Exploring how grade 12 Physical Sciences learners make sense of the concepts of work and energy

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By

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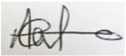
DECLARATION

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

Signature:  Date: March 19, 2016

ABSTRACT

Physical Sciences is one of the subjects in which students perform most poorly in the National Senior Certificate examinations. For example, in the Eastern Cape in 2013, a mere 29.9% of the candidates who sat for the Physical Sciences National Senior Certificate examination managed to achieve a mark of 40% or above (Department of Basic Education, 2014). According to the Chief Markers' reports (ibid), questions on the topic of Work, Energy and Power are amongst the most poorly answered in the National Senior Certificate examinations. This fact triggered my interest to explore how grade 12 Physical Sciences learners make sense of the concepts of Work and Energy with particular emphasis on the work-energy theorem and its application in problem solving.

I carried out the study in a village school in the Queenstown district. The study adopted an interpretive paradigm in which the case study approach was used. Data were generated using a diagnostic test, focus group interviews, video-recorded lessons, analysis of learner journals and a summative test. Analysis of the qualitative data involved identifying themes from the data and using analytical statements that answered the research questions. The study was informed by Vygotsky's (1978) social constructivism theory, and in particular, the notions of the mediation of learning and the Zone of Proximal Development (ZPD). Learners were given tasks on the work-energy theorem and related concepts and these were designed in such a way that they were situated in the learners' ZPD, since this is where most powerful learning takes place (Thompson, 2013).

The findings of the study revealed that grade 12 Physical Sciences learners do not have sufficient prior knowledge on concepts related to the work-energy theory to successfully make sense of the work-energy theorem. The other finding is that learners construct knowledge of the work-energy theorem and its application collaboratively through group work. In the group discussions learners used *isiXhosa* and this enhanced their sense making. A number of challenges that make it difficult for learners to solve problems using the work-energy theorem were identified.

DEDICATION

This thesis is dedicated to my family. First to my daughter, Gina whom I hope will be inspired to appreciate that education is not about preparing life but it is life itself (John Dewey). Second, to the special lady in my life Hamunyare, for the patience and moral support during the final stages of the drafting of this thesis when I almost ignored her completely as I worked on finalising this thesis.

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As Dr. Ken always said, 'if we want to walk far let us walk together' indeed we walked together all the way to the end.

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CHAPTER 1: SITUATING MY STUDY

1.1 Introduction

The main goal of this study was to explore how grade 12 Physical Sciences learners make sense of the concepts of work and energy. The work-energy theorem explains the relationship between work done on an object and the resultant change in its kinetic energy. As outlined in the CAPS document for Physical Sciences, learners are required to apply the work-energy theorem and related concepts to solve problems for objects lying on both flat and inclined surfaces.

I provide the reasons for embarking on this particular study and follow this with the research goals and questions that guided the process. The theoretical framework informing this study is briefly discussed and the key terms that are used in this thesis are defined. A thesis outline indicating the contents of each chapter is provided and the chapter ends with some concluding remarks.

1.2 Rationale for this study

The Trends in International Mathematics and Science Study (TIMSS) is a cross-national assessment of the performance of grade 4 - 9 learners in Mathematics and Science (Howie, Scherman, & Venter, 2008). According to the Human Sciences Research Council, South Africa has taken part in the TIMSS in 1995, 1999, 2002, and 2011 and has consistently been ranked lowest amongst all participating countries. The 2011 assessment included 42 countries including African countries such as Ghana, Botswana and South Africa (Human Sciences Research Council, 2012). Although the TIMSS's focus is on Natural Sciences it is an indicator that science education in South Africa is in a crisis.

A closer look at the TIMSS 2011 report reveals that within South Africa, the Eastern Cape Province in particular, had the worst performance in both Mathematics and Science. Furthermore, schools in the disadvantaged areas such as townships and rural areas fared much worse compared to former model C schools. However, the overall performance of South African learners as presented by the TIMSS gives an average which does not reflect the performance of different schools. For instance, the fact that grade 8 learners are doing poorly in the TIMSS is a pointer to the fact that that Physical Sciences learners enter grade 10 with a weak Natural Sciences background. It is here in the Natural Sciences that most basic concepts are introduced.

In South Africa, the subject Physical Sciences in grades 10-12 covers topics on chemistry and physics. In recent years this subject in these grades has been the one which performed most poorly. In 2013, for example, nationally only 67,4% of learners who sat for the National Senior Certificate Examination managed to get a mark of 30% or more and in the Eastern Cape Province this dropped to 55,8%. In the Eastern Cape in 2013 a mere 29,9% of the candidates who sat for the Physical Sciences National Senior Certificate examination managed to achieved a mark of 40% or above (Department of Basic Education [DBE], 2014). According to the 2013 Physical Sciences Chief Marker's report (DoE, 2012) as well as from my own experience as a Physical Sciences educator and National Senior Certificate Examination Paper 1 marker since 2008, questions on the topics of Work, Energy and Power are amongst the most poorly answered questions in the National Senior Certificate Physical Sciences Paper 1 examinations.

