariant between the two questions were: one object in motion, horizontal plane, friction present, applied force present. The dimensions of variation were that in Q1 the velocity could be constant or changing, and the applied force is a pulling force at an angle to the horizontal by a person. The dimensions of variation in Q4 was that the velocity is constant and applied force is a pulling force by a person in horizontal direction. The pattern of variation between these two questions is separation: that is how the learners understand the amount of work done by the frictional force and the applied force in different

situations. These two questions were intended to explore the learners' understanding of the work done by the applied force on an object moving in a horizontal direction in the presence of friction. The data pertaining to the alternative conceptions, problem-solving approaches and problem-solving difficulties displayed by learners in their TAPS were coded and recorded using NVIVO. As stated in the preceding section, this data has already been presented, analysed and discussed in Chapters 6 and 7, but it has been included here for purposes of further analysis with respect to patterns of variation. The variation in learner responses to these two questions were also recorded. This data is presented in Table 8.3.

**Table 8.3: Pattern of Variation: Separation**

Critical Features of Work	Invariant	Dimension of Variation	Pattern of variation	Ann	Patience	Gift	Gold	London	Timber	Jasmine	Blue
Q1: Determining the amount of work done by a force	Object in motion, One object, horizontal plane, friction present, applied force present	Velocity could be constant or changing, applied force is a pulling force by a person at an angle to the horizontal	Separation	LIS	LIS	LIS	LIS	LIS	LIS	MPS	LIS
Q4: Determining the amount of work done by a force	Object in motion, horizontal plane, friction present, applied force present, Net work done is zero	Velocity is constant, applied force is a pulling force by a person in horizontal direction		LIMITED, LOA, ACW6	LIMITED, LOC, LOA, ACW6	LIS	LIMITED, LOA, ACW6	LIS	LIMITED, LOA, ACW6	LIMITED, LOA, ACW6	LIMITED, LOR, ACW6

Critical Features of Work	Invariant	Dimension of Variation	Pattern of variation	Ann	Patience	Gift	Gold	London	Timber	Jasmine	Blue
Variation in learner responses				Q1 correct. Q4 incorrect and ACW6	Q1 correct. Q4 incorrect and ACW6	Q1 correct, Q4: Correct reasoning but comes to wrong conclusion. It seems like a language issue regarding the terms "zero" and "non-zero".	Q1 correct. Q4 incorrect and ACW6	Q1 and Q4 correct	Q1 correct. Q4 incorrect and ACW6	Q1 correct. Q4 incorrect and ACW6	Q1 correct. Q4 incorrect and ACW6
Evidence of separation				No	No	Yes	No	Yes	No	No	No

It is evident from the data presented in Table 8.3, that only one learner, London, was able to solve the problems in Q1 and Q4. He did not display any problem-solving difficulties or alternative conceptions when answering either of these two questions. All eight learners chose the correct option for Q1. Seven learners chose the incorrect option for Q4. Of these seven learners one learner, Gift, displayed correct reasoning but chose the incorrect option (option C). It seems like he had a language issue regarding the terms "zero" and "non-zero". His correct reasoning, but incorrect choice displaying a language issue is shown in his TAP lines 52-63.

52 *So basically my question it's er that I'm given is that considering the motion of the er the box.*

53 *I want to know which statement is true.*

54 *I'm having 5 options*

55 *so I think er the one that is relevant and correct is the er the total work done on the box by the net force it's zero (This is correct but is not one of the options given. He chooses option C which states that "The total work done on the box by the net force is non-zero.").*

56 *Yes. For example the the box was in a constant velocity.*

57 *If the box was in a constant velocity it obviously means the acceleration wa was the acceleration is zero*

58 *and if the acceleration is zero then in terms of er the the the the mechanical energy obviously will be zero because it's gonna affect g.*

59 *Yes so er when the acceleration is zero and the er it means the initial velocity and the final velocity is the remains the same so if it remains the same*

60 *the change in the kin object's kinetic energy will be zero*

61 *and the according to the work energy theorem is saying the net work done on object the total work on an object is equal to the object's change in er the object's change in kinetic energy*

62 *so since the kinetic energy it will be zero from initial in terms of the velocity and the final and so if you subtract the the the both then you will get zero*

63 *which means the the the net work done the total work done of the of the of the its non-zero.*

The remaining six learners all chose an incorrect option for Q4 and they also displayed an alternative conception about work ACW6 Work must be done on an object to keep it in motion. These six learners all arrived at the correct solution to Q1 but displayed problem-solving difficulties when solving Q4 and all six of them also displayed the same AC about work. This highly prevalent AC that is revealed by looking at the separation pattern of variation, is that six of the eight learners, Ann, Patience, Gold, Timber, Jasmine and Blue, believed that work must be done on an object to keep it in motion. Four of these six learners arrived at the same incorrect option E and two arrived at option C. Both these options show that the learners could not see that the work done by each of the forces (friction and applied force) were equal in magnitude, but opposite in sign. They failed to qualitatively determine the work done by each force when there was a variation in the information provided by the question on velocity. By separation of the critical features relating to the magnitude and sign of the work done and varying other critical features, it was possible to reveal the alternative conception ACW6 about work. This analysis is thus indicating that there is evidence of separation only in the response of one learner. This learner could separate the critical features of work among all the variations in other critical features of work that the two problems in Q1 and Q4 presented to him.

One can therefore conclude that six of the eight learners did not fully understand the work done by individual forces on an object as related to net work done by all the forces on that object. This further shows that these learners could not separate concepts from the whole and bring all the concepts back together in an understanding of the whole. This possibly accounts for their display of problem-solving difficulties and alternative conceptions. These learners are not able to apply their knowledge of work when exposed to different dimensions and patterns of variation of the critical features of this concept.

The utilisation of the separation pattern of variation as explained by Marton et al. (2004) in understanding learner responses to problem-solving exercises has been used to account for learners holding alternative conceptions and problem-solving difficulties. This has shown that while some learners can successfully solve a problem based on certain concepts on Work Energy Power, they may not necessarily be able to solve other problems based on the same concepts. This leads one to conclude that the learners do not fully understand the concepts that are being assessed and perhaps greater exposure to such

problems with carefully thought-out dimensions and patterns of variation could contribute towards deeper and fuller understanding of concepts.

### 8.2.4 Fusion

Q3 and Q5 of the TAQ required the learners to fuse several critical features like force, friction, shape, distance, displacement, height, velocity and kinetic energy in order to solve the problems in them. The acceleration of objects that fall towards the earth in the absence of air friction is equal to the acceleration of gravity and is not dependent on the mass of the falling object. The acceleration of the object in this case is only dependent on the acceleration due to gravity and on the height from which the object started its fall. The path followed by the object that is falling due only to the force of gravity, does not affect the acceleration and therefore the velocity with which the object falls. One way of understanding this (using energy principles and not equations of motion) is that the force of gravity is the only force doing work on the object in this situation and therefore the net work done on the object is the work done by the force of gravity.

In the case of two different objects with different masses sliding towards the earth on a frictionless slide, net work done on the 75 kg person is three times the work done on the 25 kg niece. Hence the change in kinetic energy for the 75 kg person is three times the change in kinetic energy for the 25 kg niece. This leads to the conclusion that the change in speed will be the same for both objects although the final kinetic energy of the more massive object will be more as shown below where the subscript 1 represents the 75 kg person and subscript 2 represents the 25 kg niece:

$$W_1 = 3W_2$$

$$\frac{1}{2}m_1v_{f_1}^2 - \frac{1}{2}m_1v_{i_1}^2 = 3\left(\frac{1}{2}m_2v_{f_2}^2 - \frac{1}{2}m_2v_{i_2}^2\right)$$

$$\frac{1}{2}m_1(v_{f_1}^2 - v_{i_1}^2) = 3\left(\frac{1}{2}m_2(v_{f_2}^2 - v_{i_2}^2)\right)$$

$$\text{Now } v_{i_1} = v_{i_2} = 0 \text{ and } m_1 = 3m_2$$

$$\therefore \frac{1}{2}(3m_2)v_{f_1}^2 = 3\left(\frac{1}{2}m_2v_{f_2}^2\right)$$

$$\therefore v_{f_1}^2 = v_{f_2}^2$$

$$v_{f_1} = v_{f_2}$$

A simpler explanation for the final velocity of the two objects being the same is that they have the same acceleration under frictionless conditions, which is the acceleration due to gravity.

There is a sense of mathematical logic that is required here and that is that although the work done on the more massive object is greater (by a factor of three), the change in velocity experienced by both objects is the same. The same conclusion can be reached using the equations of motion. Therefore, since the two objects have the same initial velocity and the same change in velocity, their final velocities will be the same. In Q3 and Q5 learners need to be able to simultaneously take into account the masses of the two people, their initial velocities, frictionless conditions, conservative nature of the force of gravity, net work done, kinetic energy, velocity and change in kinetic energy. They also need to simultaneously have a sense of mathematical logic. Questions 3 and 5 test the ability of the learner to fuse the concepts mentioned in this paragraph. The pattern of variation for Q3 and Q5 is fusion. I will discuss the fusion pattern of variation using Q5.

Q5 is an MCQ. In Q5 the learners were required to compare the speed of two people of different masses sliding down a frictionless slide, having started from rest from the same height. Q5 was chosen to illustrate the pattern of variation titled fusion because it required learners to engage with the other three patterns of variation (contrast, generalisation, separation) as well in order to deal with the question. Contrast: In order to fully understand how the mass of an object affects its speed as it falls freely, learners needed to contrast what happens with different masses like 75 kg, 25 kg etc. Generalisation: Learners also needed to understand that the acceleration of different objects falling under the influence of gravity only, is the same. Separation: Learners also needed to understand that the work done by the gravitational force on each of the different masses is different demonstrating the pattern of variation titled separation. Fusion: Together with engaging with the other three patterns of variation learners needed to simultaneously take into account several critical features like slope, friction, mass, gravitational force, kinetic energy, acceleration and velocity in order to deal with the question. The pattern of variation in Q5 is fusion. The data pertaining to the alternative conceptions, problem-solving approaches and problem-solving difficulties displayed by learners in their TAPS were coded and recorded using NVIVO. As stated in the preceding section, this data has

already been presented, analysed and discussed in Chapters 6 and 7, but it has been included here for purposes of further analysis with respect to patterns of variation. The variation in learner responses to Q5 questions was also recorded. This data is presented in Table 8.4.