As stated in the 2013 Physical Sciences Chief Marker's report, "Problem solving using the work-energy theorem is really a challenge for learners" (DoE, 2012, p. 264). Although this research places emphasis on the work-energy theorem, the theorem is not treated in isolation since scientific concepts tend to be interconnected. Hence, the study focused on work and energy concepts in general and the work-energy theorem in particular. Challenges faced by learners in understanding and applying the work-energy theorem could be caused by any number of causes, including most likely a lack of understanding of the basics of work and energy concepts and/or related concepts.

1.3 Research goal and questions

1.3.1 Research goal

The goal of this research is to explore how grade 12 Physical Sciences learners make sense of the concepts on Work and Energy

1.3.2 Main research question

How do grade 12 Physical Sciences learners make sense of the concepts on Work and Energy?

1.3.3 Sub – Questions

1. What prior content knowledge about Work and Energy concepts do grade 12 Physical Sciences learners have?

2. How do grade 12 Physical Sciences learners make sense of the work-energy theorem using lessons designed based on social constructivist principles?
3. What factors enable or constrain grade 12 Physical Sciences learners to solve problems related to the work-energy theorem?

1.4 Problem statement

Using the TIMSS's report and the Chief Markers' reports it is evident that science education in South Africa needs urgent and serious remediation. In order to improve the overall performance of learners in examinations there is need to get to the root of the problem. As highlighted above, questions on work and energy in Physical Sciences cause problems for learners. In order to come up with a solution, my study sought to explore how learners construct knowledge with the view of providing an enabling atmosphere for improved learning using the idea of constructivist learning. The study also sought to explore the specific difficulties that learners experience when they solve problems using the work-energy theorem. It is hoped that my findings could be used to develop appropriate teaching approaches.

1.5 Potential value of my study

As alluded to earlier, Physical Sciences is one of the subjects in which learner performance is weak, especially in the Eastern Cape Province, which traditionally displays poor science education achievement. It is imperative that research aimed at improving the general achievement of learners in this subject be conducted.

Findings from this study will be valuable to a number of parties:

- The diagnostic test can be used as a tool to ascertain learners' prior knowledge before teaching the topic Work, Energy and Power. Knowing learners' prior knowledge is important in preparing lessons which employ constructivist teaching and learning principles.
- It is envisaged that the unit of work that was developed during this study could assist teachers and learners in teaching work and energy more effectively.
- An understanding of factors that enable or constrain learners to solve problems involving the work-energy theorem may also inform the work of other teachers, subject advisors, curriculum developers, and textbook writers

thereby contributing to improved achievement by the Physical Sciences learners.

- Furthermore, exploring how grade 12 Physical Sciences learners make sense of the concepts of work and energy might lead to a better understanding of the problems learners face in understanding these concepts.
- Finally, this study might provide all stakeholders involved in education with an empirical foundation for addressing the problems being experienced in teaching and learning of these concepts.

1.6 Case Study

The data used to answer my research questions were gathered using a case study. A case study was chosen in order to get an in-depth understanding of how in the particular context of Physical Sciences learners in grade 12, make sense of the concepts of work and energy. As stated by Ashley (2013), a case study allows the researcher to use multiple data gathering techniques to investigate the case in-depth, to probe and get to its complexity.

1.7 Theoretical framework

The study is informed by a social constructivist perspective as proposed by Vygotsky (1978). From a social constructivist perspective, learning entails sense making by the individual learner through social interactions which involve the use of language in both oral and written forms. Individuals engage socially in talk and activity about shared problems or tasks. In these discussions the more capable learners can support the less capable ones. In this study, learners were afforded opportunities for social construction of knowledge through small group activities and class discussions.

1.8 Data gathering techniques

To answer the research questions, data sets were gathered using a number of methods to allow for triangulation. Triangulation involves using more than one method to gather data with the aim of improving the validity (Cohen, Manion & Morrison, 2011). The following data gathering techniques were used:

- Diagnostic test;
- Observation;
- Learner journals;
- Summative test;
- Stimulated recall interviews; and
- Semi-structured interviews.

1.9 Definition of key terms

I now define some key terms in order to clarify their meanings in the context of this particular study.

1.9.1 Sense making

A way of thinking and speaking that is learned in the context of interaction with others. Sense making and meaning making are used interchangeably in this study.

1.9.2 Work-Energy theorem

The work-energy theorem shows the relationship between the work done on an object and its kinetic energy. It states that, the work done on an object is equal to the change in the kinetic energy of the object.

1.9.3 Prior knowledge

This the knowledge possessed by learners before any learning or teaching of a particular topic commences.

1.9.4 Social constructivism

This is a learning theory that proposes that learning takes place through the construction of knowledge by an individual within a social context.

1.9.5 Mediation of learning

Mediation consists of activities done or facilitated by the teacher that enable the process of construction of knowledge by individuals.

1.10 Thesis outline

Chapter One which is titled, 'situating the study' introduces the study. The rationale for this study as well as its potential value are outlined. This is followed by the research goal and the questions that guided data gathering and analysis are also stated. The problem statement is described. I then proceed by describing the potential value of this study before I justify why I chose to use the case study methodology. The theoretical framework guiding this research is outlined. Data gathering techniques employed are described. I finally define some key terms to avoid ambiguity or misinterpretation of their meanings.

Chapter Two reviews some of the literature that is relevant to the study with a view to situating the study within the body of knowledge gathered through research. The study deals with a topic which is part of the South African grade 12 Physical Sciences curriculum so curriculum requirements are therefore discussed. The notion of sense making in science is reviewed by making reference to various readings. Prior knowledge on the concepts of the work-energy theorem is also reviewed. I consulted both international and South African research studies done on the learning of work and energy concepts. Social construction of knowledge involves the use of language so the effect of learning science in a second language is also reviewed. The chapter ends by describing social constructivism as the guiding theoretical framework.

Chapter Three describes the research methodology used. In this chapter I start by relating my research questions to the data gathering techniques. The research designed is explained and the research site is described. The data gathering techniques stated in Chapter One are described. Ethical considerations made are also discussed. Finally, I end the chapter with a discussion of the trustworthiness and limitations of the study.

In **Chapter Four,** I present and analyse the data gathered using techniques outlined in Chapter Three. From the analysis of data I came up with themes which form the basis of the analytical statements I construct and expand on in Chapter Five.

In **Chapter Five** I interpret and discuss my findings on how grade 12 Physical Sciences learners make sense of the concepts of work and energy which I presented and analysed in Chapter Four.

In **Chapter Six,** I make recommendations based on the findings presented. I also critically reflect on the research process. Suggestions for further research inspired by this study are also made.

1.11 Concluding remarks

In this chapter I situated my study by outlining the rationale and potential value of the study. The research goal and questions are stated so as to put the rest of the thesis in perspective. Important terms are defined to reflect the way they have been applied in the thesis. Finally, the thesis chapters are outlined.

In the next chapter I discuss the literature relevant to my study.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The main goal of this study was to explore how grade 12 Physical Sciences learners make sense of the concepts of work and energy. In this chapter I thus review some literature on the teaching and learning of work and energy with particular emphasis on the concept of the work-energy theorem at grade 12. I explore the South African National Senior Certificate (NSC) Physical Sciences curriculum requirements. Some studies carried out both internationally and in South Africa in relation to the teaching and learning of work and energy concepts are reviewed.

As the theoretical framework adopted in this study is social constructivism, relevant literature on the application of this framework in the teaching and learning of Physical Sciences is reviewed. Since this study was carried out in a rural school with learners who are English second language speakers, some literature on language and its effects on learning science is also included.

2.2 South African Physical Sciences curriculum requirements

The South African grade 12 Physical Sciences curriculum (Department of Basic Education [DBE], 2011, p. 82) requires learners to be able to:

- Define the work done on an object by a force as : $W=F\Delta xCos\theta$;
- 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;
- Draw a force diagram showing only forces that act along the plane. Ignore perpendicular forces;
- Calculate the resultant force (along the plane); and
- Calculate the net work done on an object by taking the product of the resultant force (along the plane) acting on the object and its displacement along the plane.

With respect to the work-energy theorem learners should be able to:

- Know that the net work done on an object causes a change in the objects kinetic energy – the work-energy theorem $W_{net} = E_{kf} - E_{ki}$; and
- Apply the work-energy theorem to objects on horizontal and inclined planes (frictionless and rough) (Department of Basic Education, 2011, p. 83).

The work-energy theorem and the curriculum requirements are explained in the next section.

2.3 Work and energy concepts

As mentioned earlier, the Physical Sciences curriculum in South Africa includes coverage of both Chemistry and Physics topics and each is divided into three knowledge areas (DBE, 2011). The three Physics knowledge strands are assessed in the Physical Sciences examination paper 1 while the three Chemistry knowledge strands are assesed in the Physical Sciences examination paper 2. Furthermore, work and energy concepts are included in the Mechanics section of the Physics component of Physical Sciences in South African schools (ibid).

The concept of energy is important in developing an understanding of mechanics. There are studies that challenge teachers' perceptions of energy as well as how teachers normally teach the concept of energy in schools. For example, "there is really no unique, absolute or universal concept of energy and it has no simple definition" (Sefton, 2004, p. 2). This contributes to the energy concept being problematic to introduce and teach. However, curriculum documents and textbooks provided some working definitions of the term energy. For instance, energy is traditionally defined 'the capacity to do work' (Kelder, Govender, & Govender, 2013, p. 151). The fact that the common definition stated in textbooks emphasizes the relationship between the concepts of work and energy provides support for this study focusing on both of these concepts.

"Textbook introductions of work involve a discussion of a force, F applied to an object, which then moves through some displacement, Δx" (Jewett, 2008, p. 38). This is followed in the textbooks by the presentation of the following equation:

$$W = F.\Delta x.\cos\theta$$

In the above formula, W is the work done by the force and θ is the angle between the direction of force applied and that of displacement of the point of application of the force. From the above formula for work there is an association between work, displacement and force concepts. To a large extent, learning the concept of energy depends on the force concept, which is one of the principal concepts of physics. For work to be done, a force has to be applied and therefore an understanding of the concept of force is important in order to understand energy (Saglam-Arslan & Kurzen, 2009). Saglam-Arslan and Kurzen (2009) report that studies have shown the concepts of work, energy and force are often confused with each other and students cannot state the difference between them.