**Table 8.4: Pattern of Variation: Fusion**

Critical Features	Dimensions of Variation	Pattern of Variation	Ann	Patience	Gift	Gold	London	Timber	Jasmine	Blue
Q5: Falling objects in absence of friction, $a$ is equal to $g$ . If initial velocity is the same for each object, then final velocity is the same, $a$ and velocity are independent of mass under frictionless conditions	Different masses	fusion	LIMITED, LOA	LIMITED, LOA	LIMITED, LOA	LIMITED, LOA	LIS	MPS, LOA	MPS, LOC	LIMITED, LOA
Final answer for Q5			D	D	D	C	A	C	A	E
Variation in learner responses			Incorrect: She says the greater the mass the lower the acceleration	Incorrect: She says the greater the mass the lower the acceleration	Incorrect: He says the greater the mass the lower the acceleration	Incorrect: She says the greater the mass the lower the acceleration	Correct	Incorrect: He says the greater the mass the lower the acceleration	Correct: She says weight and acceleration are inversely proportional	Incorrect: He takes less time as a given
Evidence of fusion			No	No	No	No	Yes	No	No	No

The data presented in Table 8.4 shows that only two learners, London and Jasmine, were able to solve the problem in Q5. While London did not display any problem-solving difficulties or alternative conceptions when answering this question, Jasmine displayed confusion as is evidenced in her TAP lines 113-119:

*113 So, you, because your greater weight causes a greater downward acceleration.*

*114 This is so much wrong. Like it's it's wrong because weight and acceleration they are inversely proportional. (She discards this option but with incorrect reasoning)*

*115 Like weight and mass they are inversely proportional, like something that kind like, I understand what I'm saying.*

*116 Your niece, because lighter objects are easier to accelerate.*

*117 You, because you take less time to slide down.*

*118 Er mm in terms of time aish.*

*119 I'm going to come back to it.*

Jasmine came back to the question as she promised in line 119 of her TAP where she read the question again and wrote down the correct answer on her script without any further “thinking aloud”.

The remaining six learners chose the incorrect option. Of these, five learners displayed the alternative conception that “the greater the mass the lower the acceleration”. Jasmine also displayed this AC. These learners could not fuse their understanding of mass, acceleration, force with work done by the gravitational force. Their understanding of the relationship between mass and acceleration is not logical as it does not take force into account. In order to talk about a relationship between mass and acceleration, force must be kept constant. This lack of fusion of ideas shows that the learners do not fully understand Newton’s second law, and this impacted negatively on their ability to solve this problem. This AC “the greater the mass the lower the acceleration” is similar to ACP2 *greater work greater power* and ACP3 *more time less power*. In displaying ACP2 learners had omitted to consider  $\Delta t$  in the formula for power and in displaying ACP3 they omitted to consider work done. These alternative conceptions are probably also due to a lack of understanding of the mathematical concept of proportionality. Both these alternative conceptions about Power were discussed in Chapter 6. An example of this inability to

fuse the concepts of mass, force, acceleration, velocity, force of gravity, kinetic energy and work done is displayed by Patience in lines 107-112 of her TAP:

*107 energy is equals to half  $m v$  squared. (She does not take this idea further correctly).*

*108 So if it's half  $m v$  squared you have, you know what your masses differently but the velocity is initially the same.*

*109 So if initially your velocity is initially the same mmm then your thus mean that, the mass,*

*110 the one with the with the with the with the lower mass, which is your little niece will accelerate more,*

*111 and accelerating more it means that the mass is inversely proportional to the net force.*

*112 So your niece because she is lighter ughm ughm*

Seven of the eight learners displayed an inability to fuse different critical features of different concepts in order to solve a problem. This shows that some learners who cannot solve problems and who hold alternative conceptions do so because of an inability to fuse their ideas about different concepts to form one coherent whole. This points towards an inability to handle several concepts simultaneously and this could lead to developing alternative conceptions like the one evidenced by six of the eight learners in their TAPS, namely “the greater the mass the lower the acceleration”.

One can therefore conclude that seven of the eight learners are unable to fuse several critical features of different concepts to arrive at a complete whole idea about work and energy. This lack of fusion possibly accounts for their display of problem-solving difficulties and alternative conceptions. These learners are not able to apply their knowledge of work and energy when exposed to different dimensions and patterns of variation of the critical features of these concepts.

The utilisation of the fusion pattern of variation as explained by Marton et al. (2004) in understanding learner responses to problem-solving exercises has been used to account for learners holding alternative conceptions and problem-solving difficulties. This has shown that some learners cannot successfully solve problems that require fusion of

several critical features of different concepts on Work Energy Power. This leads one to conclude that the learners do not fully understand the concepts that are being assessed and perhaps greater exposure to such problems with carefully thought-out dimensions and patterns of variation could contribute towards deeper and fuller understanding of concepts leading to greater success in problem-solving.

### 8.3 Analysis: Patterns of Variation

In section 8.2, the four patterns of variation namely, contrast, generalisation, separation and fusion were used to account for learners' holding alternative conceptions and experiencing problem-solving difficulties. These four patterns of variation were first identified by Marton et al. (2004, pp. 16-17).

In this section, a further analysis of this data is conducted and presented in Table 8.5. This analysis shows that five of the learners displayed that they cannot contrast, generalise, separate or fuse critical features of concepts when doing problem-solving exercises. These five learners are Ann, Gold, Timber, Jasmine and Blue. One learner, Patience, can at least generalise some critical features of concepts which means that at least she can solve problems based on these critical features in varying situations. Another learner, Gift, can at least separate some critical features from other aspects of a concept and show understanding of them. One learner, London, was able to show that he can contrast, separate and fuse critical features of concepts involved in problems that he was solving. London only showed an inability to generalise some critical features of Work Energy Power as shown in Table 8.5.

**Table 8.5: Analysis: Patterns of Variation**

Learners	Ann	Patience	Gift	Gold	London	Timber	Jasmine	Blue
Evidence of contrast	No	No	No	No	Yes	No	No	No
Evidence of Generalisation	No	Yes	No	No	No	No	No	No
Evidence of separation	No	No	Yes	No	Yes	No	No	No
Evidence of fusion	No	No	No	No	Yes	No	No	No

In Chapter 6, it was shown that all eight learners displayed at least one alternative conception and experienced some problem-solving difficulties on Work Energy Power. The analysis in Table 8.5 shows that none of the learners showed evidence of success on all four patterns of variation. Hence, one can conclude that this analysis is showing that the four patterns of variation are a possible way to account for the high prevalence of alternative conceptions and problem-solving difficulties discussed in Chapter 6. The finding in this chapter is that the four patterns of variation are a possible way to account for the high prevalence of alternative conceptions and problem-solving difficulties on Work Energy Power experienced by the sample of eight Grade 12 Physical Sciences learners.

#### **8.4 Discussion: Patterns of Variation**

The four patterns of variation, namely, contrast, generalisation, separation and fusion were used to account for the prevalence of alternative conceptions and problem-solving difficulties on Work Energy Power among a sample of eight Grade 12 Physical Sciences learners in one school in South Africa. This finding lends support to the significance of variation in learning and assessment thereof as championed by several researchers (Bussey et al., 2013; Lo, 2012; Marton, 1981; Marton et al., 2004). The ability to experience the different critical features of a concept by being able to contrast them with other critical features plays an important role in a learner's ability to understand them (Bussey et al., 2013; Marton et al., 2004). As an example, for a learner to understand work done on an object, the learner should be able to contrast it with net work done on an object.

Seven of the eight learners displayed an inability to fuse different critical features of different concepts in order to solve a problem. This shows that some learners cannot solve problems and they hold alternative conceptions because of an inability to fuse their ideas about different concepts. This points towards an inability to handle several concepts simultaneously and this could lead to developing alternative conceptions like the one evidenced by six of the eight learners in their TAPS, namely "the greater the mass the lower the acceleration". This finding also supports Marton et al. (2004) that learners need to take several critical features of a phenomenon/object into consideration simultaneously

in order to fully understand that phenomenon or concept. However, this finding could also be interpreted differently, that the ACs and PSADs interfere with the learners' thinking and result in their inability to contrast, generalise, separate and fuse the different critical features of different concepts. This begins to look more like a vicious cycle of ACs and PSADs causing the inability to contrast, generalise, separate and fuse critical features or vice versa.

The main finding in this chapter is that the learners in this sample hold alternative conceptions and experience problem-solving difficulties because they cannot always contrast, generalise, separate or fuse critical features of WEP or vice versa.

In this chapter it is shown that the four patterns of variation can be used to account for Grade 12 Physical Sciences learners holding alternative conceptions and experiencing problem-solving difficulties on Work Energy Power.

## **8.5 Conclusion**

The fourth objective of this study was to account for Grade 12 Physical Sciences learners' alternative conceptions and problem-solving difficulties using the variation theory of learning. This chapter focused on the fourth research question in this study: *How can the Grade 12 Physical Sciences learners' alternative conceptions and problem-solving difficulties on work, energy and power be explained, using the variation theory of learning.* In Chapter 7, the reasons for learners holding alternative conceptions and experiencing problem-solving difficulties were discussed. Five reasons, LOA, LOD, LOR, LOL, and LOC had emerged from the think aloud protocols of the learners. In this chapter, "patterns of variation" (Marton & Pang, 2006) are taken into consideration as a possible explanation for the prevalence of these reasons (p. 199).

In this chapter, it has been shown that the "four patterns of variation" suggested by Marton and Pang (2006) can be used to account for Grade 12 Physical Sciences learners holding alternative conceptions and experiencing problem-solving difficulties on Work Energy Power (p. 199). The "four patterns of variation: contrast, generalisation, separation and fusion" were found to account for the prevalence of alternative conceptions and problem-

solving difficulties on Work Energy Power among a sample of eight Grade 12 Physical Sciences learners in one school in South Africa (Marton et al., 2004, pp. 16,17). These four patterns of variation were first identified by Marton et al. (2004, pp. 16-17). The TAQ was analysed to identify the four patterns of variation. This analysis was followed by the analysis of the TAPs in relation to the four patterns of variation that were identified in the TAQ. This study has shown that the four patterns of variation namely “contrast, generalisation, separation and fusion” can be used to account for Grade 12 Physical Sciences learners’ alternative conceptions, problem-solving approaches and difficulties on WEP (Marton & Booth, 1997, p. 199).

This finding lends support to the significance of variation in learning and assessment thereof as championed by several researchers (Bussey et al., 2013; Lo, 2012; Marton, 1981; Marton et al., 2004). The ability to experience the different critical features of a concept by being able to contrast them with other critical features plays an important role in a learner’s ability to understand them (Bussey et al., 2013; Marton et al., 2004). This finding also supports Marton et al. (2004) view that learners need to take several critical features of a phenomenon/object into consideration simultaneously in order to fully understand that phenomenon or concept.

## Chapter 9 - CONCLUSIONS AND RECOMMENDATIONS

### 9.1 Introduction

The purpose of this study was to explore Grade 12 learners' understandings of, and problem-solving approaches to Work-Energy-Power in Physical Sciences in high schools. The problems underlying this research were twofold. Firstly, learners hold alternative conceptions regarding several concepts in Physics including Work Energy Power. Secondly, learners experience difficulties in problem-solving. Attempts to address these problems have not resulted in improved understanding and problem-solving approaches to Work Energy Power among Grade 12 learners in high schools. The research on alternative conceptions and problem-solving in South Africa was found to be very limited and focused mainly on electricity and mechanics in general. Currently there is no research in South Africa on alternative conceptions and problem-solving that focuses specifically on work, energy and power amongst Grade 12 Physical Sciences learners. Furthermore, a search for research on alternative conceptions and problem-solving approaches in Physics using the Think Aloud method also yielded zero results. "Although Variation Theory has been used as a theoretical framework" in some research studies in Physics education, it has not been used specifically on Work Energy Power (Bernhard, 2010; 2018, p. 823; Bussey et al., 2013). Therefore, gaps regarding alternative conceptions and problem-solving approaches using Think Aloud method and VT in research on Work Energy Power has not been found to exist in South Africa. This study is an attempt to fill these gaps and also to add to the existing literature on studies concerning Work Energy Power education in high schools. Therefore, the findings in this study are new as they have not been found elsewhere among learners in South Africa.