In many examples used during Physical Sciences lessons and examination questions, it is highlighted that more than one force acts on an object. Each of these forces does its own work on the object. "The net work done by multiple forces on an object is equal to the product of the net force on the object and the displacement of the object" (Jewett, 2008, p. 40). The net force is the overall force on an object when all forces are added. The fact that displacement results from work being done implies that there is kinetic energy involved. Kinetic energy is the energy possessed by a moving body. It is calculated by the formula, $E_k = \frac{1}{2}mv^2$. In the formula, E_k refers to kinetic energy, m to the mass, and v to the velocity of the object.

Moving an object from one point to another may result in a change in velocity of the object and the kinetic energy of the object. In this case the **work-energy theorem** describes the relationship between work done and change in kinetic energy. "The work-energy theorem states that work done by the net force acting on an object is equal to the change in the kinetic energy of the object" (Booster, Carter, & James, 2009, p. 27).

$$W_{net} = \Delta E_k$$
$$= E_{k\,final} - E_{k\,initial}$$

In the South African grade 12 Physics examination papers (e.g. November 2012, November 2013 & February 2014), learners were presented with questions involving bodies on inclined planes. This presents a further challenge for learners answering questions on work and energy concepts since forces have to first be resolved into components. In most of the examination questions, it is only a component of applied force that causes the displacement. Hence, knowledge of basic trigonometry is required for the resolution of forces.

2.4 Sense making

Audet, Hickman and Dobrynina (1996) contend that some of the activities that a learner does during the sense making process include detecting patterns, asking focusing questions and seeking explanations. Audet et al. (1996) further suggest that analysing what learners write can give the teacher insights into the sense making processes that learners go through. In the same vein, Crowder (1996) aserts that sense making in learners can be recognized in the way they talk about scientific ideas. For instance, learners who are in the process of sense making present their ideas in multiple stops, starts, and revisions. Such unpolished statements may signal that learners are involved in actively constructing knowledge (Crowder, 1996). In order to gain insight into learners' sense making processes this study used video-recordings of learner talk and an analysis of learners' written work.

Driver, Osoko, Leach, Mortimer and Scott (1994) acknowledge that meaning making involves a dialogue between persons. This is in line with the social constructivist view of the sense making process which is my theoretical framework in this study (see Section 2.8). Lemke (1990) emphasizes that meanings are constructed using language, mathematics, diagrams, and techniques. According to Lemke (1990), meaning making can thus be detected in behaviours such as talking, reasoning, drawing, and gesturing. Analysing learners' talk and written work, and observing their class discussions can therefore provide an awareness of their meaning making processes.

One form of written work that can be used for analysis is learner journals. Audet et al. (1996) suggest the use of learning journals as a way of enhancing sense making by learners. Analysing these journals can provide a teacher with insights about the learners' levels of understanding, their thought processes, misconceptions, and other factors associated with learning. Writing in journals which the teacher reads is a form of dialogue between the teacher and an individual learners that is important in the construction of knowledge from a constructivist point of view. For this reason journals were used as one of the data gathering tools in this study.

2.5 Learners' prior knowledge

The concepts of work and energy that are examined at grade 12 level have their roots in instruction received in earlier grades. Prior knowledge learnt in earlier grades is a requirement for learners to be able to construct concepts correctly at grade 12 level. For example, South African learners are introduced to force, energy and work concepts when doing the Energy and Change content strand of the Natural Sciences learning area in the General Education and Training (GET) phase. Roschelle (1995) contends that there is substantial evidence pointing to the fact that learning tends to proceed from prior knowledge and learners are expected to use this prior knowledge to construct concepts on work and energy when they get to the Further Education and Training (FET) phase.

Learners come to the grade 12 Physical Sciences classroom with some prior knowledge which is both knowledge from the content learned in earlier grades and some everyday knowledge relevant to science. Prior everday knowledge is also called intuitive knowledge. The use of prior knowledge from earlier grades and intuitive learning is important in the contructivist approach to teaching and learning as proposed by Roschelle (1995).

Intuitive physics knowledge is the knowledge about physical phenomena that students bring to the learning of formal science (Sherin, 2006). This is knowledge learners acquire informally either through their own experiences or from other members of the society. Learners have experienced pushing things up or down ramps or played on slides, for example. These examples are some of the everyday applications of what the grade 12 Physical Sciences curriculum intends to expand on. Driver et al. (1994) contend that learners bring to the science classroom informal ideas about scientific phenomena that are constructed, communicated and validated within everyday culture. These authors argue that everyday representations of natural phenomena are sometimes different from scientific represenations. Driver et al. (1994) report that “there is a commonly held conception that a constant force is to maintain an object in motion” (p. 8). This differs from Newtonian physics which associates force with acceleration. This is an example of a case where the everyday understanding of natural phenomena differs from the scientific understanding. Driver et al.(1994) further argue that if everday representions of particular natural phenomena are very different from scienctific represenations, learning may prove difficult.

Sherin (2006) supports this by saying that research has shown that these everyday experiences form a substantial body of knowledge of the physical world that learners bring to the classroom. Some of this knowledge may be in contradiction with scientific principles. In the teaching of the topic on work and energy learners were provided with opportunities to share their intuitive knowledge in order to build new concepts and provide explanations of their everyday experiences. It was hoped that the sharing of intuitive knowledge would also assist in the identification of those everyday representations of natural phenomena that differ from scientific representations to help to mediate the learning of the scientific point of view.