This study used a mixed method approach and was heavily weighted on the qualitative approach when compared to the quantitative aspect. The quantitative approach was limited to the utilisation of descriptive statistics to support the analysis (generating themes) of the qualitative data. Data was initially collected from a purposively selected sample of 100 NSC Physical Sciences scripts from one education district in South Africa. This was followed by data being collected from a purposively selected sample of eight learners from the same education district. The eight learners participated in a Think Aloud

session where audio data was collected using voice recording devices and written data was collected via answer scripts. Overall, data was collected via answer scripts, focus group interviews, field notes, audio recordings and document analysis. The data was analysed both quantitatively and qualitatively. The quantitative data was used to support the collection of and findings of the qualitative data. VT was used as a lens via which the data was analysed.

This chapter comprises of five sections. The first section provides a summary of the findings and conclusions for each of the four research questions. This is followed by the second section which discusses the contributions of this study. Finally, the third, fourth and fifth sections discuss the limitations of this study, recommendations and concluding remarks respectively.

## **9.2 Summary of the results and findings**

The purpose of this study was to explore Grade 12 learners' understandings of, and problem-solving approaches to work-energy-power in Physical Sciences in high schools. Four research questions were developed to facilitate this exploration. The four research questions are presented below:

- i. How do Grade 12 Physical Sciences learners perform on the questions on work, energy and power in the National Senior Certificate (NSC) examinations?
- ii. What are the alternative conceptions and problem-solving difficulties of Grade 12 Physical Sciences learners on work, energy and power?
- iii. Why do Grade 12 Physical Sciences learners' hold certain alternative conceptions and problem-solving difficulties on work, energy and power?
- iv. How can the Grade 12 Physical Sciences learners' alternative conceptions and problem-solving difficulties on work, energy and power be explained using the variation theory of learning?

The summary of the findings and conclusions presented below are based on the four research questions listed above.

***Research Question One: How do Grade 12 Physical Sciences learners perform on the questions on work, energy and power in the National Senior Certificate (NSC) examinations?***

On the performance of learners in the NSC Physical Sciences examinations, the study found that many learners displayed a poor understanding of concepts and poor problem-solving skills while a few learners displayed the opposite. Four PSADs have been identified namely MPS, LFS, DRS and LIS. It has been found using phenomenography and VT that there is a small number of learners who display a linked and integrated problem-solving approach which led them to successfully solve physics problems. However, a larger number of learners could not solve physics problems successfully because they missed the point (MPS), had limited factual knowledge to tackle the problem (LFS) or made disjointed and incorrect relationships between aspects/concepts (DRS).

Although some learners displayed a good understanding of some concepts involving WEP, the majority of the learners have also displayed ACs about WEP in the NSC. This finding is supported by Maseko et al. (2010) who found that learners display a “naïve” and “superficial” understanding of scientific concepts in the NSC examinations (p. 31). The study also resonates with the findings of ACs in mechanics by Mchunu and Imenda (2013). Another finding was that learners experience difficulties in applying energy principles to solve problems. This finding supports the finding that learners are “often unable to employ energy concepts appropriately” when solving problems (Singh & Schunn, 2009, p. 26).

***Research Question Two: What are the alternative conceptions and problem-solving difficulties of Grade 12 Physical Sciences learners on work, energy and power?***

For a deeper exploration of learners’ understandings of WEP, the TA method was employed with the TAQ. It is to be noted that all learners in the sample displayed a good understanding of CFs of some concepts involving WEP when solving some problems in the TAQ. However, all learners in the sample also demonstrated the presence of ACs

about WEP as they worked their way through some of the questions in the TAQ. The following seven ACs about work were displayed by learners:

- AC W1: Work and Net Work can be used inter-changeably
- AC W2: WET does not apply to accelerating objects
- AC W3: Work by gravitational force is dependent on the path taken
- AC W4: Greater velocity greater work done
- AC W5: More force more work
- AC W6: Work must be done on an object to keep it in motion
- AC W7: Positive force positive work negative force negative work

The following four ACs about power were displayed by learners:

- AC E1: Change in velocity equals change in kinetic energy
- AC E2: Kinetic energy and mechanical energy of an object decreases as it falls freely
- AC E3: Mechanical energy is conserved in the presence of non-conservative forces
- AC E4: A change in mechanical energy depends only on changes in velocity and not on changes in height

The following three ACs were displayed by learners about power:

- AC P1: More power is expended where more energy or work is needed or where more difficulty is experienced
- AC P2: Work alone determines power irrespective of time
- AC P3: Time alone determines power irrespective of work

Another major finding in this study were the seven problem-solving approaches that have been identified namely Linked and Integrated State (LIS), Missed the Point State (MPS), Limited (L), Plug and Chug Trial (PACT), Layman's Approach (LAY), By Elimination (BE) and Not Shown (NS). These problem-solving approaches include problem-solving difficulties with the exception of the LIS approach. This finding shows the qualitatively

different ways in which several learners approach the same problem as well as the qualitatively different ways in which one learner approaches different problems. Several researchers have found that many learners experience problem solving difficulties and display different problem-solving approaches when solving problems (Bing & Redish, 2009; Chen & Bradshaw, 2007; Chi & Glaser, 1983; DBE, 2015a; Docktor et al., 2016; Docktor et al., 2015; Holyoak, 1995; Kim & Pak, 2002; Schultz & Lochhead, 1988; Walsh et al., 2007).

The finding that a single learner displays a variety of problem-solving approaches when confronted with different problems can be explained by using VT. When a learner is faced with a problem the learner proceeds in a manner that is informed by his/her awareness, discernment and simultaneity regarding the concepts pertinent to the problem at that particular time. This is also influenced by the other conditions that have been described in Chapter 8 namely the employment of reason, logic and clarity when solving physics problems in particular. These conditions can change for the learner as he/she moves from one problem to another. Since all learners displayed the LIS problem solving approach in at least one of the problems, it can be concluded that all learners in the sample have the ability to solve problems successfully but that they are constrained by the absence of some of the conditions for successful problem-solving namely awareness, simultaneity, discernment, reason, logic and clarity.

The problem-solving difficulties in problem-solving among Grade 12 learners in Physical Sciences can be listed as:

- Missed the Point (MPS)
- Limited (L)
- Plug-And-Chug Trial (PACT)
- Layman's Approach
- By Elimination (BE)
- Not Shown (NS)

***Research Question Three: Why do Grade 12 Physical Sciences learners' hold certain alternative conceptions and problem-solving difficulties on work, energy and power?***

Five possible reasons that explain why learners display ACs and PSDs have been identified. These are lack of awareness (LOA), lack of discernment (LOD), lack of logic (LOL), lack of clarity (LOC) and lack of Reason (LOR). These reasons show the limited number of qualitatively different ways in which the learners experienced the object of learning. These reasons can explain why learners experience problem-solving difficulties (PSDs) and display alternative conceptions (ACs). Lack of awareness was the most prevalent reason for their PSDs and ACs followed by LOD, LOL, LOC and LOR.

52% of the learner responses showed that there was a LOA of critical features, while 10% of all the learner responses showed that there was a LOC. It is important to note that these percentages are only provided as descriptive statistics to show the prevalence of these reasons. They do not have any further statistical significance as this is a phenomenographic study in which only a small sample has been analysed. Even a small percentage is significant as it would be indicating that a particular reason has been observed in this small sample. The reader could conduct further studies in order to check the prevalence of any of the reasons provided here in other studies that he/she may conduct, as suggested by Lincoln and Guba (1985). There is no attempt in this study to generalise the findings.

Another finding is that the more complex the concepts, theorems and principles, the more prevalent LOA. In other words, one needs to be simultaneously aware of multiple features of a phenomenon in order to fully understand and experience it. The phenomenon here refers a concept, problem, event, etc.

These findings indicate that for a learner to fully understand and experience a phenomenon and be able to tackle problems regarding that phenomenon, there should be awareness, simultaneity, discernment, reason, logic and clarity.

Marton and Booth (1997) have suggested that awareness, simultaneity and discernment are necessary conditions of learning. This study proposes additions to this discourse but relating specifically to understanding and problem-solving in physics. These additions are reason, logic and clarity. This study has shown that these concepts, awareness, simultaneity, discernment, reason, logic and clarity are important conditions for learners to fully understand scientific phenomena and successfully solve problems in physics by showing that in their absence learners hold ACs and PSDs.

***Research Question Four: How can the Grade 12 Physical Sciences learners' alternative conceptions and problem-solving difficulties on work, energy and power be explained using the variation theory of learning?***

The four patterns of variation provided by Marton and Booth (1997) have been employed to account for learners' alternative conceptions and problem-solving difficulties. The analysis showed that none of the learners showed evidence of success on all four patterns of variation. Hence, one can conclude that this analysis is showing that the four patterns of variation are a possible way to account for the high prevalence of alternative conceptions and problem-solving difficulties identified in this study. The finding is that the four patterns of variation are a possible way to account for the high prevalence of alternative conceptions and problem-solving difficulties on Work Energy Power experienced by the sample of eight Grade 12 Physical Sciences learners.

This study suggests that learners' hold ACs and display certain PSADs probably because they cannot always do any or all of the following:

- i. Contrast: compare critical features of concepts. Example: to understand the work done by a conservative force, one must also experience situations in which work is done by a non-conservative force;
- ii. Generalisation: experience a concept in varying exhibitions of that concept. Example: to understand the work energy theorem, one must experience the application of this theorem in situations where all the forces acting are either

conservative or non-conservative or where some forces acting are conservative and some are non-conservative.

- iii. Separation: experience situations involving a critical feature of a concept in different situations where that critical feature varies, and other critical features are kept invariant. Example: to understand the concept of work done by a force, one must experience work done by different kinds of forces on a horizontal surface or an inclined lane. Another example: one must experience work done by several forces on an inclined plane.
- iv. Fusion: experience several critical features of a concept changing simultaneously. Example: to understand the effect of mass and path difference on the final velocity of objects falling towards the earth one must experience problem-solving exercises in which both the mass and path difference vary simultaneously. An example could be two objects of different masses sliding down two differently shaped slides having started from rest at the same height.

This study has shown that the four patterns of variation can be used to account for Grade 12 Physical Sciences learners holding alternative conceptions, approaching problems in a certain way and experiencing problem-solving difficulties on Work Energy Power.

### 9.3 Conclusions

The conclusions presented in this section are based on the discussions made in Chapters 5, 6, 7 and 8. The discussions are centred around the four research questions and are presented accordingly.