2.6 Studies on the teaching and learning of work and energy concepts

Some studies on the teaching and learning of work and energy concepts carried out internationally and from South Africa are discussed below. It is important to review these studies so that my own investigation can identify gaps and make a meaningful contribution to ongoing research.

2.6.1 International studies on the learning of the work and energy concepts

A study by Lawson and McDermott (1987) in the United States of America that involved under-graduate students doing introductory courses in Physics revealed a lack of ability to interpret the work-energy theorem as “a statement that doing work on a body produces an increase in kinetic energy” (p. 816). Although this study involved under-graduate students as opposed to my study which involves grade 12 learners, the findings are still relevant since it involved the application of the work-energy theorem which is central to my study.

The study by Lawson and McDermott (1987) assessed students’ understanding of the impulse-momentum and work-energy theorems by asking the students to perform tasks requiring the application of these theorems in a real life motion situation. The students were asked to compare the changes in momentum and kinetic energy of two dry ice pucks that were made to move by the same constant force along a glass table. Many of the students involved in the study failed to apply the work-energy theorem to the motion of a body experiencing a constant force. From the study, Lawson and McDermott concluded that, “to develop a functual understanding, most students need experience in interpreting the formal relationships of physics in a variety of contexts” (p. 817). This finding from the study suggests that learners can remember formal relationships such as the work-energy theorem without any real sense making as they fail to apply it to real life situations.

Tang, Tan and Yeo (2011) carried out a study in Singapore to investigate how students construct meaning of the work-energy concept through the integration of multiple methods such as verbal, visual, mathematical, and gestural modes. Tang et al. (2011) explain that a mode of representation is a sense making resource system that is formed and used over time. These authors postulate that conceptual understanding is dependent on the multimodal representations that are used in the teaching and learning process. The study by Tang et al. (2011) used data from a group of learners working collaboratively to make sense of the work-energy concept from a practical real life example.

One of the objectives of the study by Tang et al. (2011) was to investigate how students construct meanings through intergration of different modalities. In their study, the authors worked with small groups of learners who were guided in constructing knowledge by a computer programme. Data were gathered from various sources including video-recorded observations and online student journals.

Tang et al. (2011) observed verbal dialogue, mathematical symbolism and gestures as the multimodal construction of the work-energy concept. For example, the learners managed to identify correctly each of the abstract mathematical entities of the work–energy equation in the case of a moving ball and related their meanings through spoken language. Tang et al. (2011) further explain that "this dynamic juxtaposition of spoken language and written formulation was crucial and necessary for them to overcome the linguistic difficulties of nominalisation and abstraction that are prevalent in scientific text" (p. 1796).

International studies reveal some insights into the way learners make sense of work and energy concepts as well as some of the difficulties they face in the process. I will now discuss a few South Africa studies whose context and curriculum is similar to my own study.

2.6.2 Some South African studies on the learning of Work and Energy concepts

A study involving grade 10 Physical Sciences learners from four South African provinces, namely, North West, Mpumalanga, Gauteng and Limpopo revealed that many grade 10 learners do not have enough prior knowledge about the concept of energy from the GET phase for them to be able to adequetly grasp the concept in the FET phase (Lemmer, 2011). In the study by Lemmer (2011) learners were asked questions which sought to investigate their conceptual undestanding of the concepts of work, force, energy and energy conversions. The question the respondents answered were based on an everyday situation of a boy who pulls a cart up the hill. The results from the study indicated that the learners lacked conceptul understanding of the following:

- As the cart is pulled up the hill both the cart and the boy who is pulling have energy;
- Both the cart and the boy exert forces as the cart is pulled up the hill; and
- The total mechanical energy of the cart remained constant throughout its motion.

In Physics, work, energy, force, and energy energy conversion are related. An applied force that displaces a body does work and changes its kinetic energy. This relationship is the work-energy theorem on which the current study is centred. This lack of prior knowledge by grade 10 learners further contributes to learning difficulties when the topic work, energy and power is developed through to grade 12 (Lemmer, 2011). It is because of this gap in knowledge that this study used a diagnostic test to explore prior knowledge from earlier grades as a starting point to assess what grade 12 learners knew about the work-energy theorem.

In his doctoral thesis, Mchunu (2012) carried out a study in KwaZulu Natal province which sought to identify the conceptual difficulties faced by grade 12 Physical Sciences learners in the mechanics section of the curriculum (which is where the focal content in this study is situated). With respect to work and energy concepts the study concluded that "learners experienced conceptual difficulties with regard to (a) resolving the components of weight; (b) the work concept; (c) work-energy theorem application; (d) the kinetic energy concept; and (e) the principle of conservation of mechanical energy application" (Mchunu, 2012, p. 44). These conceptual difficulties identified by Mchunu form some of the key concepts in my study.

These conceptual difficulties could be a contributing factor to learners not being able to apply the work-energy theorem to solve questions of the kind set in National Senior Certificate examinations. By investigating how learners make sense of these concepts I expected to gain some insights into the underlying causes of the conceptual difficulties identified by Mchunu (2012) in his study. It is recognised, however, that the contexts of the studies are different.

Another South African study related to my study was carried out in a village in the Northwest Province by Rhankumise, Raphoto, and Maimane (2014). The study investigated the alternative ideas grade 10 learners have on the principle of the conservation of mechanical energy. Mechanical energy is the sum of the kinetic energy and mechanical energy of a body. The problem Rhankumise et al. (2014) intended to address was how to treat and handle learners' alternative conceptions relating to conservation of mechanical energy. From the pre-test they administered it was established that learners' knowledge about energy and forms of energy was obscure and confused. Learners in that study associated energy with motion, size of the object and human activities. From the perfomance of learners in the post- test the authors concluded that the ideas held by learners on the energy concept can be used to construct scientific conception of energy. This should have a positive effect on the learning of the work energy theorem. Tang et al. (2011) highlighted the importance of using both written and spoken language in making sense of work and energy concepts. My study was done with learners whose home language is *isiXhosa* whilst the language of learning and teaching (LoLT) used is English. Some literature on the impact that learning science in a language other than one's home language will now be discussed.

2.7 Language and learning science

The construction of the meaning of science concepts is mediated through language. Learners in this study have *isiXhosa* as their home language and yet the official language of learning and teaching (LoLT) at the school is English. Learners who are learning science in an additional language have to simultaneously learn English and the language of science in order to understand and explain the concepts. In order for the learners to develop their langauge skills, teachers need to afford them opportunities for language usage and learning (Msimanga & Lelliot, 2014). Group work is one way teachers can afford learners the opportunity to construct meanings for scientific concepts as well as learn the English language. However, some research findings show that in small groups learners revert almost entirely to their home language (Msimanga & Lelliot, 2014; Ferreira, 2011; Probyn, 2015). Msimanga and Lelliot claim that reverting to their home language helps learners who lack confidence in English to construct understandings of scienctific concepts.

In bilingual classrooms such as the one in my study, teachers need to make use of both the LoLT and learners' home language to enhance conceptual understanding. In this regard, Probyn (2015) advocates for translanguaging. According to Probyn (2015), translanguaging is the practice of changing from the LoLT to the learners' home language for an extended period of time. This is unlike code switching which involves relatively short switches from LoLT to learners' home language. Probyn (2015) also contends that exploratory talk amongst learners tends to be mostly in their home language whilst presentational talk and writing are then translated to the LoLT.

Notwithstanding, the reality is that the language of assessment determines the language of learning and teaching. In a study in KwaZulu Natal (KZN) province, Zuma and Demster (2008) translated some questions used in the TIMSS study into *isiZulu* before administering them to some grade 9 learners. Results from this study did not show any significant improvement from the same test that was administered with questions in English. These findings suggest that science concepts can be learnt and assessed in learners' home language. For this reason, learners in the current study were allowed to discuss and answer oral questions in *isiXhosa*, their home language. The fact that the LoLT and formal assessment are in English meant that the teaching was done in Engish as well as all written work.

2.8 Theoretical framework

In the teaching of concepts on work and energy I applied the social constructivist perspective which proposes that meanings of concepts are constructed by individuals together with the help of others. In the application of the principles of social constructivist emphasis was put on the concept of the Zone of Proximal Development (ZPD) (Vygotsky, 1978). Notions of mediation, use of language and dialogue are discussed in connection with the ZPD and in relation to their application in the teaching and learning of the work-energy theorem in grade 12 Physical Sciences. I now discuss each of these below.

2.8.1 Social constructivism

Constructivism is a learning theory which proposes that learning takes place through the construction of new knowledge based on the learner's prior knowledge and experiences.

> It is assumed that learners have to construct their own knowledge … individually and collectively. Each learner has a tool kit of concepts and skills with which he or she must construct knowledge to solve problems presented by the environment. The role of the community … other learners and the teacher is to provide the setting, pose the challenges, and offer the support that will encourage mathematical thinking (Davis, Maher, & Noddings, 1990, p. 7).

Davis et al. (1990) are essentially acknowledging that learning is an individual activity and that knowledge and ideas are constructed within an individual but during that process individuals need assistance such as from more knowledgeable others.

Lending support to this notion, Brooks and Brooks (1993) contend that "Constructivism is not a theory about teaching… it is a theory about knowledge and learning … the theory that defines knowledge as temporary, developmental, socially and culturally mediated, and thus, non-objective" (p. vii). Constructivism puts more focus on the learner and how learning occurs rather than on the teacher and their teaching. Brooks and Brooks (1993) are also alluding to the gradual construction of knowledge and the influence of culture. The implication here is that people in different socio-cultural settings do not necessarily learn the same way.

McRobbie and Tobin (1997) posit that from a social constructivist perspective learning is a process of sense making by the individual learner through social interactions. Lending support, Staver (1998) asserts that social constructivism centers its focus on the study of meaning making through language. As Driver et al. (1994) contend, construction of scientific knowledge happens when individuals engage socially in talk and activity about shared problems or tasks. McLeod (2014) citing Vygotsky (1978) contends that much important learning by the child occurs through social interaction with a skillful tutor. The skillful tutor may be the teacher or more capable learners in the class or group. In this study learners were afforded opportunities for social construction of knowledge through small group activities and whole class discussions.