**Research Question One: *How do Grade 12 Physical Sciences learners perform on the questions on work, energy and power in the National Senior Certificate (NSC) examinations?***

The first research question set out to explore how the Grade 12 Physical Sciences learners performed on the questions WEP in the NSC examinations. The results and findings have

shown that many learners in the sample have displayed ACs about WEP in the NSC examinations. The quantitative analysis of data from the NSC scripts of 100 learners has shown that 68% of the learners have poor understanding of work and power. 85% of the learners in the sample could not solve a multi-step problem that required the application of the WET. Four PSADs were identified among the sample of 100 learners and these were MPS, LFS, DRS and LIS. The LIS problem-solving approach is the only approach where the learners did not display any difficulties and where they successfully solved the problems. Only 15% of the sample could solve the multi-step problem based on the WET.

**This lead to the following conclusion:**

Many learners in the NSC harbour alternative conceptions and experience problem-solving difficulties on the topic Work Energy Power.

***Research Question Two: What are the alternative conceptions and problem-solving difficulties of Grade 12 Physical Sciences learners on work, energy and power?***

The second research question set out to determine the alternative conceptions and problem-solving difficulties of Grade 12 Physical Sciences learners on work, energy and power. The TA method was used to collect data on the “thinking” of a small sample of eight learners while they were answering the questions on the TAQ. It was found that all eight learners had demonstrated the presence of ACs as they worked their way through the questions on the TAQ.

All eight learners had demonstrated problem-solving difficulties while answering some of the questions on the TAQ. It was also found that each learner displayed different PSADs when confronted with different problems. The learner’s PSADs deferred according to his/her focus on different critical features of WEP demanded in the problems. Another important finding was that all learners displayed the LIS problem-solving approach in at least three out of a total of 21 responses. One major problem-solving difficulty that was displayed was that learners make disjointed relationships between concepts and variables, and they cannot relate the parts to the whole. Although all learners displayed difficulties in solving some of the physics problems, they also

displayed the LIS problem-solving approach in at least three of the twenty-one problems that they had solved.

**These findings led to the following two conclusions:**

Some learners of Physical Sciences display alternative conceptions (ACs) on WEP. Some learners experience problem-solving difficulties in Physical Sciences. These problem-solving difficulties (PSDs) of Physical Sciences learners are missed the point state (MPS), limited (L), plug-and-chug-trial (PACT), layman's approach (LAY), by elimination (BE) and not shown (NS).

The ACs on work were:

- Work and Net Work can be used inter-changeably
- WET does not apply to accelerating objects
- Work by gravitational force is dependent on the path taken
- Greater velocity greater work done
- More force more work
- Work must be done on an object to keep it in motion
- Positive force positive work negative force negative work

The ACs on energy were:

- Change in velocity equals change in kinetic energy
- Kinetic Energy and mechanical energy of an object decreases as it falls freely
- Mechanical energy is conserved in the presence of non-conservative forces
- Mechanical Energy remains constant when an object moves uphill at constant velocity

The ACs on power were:

- More Power is expended where more Power is needed
- Greater work greater power

- More time less power

**Research Question Three: *Why do Grade 12 Physical Sciences learners' hold certain alternative conceptions and problem-solving difficulties on work, energy and power?***

A TA method was employed to collect data on the “thinking” of learners so as to understand why they hold certain ACs and experience problem-solving-difficulties on WEP. The results obtained from the TAPs were analysed using VT as an analytical lens. There were five qualitatively different ways in which the learners experienced the problems presented on Work Energy and Power which in this study is the intended object of learning. The analysis revealed that not all learners experienced all the dimensions of variation of the object of learning in the same way. These are lack of awareness (LOA), lack of discernment (LOL), lack of logic (LOL), lack of clarity (LOC) and lack of Reason (LOR). These reasons show the limited number of qualitatively different ways in which the learners experienced the object of learning. These reasons can account for their problem-solving difficulties (PSDs) and alternative conceptions (ACs). Lack of awareness was the most prevalent reason for their PSDs and this was followed by LOD, LOL, LOC and LOR.

These findings indicate that for a learner to fully understand and experience a phenomenon and be able to tackle problems regarding that phenomenon there should be awareness, simultaneity, discernment, reason, logic and clarity.

Marton and Booth (1997) have suggested that awareness, simultaneity and discernment are necessary conditions of learning. This study proposes additions to this discourse but relating specifically to understanding and problem-solving in physics. These additions are reason, logic and clarity. This study has shown that these concepts, awareness, simultaneity, discernment, reason, logic and clarity are important conditions for learners to fully understand scientific phenomena and successfully solve problems in physics by showing that in their absence, learners hold ACs and PSDs.

**This has led to the following conclusion:**

Awareness, simultaneity, discernment, reason, logic and clarity are important conditions for learners to fully understand scientific phenomena and successfully solve problems in physics.

*Research Question Four: How can the Grade 12 Physical Sciences learners' alternative conceptions and problem-solving difficulties on work, energy and power be explained using the variation theory of learning?*

The four patterns of variation namely contrast, generalisation, separation and fusion were used to account for the prevalence of alternative conceptions and problem-solving difficulties on Work Energy Power among a sample of eight Grade 12 Physical Sciences learners in one school in South Africa. These four patterns of variation were first identified by Marton et al. (2004, pp. 16-17). The TAQ was analysed to identify the four patterns of variation. This analysis was followed by the analysis of the TAPs in relation to the four patterns of variation that were identified in the TAQ. This study has shown that the four patterns of variation namely contrast, generalisation, separation and fusion can be used to account for Grade 12 Physical Sciences learners' alternative conceptions, problem-solving approaches and difficulties on WEP (Marton & Booth, 1997).

This finding lends support to the significance of variation in learning and assessment thereof as championed by several researchers (Bussey et al., 2013; Lo, 2012; Marton, 1981; Marton et al., 2004). The ability to experience the different critical features of a concept by being able to contrast them with other critical features plays an important role in a learner's ability to understand them (Bussey et al., 2013; Marton et al., 2004). This finding also supports Marton et al. (2004) view that learners need to take several critical features of a phenomenon/object into consideration simultaneously in order to fully understand that phenomenon or concept.

**This has led to the following conclusion:**

The four patterns of variation: - contrast, generalisation, separation and fusion are a possible explanation for the prevalence of alternative conceptions and problem-solving difficulties among Grade 12 Physical Sciences learners.

**9.4 Contributions of this study****9.4.1 Contribution to scholarship**

Research on understandings and problem-solving in South Africa has been taking place. However, studies that are conducted using phenomenography and VT as theoretical perspectives underpinning them are rare. Studies have been conducted in South Africa about learners' understandings on Mechanics, but studies specific to Work Energy Power are rare. There are limited studies on the use of Think Aloud in South Africa. Furthermore, the use of the Think Aloud to gain insight into learners' thinking in the field of understanding and problem-solving on Work Energy Power in high schools has not been done in South Africa prior to this study. The employment of VT to interpret learners' examination scripts and answers to problems in physics is also rare in South Africa. This study is therefore significant because it contributes to the limited body of knowledge on understanding and problem-solving involving Work, Energy and Power. It is also significant as it contributes to the body of research that employs VT and the Think Aloud method to gain insights into learners' thinking on topics in high school physics.

Marton and Booth (1997) have suggested that awareness, simultaneity and discernment are necessary conditions of learning. This study proposes additions to this discourse but relating specifically to understanding and problem-solving in physics. These additions are reason, logic and clarity. This study has shown that these conditions, awareness, simultaneity, discernment, reason, logic and clarity are important conditions for learners to fully understand scientific phenomena and successfully solve problems in physics by showing that in their absence learners hold ACs and PSDs. The proposed necessary conditions for understanding and problem-solving in physics is provided in Figure 7.6 in this study.

### **9.4.2 Teacher education**

The alternative conceptions, problem-solving approaches and difficulties identified in this study can be a useful resource that could be utilised in teacher development activities. Teacher development activities invoking these identified alternative conceptions can be developed in order to strengthen prospective teachers' understanding's as well as provide them with ideas to include in their development of lesson plans.

### **9.4.3 Curriculum design**

Curriculum design that supports learning through the application of Variation Theory has not been employed in the South African System. In some countries, for example Australia, Phenomenography and Variation Theory were employed to develop, design and trial a model of curriculum design that aimed to assist student learning (Akerlind et al., 2011). This study has the potential to contribute to curriculum modelling projects that are designed to assist in learning in the Physical Sciences through the application of Phenomenography and Variation Theory.

## **9.5 Limitations**

It is important to identify limitations in any study as this assists the reader in viewing the study within those limitations.

Although measures were employed to minimise the limitations of this study by employing trustworthiness checks, one possible limitation of this study is that other researchers working with different samples of participants could possibly come to a different set of findings. This is inherent in the nature of phenomenographic studies. Just as there are qualitatively different ways in which participants in a study experience a phenomenon, there could be qualitatively different ways in which researchers experience the study (which will be the "phenomenon" to the researchers).

## **9.6 Recommendations**

### **9.6.1 Recommendations for curriculum managers**

It is recommended that curriculum managers consider the findings in this research in the development of curriculum support materials for teachers and learners. The alternative conceptions can be used for example in the development of diagnostic tests for both teachers as well as learners and in this way be able to tease out these alternative conceptions that may be prevalent among teachers and learners.

### **9.6.2 Recommendations to teachers**

The discussions and analysis on alternative conceptions, problem-solving approaches and difficulties in this study highlight several pitfalls that learners encounter in the process of learning physics. Teachers may use these discussions and analysis to inform their lesson planning and classroom practice so as to assist learners to overcome these pitfalls.

### **9.6.3 Recommendations for future research**

The think aloud method was administered to a small sample of eight learners in this study, in order to gain insights into their thinking during problem-solving in physics. Furthermore, these eight learners were from one province only. This study can be varied and undertaken in three ways. Firstly, it could be undertaken across different topics in Physical Sciences. Secondly, it could be undertaken using small samples of learners in different schools in all nine provinces. Thirdly, it could be modified to suit other subjects and then undertaken with small samples of learners in various schools and provinces. This will assist in providing greater insights into learners' understandings and difficulties throughout the schooling sector.

## **9.7 Concluding remarks**

The data, analysis and findings of this study have shown that many learners in the sample have displayed difficulties in understanding and problem-solving involving WEP. This

study has documented fourteen ACs on WEP displayed by learners in the sample. Seven of these ACs were on work, four on energy and three on power. The study has also documented seven PSADs. Possible reasons based on phenomenography and VT have been suggested to explain why learners harbour ACs and display certain PSADs. Finally, VT was employed to account for these ACs and PSADs.