2.8.2 Zone of Proximal Development

Vygotsky (1978, p. 86) defines the Zone of Proximal Development (ZPD) as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers". The ZPD lies between what the child can do alone and what they can do with help and interacting with others.

Thompson (2013) further suggests that a learner's development in the ZPD involves social interaction, dialogue, and mediated activities between learners and the teacher and between learners themselves. Mediation activities take various forms and Thompson (2013) identifies a number of them, including direct instruction from the teacher; modelling of a behaviour or task by the teacher or more capable peer; feedback, either verbal or written; and scaffolding of a task, or part of a task. The metaphor of scaffolding was used by Bruner (1978). As McLeod (2014) explains, scaffolding involves helping the learner in a structured manner with the aim of helping the learner achieve certain goals.

The ZPD is intended to assist learners move from independent problem solving at a lower level to a level where they can solve higher level or new problems with assistance of a more capable other. This assistance takes the learner to a level where they can solve these high level problems unassisted. Thompson (2013) suggests that the learner moves from his or her actual level through the potential level to the realized level if his or her ZPD is identified and made use of.

Tharp and Gallimore (2013) caution that the transition from assisted performance to unassisted performance is not abrupt. The authors define assisted performance as those activities or tasks that a child can do with help or support of the environment, others or the self. Tharp and Gallimore (2013) outline the four stages of the ZPD which I now discuss in the following paragraphs.

There are four stages of the ZPD. The first stage is where the learner's performance is assisted by more capable others. At this stage the learner has little understanding of the concepts. The teacher has to offer modelling and direction whilst the learner imitates without much meaning making or understanding. Gradually, as the learner progresses, assistance turns from modelling and direction to leading questions and feedback.

From being assisted by the more knowledgeable others who include more capable learners, textbooks and other sources of information such as the World Wide Web, the learner moves on to the second stage where performance is assisted by self. At this stage the child is able to carry out tasks unassisted but performance is not yet fully developed. The control of task performance is transferred from the external to internal. Children can also remind themselves what they learnt from the more knowledgeable others during the first phase (Tharp & Gallimore, 2013).

Stage three is where the learner is emerging from the ZPD. Performance is now developed, automatized, and fossilized. The learner in this stage has internalized the concepts or skills and execution is automatized and can be performed without external assistance from the teacher or more capable learners.

After sometime the learner may forget how to do what they could do without teacher assistance as described above. This de-automatization of performance leads to recursion through the ZPD and is considered as stage four of the developmental process. In this stage the learner can no longer do what they could formally do automatically and the individual might revert back to the self-regulation phase. Sometimes no form of self-regulation is adequate to restore capacity to perform. This leads to further recursion to other-regulation. This is when the teacher needs to repeat some aspects of earlier lessons. Class notes or written text can serve as a more knowledge other that will play the role of other-regulation. The unit of work on work and energy concepts becomes valuable when learners get to the de-automatization stage as learners can refer to the notes and revise the concepts they would have forgotten.

2.8.3 Mediation and the Zone of Proximal Development

As the learners interact with the concepts of work and energy using the unit of work mentioned earlier, the teacher should assume the role of the more capable agent and assist the novice learners in gradually making sense of the concepts (Doehler, 2009). Mediation can be defined as “the teacher action and language (verbal and non-verbal), as a systematic answer to the students’ learning demand in their specific development pathways to the intended curriculum learning outcomes” (Lopes, Cavino, Banco, Saraiva, & Silva, 2008, p. 4). Mediation does not only occur through interactions between teachers and learners but also amongst learners working in groups which in effect become communities of learning made up of learners who participate as equal partners (Sherpadson, 1996). In order to be able to capture the moments where learning was taking place in these learning communities, some lessons were video-recorded.

2.8.4 Language and social constructivism

Vygotsky places much emphasis on the role of language in cognitive development. Vygotsky (1962) cited in McLeod (2014), contends that language plays two important roles in cognitive development. First], it is the main means by which adults transmit information to children and second, language itself is a very powerful tool of intellectual adaptation. Vygotsky (1978) cited in Thompson (2013) suggests that:

> Every function in the child’s cultural development appears twice: first, on the social level, and later, on the individual level; first, between people (*inter-psychological*), and then inside the child (*intra-psychological*). This applies equally to voluntary attention, to logical memory, and to the formation of concepts. All the higher functions originate as actual relationships between individuals (p. 266).

In the above quotation, Vygotsky is emphasizing the fact that learning starts on a social level in which the learner interacts with others and negotiates meanings of concepts before the internalization of the concepts. Dialogic discourse between the teacher and learners and amongst learners themselves as they make sense of the work-energy theorem in the context of this study and solve problems is the inter-psychological level according to Vygotsky (1978). The use of inter-personal and intra-personal speech plays an important role in the development through the use of the ZPD.

2.9 Concluding remarks

In this chapter I reviewed some of the literature that is related to aspects of my study. The study is based on the topics work and energy as required by the South African Physical Sciences curriculum and extracts from the curriculum were included. To locate my study within the ongoing body of relevant research, some international and local studies were consulted. The theoretical framework of social constructivism that informs this study was also reviewed.