It was found that all learners in the sample demonstrated the presence of ACs about WEP as they worked their way through the questions in the TAQ. The following seven ACs about work were displayed by learners: AC W1: Work and Net Work can be used interchangeably, AC W2: WET does not apply to accelerating objects, AC W3: Work by gravitational force is dependent on the path taken, AC W4: Greater velocity greater work done, AC W5: More force more work, AC W6: Work must be done on an object to keep it in motion and AC W7: Positive force positive work negative force negative work. The following four ACs about energy were displayed by learners: AC E1: Change in velocity equals change in kinetic energy, AC E2: Kinetic Energy and mechanical energy of an object decreases as it falls freely, AC E3: Mechanical energy is conserved in the presence of non-conservative forces and AC E4: Mechanical Energy remains constant when an object moves uphill at constant velocity. The following three ACs were displayed by learners about power: AC P1: More Power is expended where more Power is needed, AC P2: Greater work greater power and AC P3: More time less power.

Another major finding in this study were the seven problem-solving approaches that have been identified namely Linked and Integrated State (LIS), Missed the Point State (MPS), Limited (L), Plug and Chug Trial (PACT), Layman's Approach (LAY), By Elimination (BE) and Not Shown (NS). These problem-solving approaches include problem-solving difficulties with the exception of the LIS approach. The PSDs among Grade 12 learners in Physical Sciences were found to be as follows: Missed the Point (MPS), Limited (L), Plug-And-Chug Trial (PACT), Layman's Approach, By Elimination (BE) and Not Shown (NS). The finding that a single learner displays a variety of problem-solving approaches when confronted with different problems was explained using VT. When a learner is faced with a problem the learner proceeds in a manner that is informed by his/her "awareness, discernment, simultaneity," logic, clarity and reason regarding the concepts pertinent to the problem at that particular time (Marton & Booth, 1997, pp. 100-103).

Five possible reasons that explain why learners displayed ACs and PSDs have been identified in this study. These are Lack of Awareness (LOA), Lack of Discernment (LOD), Lack of Logic (LOL), Lack of Clarity (LOC) and Lack of Reason (LOR). These reasons show the “limited number of qualitatively different ways” (Marton & Booth, 1997) in which the learners “experienced” the object of learning (p. 100). These reasons have been proposed as a possible explanation for learners’ experience of problem-solving difficulties (PSDs) and display of alternative conceptions (ACs). Lack of awareness was the most prevalent reason for their PSDs and ACs followed by LOD, LOL, LOC and LOR.

The “four patterns of variation contrast, generalisation, separation and fusion” were found to account for the prevalence of alternative conceptions and problem-solving difficulties on Work Energy Power among the sample of Grade 12 Physical Sciences learners (Marton et al., 2004, pp. 16,17). Marton and Booth (1997) have suggested that “awareness, simultaneity and discernment” are necessary for learning to take place (p. 100). This study proposes additions to this discourse but relating specifically to understanding and problem-solving in physics. These additions are reason, logic and clarity. This study has shown that these conditions, awareness, simultaneity, discernment, reason, logic and clarity are important conditions for learners to fully understand scientific phenomena and successfully solve problems in physics by showing that in their absence learners hold ACs and PSDs.

This study is significant as it has provided lists of possible ACs and PSADs on WEP using phenomenography, VT and TA. It is envisaged that these approaches and findings will fill the gap in such studies in South Africa. It is also envisaged that these findings and approaches could be of benefit to teachers, policy makers and researchers.

## **9.8 Personal reflection**

The learners in this study enjoyed participating in this study. They had participated in the think aloud exercise enthusiastically and “thought aloud” in such volumes that made this study worthwhile. The learners participated in this study with so much trust and

enthusiasm. They had welcomed me into their school and their deepest thoughts about physics without any resistance whatsoever. This study was a very mind-opening exercise. I thank them with the greatest sincerity.

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# APPENDICES

## Appendix 1: Ethical Clearance



18 April 2018

Ms Jayanthi Siva Kumaree Maharaj (8015376)  
School of Education  
Edgewood Campus

Dear Ms Maharaj,

**Protocol reference number: HSS/2210/017D**

**Project Title:** Exploring Grade 12 learners' understandings of, and problem-solving approaches to Work-Energy-Power in Physical Sciences in high schools in Limpopo

**Approval Notification – Expedited Application**

In response to your application received 21 November 2017, the Humanities & Social Sciences Research Ethics Committee has considered the abovementioned application and the protocol has been granted **FULL APPROVAL**.

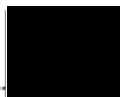
Any alteration/s to the approved research protocol i.e. Questionnaire/Interview Schedule, Informed Consent Form, Title of the Project, Location of the Study, Research Approach and Methods must be reviewed and approved through the amendment /modification prior to its implementation. In case you have further queries, please quote the above reference number.

**PLEASE NOTE:** Research data should be securely stored in the discipline/department for a period of 5 years.

The ethical clearance certificate is only valid for a period of 3 years from the date of issue. Thereafter Recertification must be applied for on an annual basis.

I take this opportunity of wishing you everything of the best with your study.

Yours faithfully



Professor Shenuka Singh (Chair)

/ms

Cc Supervisor: Dr N Govender  
Cc Academic Leader Research: Dr SB Khoza  
Cc School Administrator: Ms Tyzer Khumalo

Humanities & Social Sciences Research Ethics Committee

Professor Shenuka Singh (Chair)

Westville Campus, Govan Mbeki Building

Postal Address: Private Bag X54001, Durban 4000

Telephone: +27 (0) 31 260 3587/8350/4557 Facsimile: +27 (0) 31 260 4809 Email: [zimzap@ukzn.ac.za](mailto:zimzap@ukzn.ac.za) / [anymstrm@ukzn.ac.za](mailto:anymstrm@ukzn.ac.za) / [mohund@ukzn.ac.za](mailto:mohund@ukzn.ac.za)

Website: [www.ukzn.ac.za](http://www.ukzn.ac.za)

1910 - 2010  
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Founding Campuses: ■ Edgewood ■ Howard College ■ Medical School ■ Pietermaritzburg ■ Westville

## Appendix 2: Letter to Head of Province



Enquires: Ms JSK Maharaj  
Tel: 0787944340  
Email: [veena.jsk@gmail.com](mailto:veena.jsk@gmail.com)

Ms JSK Maharaj  
University of Kwazulu-Natal  
College of Humanities  
Edgewood Campus  
Private Bag X03  
Ashwood 3605  
27 March 2017

**Acting HOD xxx**  
**Private Bag xxx**  
**XXX**  
**xxx**  
By email: [xxx](mailto:xxx)

Dear Ms XXX

I am Ms JSK Maharaj, a student at the University of KwaZulu-Natal, where I am studying for a Doctor of Philosophy degree in Physics Education. I am currently conducting research on Learners' Understanding and Problem-Solving Approach in Physical Sciences in High Schools in South Africa.

The outcome of my study will be used to fulfil the requirements of the PhD degree, assist me in my work as a curriculum specialist in education, inform the teaching and learning of Physical Sciences and support the development and implementation of science curriculum policy. It is also anticipated that the results of this study will be beneficial as local research results on critical issues regarding high school Physical Sciences curriculum policy and implementation will inform future education curriculum reforms in South Africa.

The sources of data for this study will include the following:

- a. National Curriculum Statement;
- b. Curriculum and Assessment Policy Statement Grades 10-12 Physical Sciences; and
- c. Sample of learner scripts for Physical Sciences Paper 1 in the National Senior Certificate Examinations.

I am aware that provinces will destroy learner scripts after 30 June of each academic year, as examination material is only retained for a period of six months.

I am requesting:

1. Your approval to utilise a sample of learner scripts for Physical Sciences Paper 1 in the NSC examinations, from your province as one of the data sources for the research that I am conducting towards a PhD degree;
2. Your approval to collect a sample of 500 learner scripts from your province for Physical Sciences Paper 1 in the NSC examinations, after they have been released for destruction; and
3. The name and contact details of an official with whom I can liaise regarding the collection of the sample of scripts, if you approve points 1 and 2 above.

Kindly note that the researcher, Ms Maharaj will collect the scripts only on your approval and at her own cost. She will do so after making suitable arrangements with the head of examinations or his/her delegate in your province.

I will ensure that the examination numbers and names of learners will not be recorded during the process of data collection. Furthermore, the names or center numbers of schools and other examination centers will also be kept confidential and will be coded so as to generate fictitious numbers and/or names. The scripts will be coded using numbers from 1 to 2000, to ensure confidentiality of learners. This will prevent any form of stigmatization or victimization of learners. The data will be stored on my computer that is secured with a password. The examination scripts will be destroyed (shredded) 2 years after the study has been completed and, on a date, agreed to by my supervisor and myself.

I will ensure confidentiality of all participants by using good data storage practices. Data will be stored in a safe/or locked cupboard and electronic data will be accessed via a password. The data will be stored in my personal computer which is protected with a password. I will also store a backup of the data in a location separate from my personal computer. This location is also password protected. Access to information about individual participants will be restricted access only to my supervisor (who will get access to the password for electronic data and will also keep data in a locked cupboard safe).

In all publications, identities of participants (learners, schools, districts, provinces) will be protected by using codes and pseudonyms.

In case you need further clarification or have any questions kindly contact me via email at [veena.jsk@gmail.com](mailto:veena.jsk@gmail.com), telephone 012 357 4169 or cell 078 7944340.

You may also contact my supervisor Dr N Govender at University of Kwazulu-Natal, School of Education, Edgewood Campus at 031 260 3469 or [govendern37@ukzn.ac.za](mailto:govendern37@ukzn.ac.za) .

It would be greatly appreciated if you could respond to my request at your earliest convenience.

JSK Maharaj

Kind Regards

Jayanthi SK Maharaj

Cell: 078 7944340

Tel: 012 3574169

Email: [veena.jsk@gmail.com](mailto:veena.jsk@gmail.com)

**DECISION:**

1. Request for your approval to utilise a sample of learner scripts for Physical Sciences Paper 1 in the NSC examinations, from your province as one of the data sources for the research that I am conducting towards a PhD degree.

- This request is **approved/ amended/ not approved.**
- Signature of HOD:

2. Request for your approval to collect a sample of 500 learner scripts from your province for Physical Sciences Paper 1 in the NSC examinations, after they have been released for destruction.

- This request is **approved/ amended/ not approved.**
- Signature of HOD:

3. Request for the name and contact details of an official with whom I can liaise regarding the collection of the sample of scripts, if you approve points 1 and 2 above.

- This request is **approved/ amended/ not approved.**
- Signature of HOD:

- The name of the official with whom you may liaise is

.....

- And his/her contact details are

.....

.....

### Appendix 3: Letter of Consent from Head of Province

[REDACTED]

[REDACTED]

[REDACTED]

JSK Maharaj  
University of KwaZulu - Natal  
Private bag X03  
Asswood  
3605

RE: REQUEST FOR PERMISSION TO CONDUCT RESEARCH

1. The above bears reference.

The Department wishes to inform you that your request to conduct research has been approved. Topic of the research proposal: "LEARNERS UNDERSTANDING AND PROBLEM SOLVING APPROACH IN PHYSICAL SCIENCE IN HIGH SCHOOL IN SOUTH AFRICA ."

2. The following conditions should be considered.

3.1 The research should not have any financial implications for [REDACTED]

3.2 Arrangements should be made with the Circuit Office and the schools concerned.

3.3 The conduct of research should not anyhow disrupt the academic programs at the schools.

3.4 The research should not be conducted during the time of Examinations especially the fourth term.

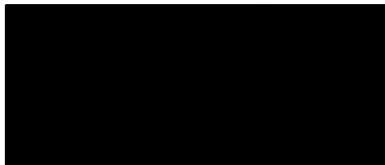
REQUEST FOR PERMISSION TO CONDUCT RESEARCH JSK MAHARAJ

CONFIDENTIAL

[REDACTED]

- 3.5 During the study, applicable research ethics should be adhered to; in particular the principle of voluntary participation (the people involved should be respected).
- 3.6 Upon completion of research study, the researcher shall share the final product of the research with the Department.
- 4 Furthermore, you are expected to produce this letter at Schools/ Offices where you intend conducting your research as an evidence that you are permitted to conduct the research.
- 5 The department appreciates the contribution that you wish to make and wishes you success in your investigation.

Best wishes.



## Appendix 4: Consent Form Principal



### Exploring Grade 12 Learners' Understandings of, and Problem-Solving Approaches to Work-Energy-Power in Physical Sciences in High Schools

School Principal Consent Form

I,

.....  
 give consent for you to approach Physical Sciences teachers and learners to participate in the above research.

I have read the Project Information Statement explaining the purpose of the research project and understand that:

- The role of the school is voluntary
- I may decide to withdraw the school's participation at any time without penalty
- Physical Sciences teachers and learners will be invited to participate, and permission will be sought from them
- Only teachers and learners who consent will participate in the project
- All information obtained will be treated in strictest confidence.
- The teachers' and learners' names will not be used, and individual teachers and learners will not be identifiable in any written reports about the study.
- The school will not be identifiable in any written reports about the study.
- Participants may withdraw from the study at any time without penalty.
- A report of the findings will be made available to the school.
- Further information on the project may be sought from JSK Maharaj (Veena) at 0787944340.

\_\_\_\_\_  
 Principal

\_\_\_\_\_  
 Signature

\_\_\_\_\_  
 School Stamp

## Appendix 5: Parents' Consent Form and Letter



**Date**

**Informed Consent of Parent**

**Consent Form**

I.....

*(full names of parent/guardian)* the parent/guardian of

.....

*(full names of son/daughter/ward)* hereby confirm that I understand the contents of this document and the nature of the research project, and I consent to the participation of my son/daughter/ward in this project.

I understand that I am at liberty to withdraw my son/daughter/ward from the project at any time, should I so desire. I understand the intention of the research. I hereby agree to the participation of my son/daughter/ward in this project.

I consent / do not consent to have the interviews recorded (if applicable).

I consent / do not consent to have the think aloud session recorded (if applicable).

I consent / do not consent to my son/daughter/ward writing the test and participating in the discussion thereafter (if applicable).

Signature of Parent

\_\_\_\_\_

Date

\_\_\_\_\_

Signature of Witness

\_\_\_\_\_

Date

\_\_\_\_\_

## Appendix 6: Letter to Parents/Guardians



Dear Grade 12 parent/guardian

### **REQUEST FOR CONSENT TO USE FINDINGS FROM YOUR CHILD'S/WARD'S CONTRIBUTION IN MY RESEARCH IN SCIENCE EDUCATION.**

**Title of the study: Exploring Grade 12 Learners' Understandings of, and Problem-Solving Approaches to Work-Energy-Power in Physical Sciences in High Schools**

I am a student who is currently studying for the degree of Doctor of Philosophy (PHD) with the University of KwaZulu-Natal (UKZN) Edgewood Campus, Faculty of Education. As part of the requirements for this degree, I am conducting a research project in which I explore learners' understanding of different science concepts and their problem-solving approaches. The purpose of this study is to explore poor conceptual understanding and weak problem-solving involving the concepts of work-energy-power in Physical Sciences in high schools. The source of data that I will be required to collect from the learner will be from semi-structured focus group interviews and from think aloud sessions. I request your permission to allow your child/ward to participate in the focus group interview and in the think aloud session.

During the focus group interviews, I will ask learners questions on some of the Physics sections of the Physical Sciences curriculum. All learners participating in the focus group interview will be given equal opportunity to answer any or all the questions. The focus group interview will be an oral session. The focus group interview will be recorded. During the think aloud session, each learner will be given a Think Aloud Activity Worksheet and a sound recording device. The Think Aloud Activity will consist of questions based on some of the Physics topics of the Physical Sciences curriculum. Learners will be asked to write down their answers to the questions and to say aloud what they are thinking as they are answering the questions. Data from the learners' answer sheets and sound recordings will be used in the research project. I request your permission to record the focus group interviews and the think aloud sessions.

Confidentiality of information: The names of learners and of the school will not be recorded. Learners are also free to leave the sessions at any point of the research without having to give any

explanation and without any negative impact on themselves or anybody else. The focus group interview will last about 30 minutes and the think aloud session will last about 1.5 hours. All information collected will be treated in strictest confidence and neither the school, principal, teachers nor individual learners will be identifiable in any reports that are written. Learners may withdraw from the study at any time without penalty. Furthermore, the role of the school is voluntary and the School Principal may decide to withdraw the school's participation at any time without penalty.

If I receive your consent, I will use this data in a way that respects your child's/ward's dignity and privacy. My notes, learners' answer sheets and sound-recordings of learners' inputs will be securely stored and disposed of if no longer required for research purposes. Your child's/ward's name or any information that might identify him or her will not be used in any presentation or publication that might come out of the study. I also like to assure you that you have no binding commitment to the study and may withdraw your consent at any time if you feel the need to. Should you withdraw your consent, your child/ward will not be prejudiced in any way.

This study is supervised by Professor Nadaraj Govender who is a senior lecturer at the school of Education, UKZN. Dr Govender can be contacted telephonically at 031-2607595 or emailed at: [govendern37@ukzn.ac.za](mailto:govendern37@ukzn.ac.za). You may also contact the Humanities and Social Sciences Research Ethics Committee whose contact details are as follows:

Premlall Mohun, University of KwaZulu-Natal, Research Office,

Email: [mohunp@ukzn.ac.za](mailto:mohunp@ukzn.ac.za)

Tel: 031 260 4557

Fax: 031 260 4609

I would appreciate it if you could take some time to consider my request and discuss it with your daughter/son/ward. Please complete, sign and return the attached consent form by or before 30 June 2018. Thank you in advance for your kind consideration of this request.

Yours sincerely



JSK Maharaj (Veena)

Researcher

UKZN



Professor Nadaraj Govender

Supervisor

UKZN

## Appendix 7: Letter to Learners



### Exploring Grade 12 Learners' Understandings of, and Problem-Solving Approaches to Work-Energy-Power in Physical Sciences in High Schools.

#### Project Information Statement/Letter of Invitation to Learners

My name is Jayanthi S K Maharaj (Veena), and I am a PhD student at the University of Kwazulu-Natal (UKZN). The purpose of this study is to explore poor conceptual understanding and weak problem-solving involving the concepts of work-energy-power in Physical Sciences in high schools. I am conducting this study under the supervision of Professor Nadaraj Govender. I request you to consider allowing me to conduct this research in your school. This study will meet the requirements of the Research Ethics Committee of UKZN.

#### The objectives of this research are:

1. To explore how Grade 12 Physical Sciences learners perform on the questions on work, energy and power in the National Senior Certificate (NSC) examinations.
2. To explain why Grade 12 Physical Sciences learners' hold certain alternative conceptions and problem-solving difficulties in work, energy and power.
3. To explore Grade 12 Physical Sciences learners' alternative conceptions and problem-solving difficulties on work, energy and power.
4. To account for Grade 12 Physical Sciences learners' alternative conceptions and problem-solving difficulties using the variation theory of learning.
5. Exploring Grade 12 Learners' Understanding and Problem-Solving Approach to Work-Energy-Power in Physical Sciences in High Schools in Limpopo province in South Africa.

#### Benefits of the Research to Schools

- This research will explore Grade 12 Physical Sciences learners' alternative conceptions and problem-solving difficulties on work, energy and power, and in so doing will provide knowledge to teachers. Teachers could then utilize this knowledge to plan improved lessons that are more effective.
- This research will account for Grade 12 Physical Sciences learners' alternative conceptions and problem-solving difficulties using the variation theory of learning. Teachers could utilize this exposition to further inform and strengthen their classroom practice.

- Authors could also utilize the findings of this research to inform and strengthen their textbooks.
- Curriculum developers could also utilize the findings to inform policy.


### **Research Plan and Method**


The source of data that I will be required to collect from the school will be from a semi-structured focus group interview and from think aloud sessions. For the focus group interview I request the participation of about 27 Grade 12 Physical Sciences learners. For the think aloud sessions I will select 8 candidates from the 27 candidates. I request your permission to record the focus group interviews and the think aloud sessions. You are free to participate or not to participate in the interview or think aloud sessions. Only those who consent will participate. You are also free to leave the sessions at any point of the research without having to give any explanation and without any negative impact on yourself or anybody else. The focus group interview will last about 30 minutes and the think aloud session will last about 1.5 hours. All information collected will be treated in strictest confidence and neither the school, principal, teachers nor individual learners will be identifiable in any reports that are written. Participants may withdraw from the study at any time without penalty. The role of the school is voluntary, and the School Principal may decide to withdraw the school's participation at any time without penalty.

### **Learner Involvement**

Once I have received your consent to participate in the study, I will provide each of you with a consent form that I request you to sign if you want to. It will be appreciated if you would please complete and return the attached form should you consent to your participation in this research. In case you need further clarification or have any questions kindly contact me via email at [veena.jsk@gmail.com](mailto:veena.jsk@gmail.com), telephone 012 357 4169 or cell 078 7944340. You may also contact my supervisor Professor N Govender at University of KwaZulu-Natal, School of Education, Edgewood Campus at 031 260 3469 or [govendern37@ukzn.ac.za](mailto:govendern37@ukzn.ac.za) . You may also contact the Humanities and Social Sciences Research Ethics Committee whose contact details are as follows: Ms Phumelele Ximba, University of KwaZulu-Natal, Research Office, Email: [ximbap@ukzn.ac.za](mailto:ximbap@ukzn.ac.za), Phone number +27312603587.

Thank you for taking the time to read this information and to welcome me in your school.

  
JSK Maharaj (Veena)  
Researcher  
UKZN

  
Professor Nadaraj Govender  
Supervisor  
UKZN

## Appendix 8: Informed Consent of Learner

Consent Form

I..... (full names of participant) hereby confirm that I understand the contents of this document and the nature of the research project, and I consent to participating in the research project.

I understand that I am at liberty to withdraw from the project at any time, should I so desire. I understand the intention of the research. I hereby agree to participate.

I consent / do not consent to have this interview recorded (if applicable).

I consent / do not consent to have this think aloud session recorded (if applicable).

I consent / do not consent to write the test and participate in the discussion thereafter (if applicable).

Signature of Participant

\_\_\_\_\_

Date

\_\_\_\_\_

Signature of Witness

\_\_\_\_\_

Date

\_\_\_\_\_

## Appendix 9: Semi-Structured Interview Schedule

### Interviewer

#### A. Opening

A.1 [Greeting] My name is Jayanthi (Veena) Maharaj and I work at the Department of Basic Education. Currently I am studying the teaching and learning of Physics and am researching learners' understanding and problem-solving ability on the topic Work Energy and Power.

This set of activities are based on the topic Work Energy Power. You have the option to write the test or not to write the test without any negative consequences to yourself or your school.

Data from this test may be used for research purposes only and your name, the name of your teacher and the name of the school will NOT be reflected in the research report.

A.2 I would like to ask you some questions about your background, your experiences in studying Physical Sciences and about one section in particular in Physics i.e. Work Energy Power.

A.3 I am currently conducting research on this topic and I hope that by talking to you I can gain insights into the teaching and learning of this topic. I hope to use this information to improve teaching and learning in schools.

A.4 The interview should take about 30 minutes. Are you available to respond to the questions at this time?

A.5 Let me begin by asking you some questions about where you live)

A.5.1 General demographic information

A.5.2 By a show of hands, tell me how many of you

A.5.3 live close to this school, i.e. about 15 -20 minutes away

A.5.4 live more than 20 minutes away

A.5.5 walk for less than 20 minutes to school

A.5.6 walk for more than 20 minutes to school

A.5.7 comes by public transport to school and you pay yourself

A.5.8 comes by scholar transport to school and you don't pay

A.5.9 live in the school hostel

A.5.10 Do you enjoy the meals?

#### B. Questions about Work Energy Power

B.1 Do you like the topic "Work Energy Power"

- B.2 Do you find this topic “Work Energy Power” easy?
- B.3 What is work?
- B.4 Are “work” and energy” related concepts? Explain your answer.
- B.5 How would you know that work is being done?
- B.6 Is work a vector or a scalar quantity?
- B.7 What is the formula to calculate work?
- B.8 Interviewer throws a ball into the air and then asks the following question:  
What is the work done by your hand on the ball when the ball is in the air and moving upwards? (Follow-up question) Did the hand do any work on the ball Yes or No? Explain.
- B.9 Discuss whether any work is being done by each of the following agents. The agent is indicated in capital letters. If so, state whether the work done is positive or negative:
- 9.1 A CHICKEN scratching the ground looking for worms,
  - 9.2 A BOY sitting at the TABLE and studying for his Physics test,
  - 9.3 A 2010 stadium construction CRANE lifting a bucket of concrete and
  - 9.4 The GRAVITATIONAL FORCE on the bucket in question B.9.3 above.
- B.10 What is Kinetic Energy?
- B.11 Let us suppose you do work on a box that is placed on the floor?  
(Interviewer places the box on the floor and asks the group how work can be done on the box.). Do you think the work that you do on the box will have any effect on the Kinetic Energy of the box?
- B.12 What do you understand by the term “negative work”?
- B.13 You throw a ball vertically upward in the air. After the ball has left your hand and is moving upward in the air, is the force of gravity doing any work on the ball? Explain. Follow-up question: is this work done by the force of gravity positive or negative?
- B.14 Can kinetic energy ever be negative? Explain
- B.15 Can Potential Energy ever be negative? Explain
- B.16 Consider the following scenario: Interviewer places a box of mass 20 kg on the horizontal floor and pushes it.
- 16.1 Explain the motion of the box. Why does the box stop?
- B.17 Consider the following scenario: A box of mass 20 kg is sliding across a frictionless horizontal floor at a constant velocity of  $1\text{m}\cdot\text{s}^{-1}$ .
- 17.1 Is any work being done on the box?

- 17.2 Thato now exerts a constant horizontal force of magnitude  $x$  on the box in the direction opposite to its motion, stopping the box. Is the work done by Thato on the box positive or negative? Can you tell what amount of work done by Thato is? Explain your answer.
- 17.3 Suppose Thato is exerting a constant horizontal force of magnitude  $x$  on the box in the direction opposite to its motion, trying to stop the box and that the box moves a horizontal distance of  $y$  meters before coming to rest. What is the amount of work done by Thato in stopping the box?
- 17.4 Suppose in question B.17.3 Thato had exerted a horizontal force of double the magnitude ( $2x$ ) on the box in the direction opposite to its motion. Do you think the work done by Thato will be same, more than or less than in B.17.3 above? Follow-up question: Will he stop the box in a shorter or longer distance?

### C. Conclusion

**A.5.11** Thank you, learners, for your wonderful participation in this interview.

## Appendix 10: Think Aloud Questionnaire (TAQ)

### Think Aloud Activity:

#### Biographical Information

Name: (Optional .....Grade: .....

Gender: .....

June Exam Percentage/mark obtained: .....

Mother Tongue: .....

### SECTION A

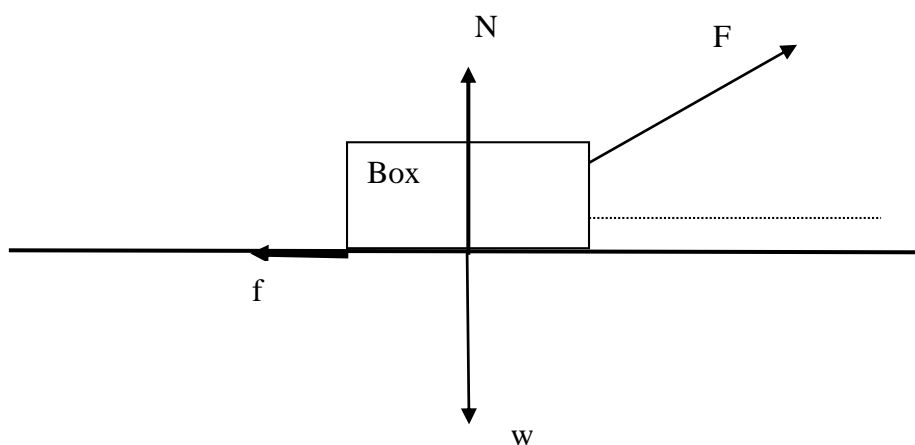
#### MULTIPLE-CHOICE QUESTIONS

#### Instructions

- Select one of the five choices a– e for each of the 6 questions. **Circle** your selected choice.
- Ignore the retarding effects of friction and air resistance unless otherwise stated.

1. A box is pulled along a straight horizontal road to the right without being lifted off the road. The force diagram below shows all the forces acting on the object.

Which ONE of the following statements is TRUE?



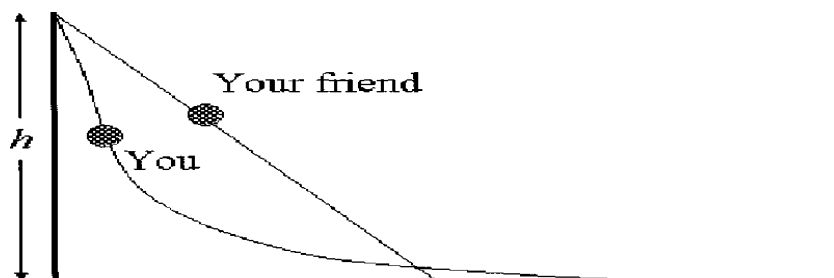
- A.  $f$  does positive work on the box.
  - B.  $F$  does zero work on the box.
  - C. Both  $F$  and  $f$  do negative work on the box
  - D.  $F$  does positive work on the box
  - E.  $f$  does zero work on the box
- (2)

2. You lift a suitcase from the floor to a table. In addition to the weight of the suitcase, select which of the following factors determine the work done by the gravitational force on the suitcase.

- (1) whether you lift it directly up to the table or along a longer path
- (2) whether you lift it quickly or slowly
- (3) the height of the table above the floor

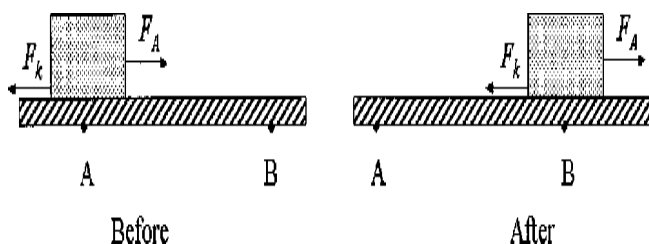
- A. 1 only
  - B. 3 only
  - C. 1 and 3 only
  - D. 2 and 3 only
  - E. 1, 2, and 3.
- (2)

3. Two frictionless slides are shaped differently but start at the same height  $h$  and end at the same level as shown below. You and your friend, who has the same weight as you, slide down from the top on different slides starting from rest. Which one of the following statements best describes who has a larger speed at the bottom of the slide?



- A. You, because you initially encounter a steeper slope so that there is more opportunity for accelerating.
- B. You, because you travel a longer distance so that there is more opportunity for accelerating.
- C. Your friend, because her slide has a constant slope so that she has more opportunity for accelerating.
- D. Your friend, because she travels a shorter distance so that she can conserve her kinetic energy better.
- E. Both of you have the same speed. (2)

4. Using a rope of negligible mass, you pull a box along a horizontal surface with a constant horizontal force  $F_A$ . The box moves at a constant velocity from position A to position B. The force of friction  $F_k$  cannot be neglected. Which one of the following statements concerning the motion of the box from A to B is true?



- A. The work done on the box by the gravitational force is non-zero.
- B. The work done on the box by  $F_k$  is positive.
- C. The total work done on the box by the net force is nonzero.
- D. The magnitude of the work done on the box by  $F_A$  is equal to the magnitude of the work done by  $F_k$ .
- E. The magnitude of  $F_A$  is greater than the magnitude of  $F_k$ . (2)

5. While in a playground, you and your niece take turns sliding down a frictionless slide. Your mass is 75 kg while your little niece's mass is only 25 kg. Assume that both of you begin sliding from rest from the same height. Which one of the following statements best describes who has a larger speed at the bottom of the slide?

- A. Both of you have the same speed at the bottom.
  - B. Your niece, because she is not pressing down against the slide as strongly so her motion is closer to free fall than yours.
  - C. You, because your greater weight causes a greater downward acceleration.
  - D. Your niece, because lighter objects are easier to accelerate.
  - E. You, because you take less time to slide down. (2)
6. You drop a ball from a high tower and it falls freely under the influence of the gravitational force. Which one of the following statements is true?
- A. The kinetic energy of the ball increases by equal amounts in equal times.
  - B. The kinetic energy of the ball increases by equal amounts over equal distances.
  - C. There is zero work done on the ball by the gravitational force as it falls.
  - D. The work done on the ball by the gravitational force is negative as it falls.
  - E. The total mechanical energy of the ball decreases as it falls. (2)

**SECTION B**

**Instructions**

- Write down your detailed solutions in the spaces provided.
- Show ALL formulae, calculations and explanations

1.

7. A mini-bus driver, travelling on a straight horizontal road, wonders why the speed of his vehicle is constant even though he has his foot on the accelerator as he is applying a constant value of “acceleration”. Supply the driver with a reason for his observation.

(3)

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8. **In the following two scenarios ignore friction and air resistance.**

**Scenario One:**

Car X approaches a hill. The driver turns off the engine at the bottom of the hill, and the car freewheels up the hill.

**Scenario Two**

Car Y, with its engine running, is driven up the hill at a constant speed.

In which of the scenarios above is the principle of conservation of mechanical energy observed (State scenario One or Scenario Two)? Explain your answer for each of the scenarios. (4)

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9. A mountain climber and a hiker (having equal masses) both start off at the same time at the foot of a mountain. The hiker takes a longer but easier route spiraling up around the mountain and is the first to arrive at the top. Later the climber arrives at the top.



- 9.1 Which one (climber or hiker) does more work in getting to the top of the mountain? Explain your answer. (4)

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- 9.2 Which one (climber or hiker) expends more power in getting to the top of the mountain? Explain your answer. (4)

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10. A small box is moving along a horizontal floor.

10.1 Does the kinetic energy of the box increase, decrease or remain the same if the velocity of the box changes from:

10.1.1  $-1 \text{ m}\cdot\text{s}^{-1}$  to  $1 \text{ m}\cdot\text{s}^{-1}$  (2)

.....  
.....

10.1.2  $-4 \text{ m}\cdot\text{s}^{-1}$  to  $-1 \text{ m}\cdot\text{s}^{-1}$  (2)

.....  
.....

10.2 In 10.1.1 above is the net work done on the box positive, negative or zero? (2)

.....  
.....

10.3 In 10.1.2 above is the net work done on the box positive, negative or zero? (2)

.....  
.....

11.

The track for a motorbike race consists of a straight, horizontal section that is 800 m long.



A participant, such as the one in the picture above, rides at a certain average speed and completes the 800 m course in 75 s. To maintain this speed, a constant driving force of 240 N acts on the motorbike.

11.1 Calculate the average power developed by the motorbike for this motion.

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(3)

Another person practises on the same motorbike on a track with an incline. Starting from rest, the person rides a distance of 450 m up the incline which has a vertical height of 5 m, as shown below.



The total frictional force acting on the motorbike is 294 N. The combined mass of rider and motorbike is 300 kg. The average driving force on the motorbike as it moves up the incline is 350 N. Consider the motorbike and rider as a single system.

11.2 Draw a labelled free-body diagram for the motorbike-rider system on the incline.

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(4)

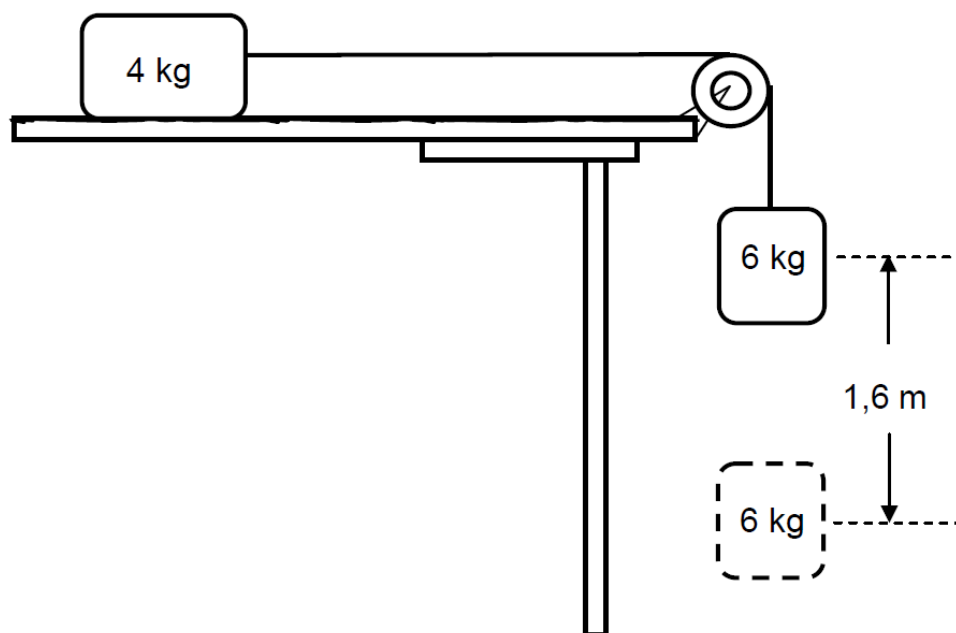




**QUESTION 13 (Start on a new page.)**

In the diagram below, a 4 kg block lying on a rough horizontal surface is connected to a 6 kg block by a light inextensible string passing over a light frictionless pulley.

Initially the blocks are HELD AT REST.



When the blocks are released, the 6 kg block falls through a vertical distance of 1,6 m.

13.1. Draw a labelled free-body diagram for the 6 kg block.

13.2. Calculate the work done by the gravitational force on the 6 kg block.

The coefficient of kinetic friction between the 4 kg block and the horizontal surface is 0,4. Ignore the effects of air resistance.

13.3. Use **energy principles** to calculate the speed of the 6 kg block when it falls through 1,6 m while still attached to the 4 kg block.

## Appendix 11: Example of a learner's transcript for question 5

The following is the transcript, which is the Think Aloud Protocol (TAP), of Timber for question 5.

1. [00:15:13]
2. 151 (Q5). Number five (5).
3. 152 Mmm says OK.
4. 153 While in a play playground, I and my niece take turns sliding down a friction frictionless slide. My mass is 75 kg while my little niece's mass is only 25 kg. Assume that both of you begin sliding from rest from the same height. Which one of the following statements best describes who has a larger speed at the bottom of the slide?
5. 154 OK before I go to the options, I think it's going to be me because I have the greater mass.
6. 155 I think so, because the formula for kinetic energy is half  $m v$  squared and if
7. 156 OK let me not include the kinetic energy.
8. 157 But I think it's me, because of I have I have a greater mass.
9. 158 But let me see the options.
10. 159 Says both of us have the same speed at the bottom.
11. 160 I don't think so.
12. 161 It says my niece, because she is not pressing down against the slide as strongly so her motion is closer to free fall than mine.
13. 162 Oh. OK. Oh. OK.
14. 163 I don't go with A,
15. 164 B, says my niece, because she is not pressing down against the slide as strongly so her motion is closer to free fall than mine.
16. 165 But OK, that might be true,
17. 166 I'll consider it for now.
18. 167 So C says me, because my greater weight causes a greater downward acceleration.
19. 168 I'm going with it definitely.
20. 169 For D, says my niece, because lighter objects are easier to accelerate.
21. 170 Mmm.

22. 171 That's true but not when they fall.
23. 172 OK let's see.
24. 173 Says E, me, because I take less time to slide to slide down.
25. 174 Not sure about it.
26. 175 I'm not going with E.
27. 176 So E is cancelled out and A is cancelled out.
28. 177 I'm left with, no and D is also cancelled out.
29. 178 I'm left with two options, B and C.
30. 179 Let me see.
31. 180 B, my niece, because she is not pressing down against the slide as strongly so her motion is closer to free fall than mine.
32. 181 Mmm mm.
33. 182 C C B B C.
34. 183 OK
35. 184 C says me, because my greater weight causes a great downward acceleration. OK.
36. 185 *(Researcher asks if he checked that its recording. Learner says ya).*
37. 186 Says B that's my niece.
38. 187 No says C says me because my greater weight causes a greater downward acceleration.
39. 188 OK let's see.
40. 189 B it says my niece, because she is not pressing down against the slide as strongly so her motion is closer to free fall than mine.
41. 190 But I can't consider it because it says that I must not consider frictionless.
42. 191 So it says sliding down its frictionless.
43. 192 So I go with C.
44. 193 *(Teacher asks learner if he locked up. Learner says "yes sir").*
45. 194 So I go with C.
46. [00:19:16]

**Appendix 12: Question 1.5 and Question 5 from NSC 2017****Questions 1.5 and Q5 from NSC 2017**

- 1.5 A person lifts a crate vertically upwards at constant velocity through a distance  $h$ . The person does work  $x$  on the crate in time  $t$ .

The person now lifts the same crate vertically upwards at constant velocity through the same distance, but in time  $2t$ .

The work done by the person on the crate will now be ...

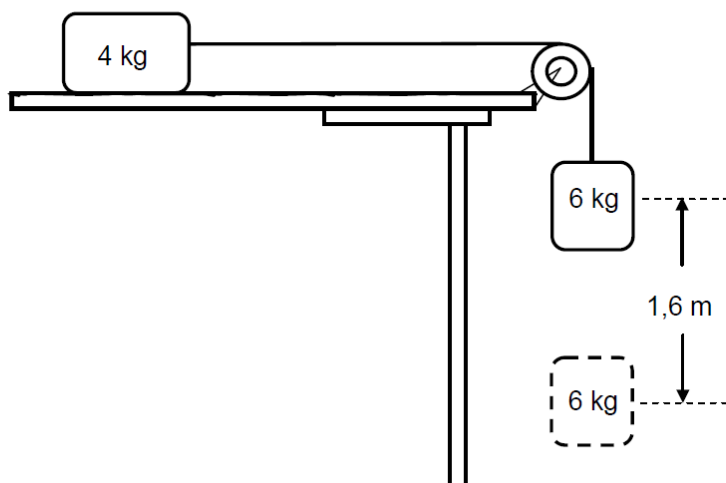
- A  $\frac{1}{2}x$
- B  $x$
- C  $2x$
- D  $4x$

(2)

**QUESTION 5 (Start on a new page.)**

In the diagram below, a 4 kg block lying on a rough horizontal surface is connected to a 6 kg block by a light inextensible string passing over a light frictionless pulley.

Initially the blocks are HELD AT REST.



- 5.1 State the work-energy theorem in words. (2)

When the blocks are released, the 6 kg block falls through a vertical distance of 1,6 m.

- 5.2 Draw a labelled free-body diagram for the 6 kg block. (2)

- 5.3 Calculate the work done by the gravitational force on the 6 kg block. (3)

The coefficient of kinetic friction between the 4 kg block and the horizontal surface is 0,4. Ignore the effects of air resistance.

- 5.4 Use **energy principles** to calculate the speed of the 6 kg block when it falls through 1,6 m while still attached to the 4 kg block. (5)

**[12]**

## Appendix 13: Editing certificate

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29/12/2021

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## **RE: EDITING CERTIFICATE**

**FOCUS AREA: EXPLORING GRADE 12 LEARNERS' UNDERSTANDINGS OF, AND PROBLEM-SOLVING APPROACHES TO WORK-ENERGY-POWER IN PHYSICAL SCIENCES IN HIGH SCHOOLS**

Submitted in partial fulfilment of the academic requirements for the degree of Doctor of Philosophy of Education in the School of Science, Mathematics, and Technology Education in the Faculty of Education at the University of KwaZulu-Natal in Durban, South Africa.

This serves to confirm that this research report has been edited for clarity, language and layout.

Kind regards,



Nereshnee Govender (PhD)

## Appendix 14: Turnitin Report

### Exploring Grade 12 Learners' Understandings of, and Problem-Solving Approaches to Work-Energy-Power in Physical Sciences in High Schools

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