In the next chapter I discuss the methodology employed to gather the necessary data to answer the research questions.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

In order to explore how grade 12 Physical Sciences learners make sense of concepts of work and energy, I analysed data from different sources. After reviewing relevant literature, I decided to conduct a mainly qualitative case study, underpinned by the interpretive paradigm. Although it is a qualitative case study, some aspects of quantitative data gathering and analysis were employed, making its overall design a mixed-method one. Mixed-method design will be explained in Section 3.3.3.

This chapter outlines the methodology used in this study. To begin with, I state the research goal and the questions that guided the data-gathering and analysis processes. The interpretive paradigm is then outlined, and the concept and use of mixed methods is briefly explained. A description of the research site, the participants involved and how they were chosen, and the rationale for choosing the site and the participants are provided. I go on to explain why I chose to do a case study in order to gather appropriate data. The data-gathering techniques employed are then described, followed by an outline of the data analysis and validation methods used. I end with a discussion of ethical considerations and a note on the limitations of this study.

3.2 Research design and methodology

The research goal and questions that guided this study are listed in the paragraphs that follow.

The methodology and instruments used to answer the questions are also outlined.

3.2.1 Research goal and questions

The goal of this research was to explore how grade 12 Physical Sciences learners make sense of the concepts of work and energy.

In order to achieve this goal I attempted to answer the following main question and related sub-questions.

3.2.1.1 Main research question

How do grade 12 Physical Sciences learners make sense of the concepts of Work and Energy?

3.2.1.2 Sub-questions

1. **What prior knowledge about Work and Energy concepts do grade 12 Physical Sciences learners have?**

To answer this question I used a diagnostic test which explored the relevant prior knowledge acquired in grades 8 to 11. The data gathered helped to expose certain patterns in respect of what prior knowledge learners had or lacked. Analysis of the diagnostic test was both quantitative and qualitative.

2. **How do grade 12 Physical Sciences learners make sense of the work-energy theorem during lessons designed using social constructivist principles?**

To answer this question I co-designed a unit of work on Work, Energy and Power with my critical friend. At the time of this study, my critical friend was a Physical Sciences teacher who was also studying for a Master of Education Degree at another South African university. He was also a Physical Sciences grade 12 National Senior Certificate examination marker. This unit of work was used as a mediating tool in the teaching and learning of concepts of work and energy. Video-recorded lessons and learner journals were used as data gathering tools. Particular attention was paid to the lessons or parts of lessons when learners were working collaboratively to construct knowledge. These recordings were transcribed and analysed.

3. **What factors enable or constrain grade 12 Physical Sciences learners to solve problems related to the work-energy theorem?**

To answer this question, a summative test was given at the end of the teaching of the unit of work. Summative test data were analysed both quantitatively and qualitatively.

3.2.2 Methodology

3.2.2.1 Introduction

This study is guided by social constructivist principles. McRobbie and Tobin (1997) suggest that from a social constructivist perspective knowledge is constructed by individuals in a social setting, based on what they already know or have learned before. For this reason I started by exploring learners' prior knowledge so as to ascertain their level of readiness for the new concepts of work and energy.

The diagnostic test outcomes informed the design of the unit of work. Aspects of prior knowledge that were found to be lacking in the learners, such as the resolving of forces (studied in grade 11), were included in the unit of work. Group exercises were designed to accord with the evidence of prior knowledge obtained from the diagnostic test.

An analysis of recorded lessons afforded me the opportunity to see how learners construct ideas on work and energy when they work collaboratively. The summative test included questions similar to those set for the grade 12 National Senior Certificate examinations. The test results enabled me to identify and analyse factors that enable or constrain learners in solving problems using the work-energy theorem and related concepts.

3.2.2.2 Interpretive paradigm

The research design is underpinned by the interpretive paradigm. Cohen, Manion and Morrison (2011) contend that the main focus of the interpretive paradigm is to understand subjective human experiences. According to Creswell (2009), researchers make an interpretation of what they see, hear and understand of events or situations in a particular moment and context. In this case, the interpretation occurs in the context of a small rural school with *isiXhosa* learners who are learning the work-energy theorem in an additional language, English. The way learners in this particular context make sense of the concepts of work and energy is not necessarily the same as might be found in different contexts.

3.2.2.3 Embedded mixed-methods design

Mixed-methods research is a procedure which involves collecting and analysing both qualitative and quantitative data within a single study (Invankova, Creswell & Plano Clark, 2012). Gathering and analysing both qualitative and quantitative data within the same study provides the researcher deeper insights into the problem (Maree, 2012). The type of mixed-methods design used in this study is termed a concurrent embedded strategy (Creswell, 2009). A concurrent embedded strategy has a "primary method that guides the project and a secondary data base that provides a supporting role in the procedures" (Creswell, 2009, p. 214). This is a qualitative case study with some quantitative data embedded within it which plays a supporting role. The scores from both diagnostic and summative tests are presented in the form of graphs and percentages are used. These are quantitative sets of data that highlight the extent to which prior knowledge is lacking and how well learners do after the teaching of the unit of work. Embedding quantitative data thus helps to show the extent to which a theme or issue is pertinent.

3.3 Research site and participants

3.3.1 Rationale

The work-energy theorem is taught at the grade 12 level, and so a grade 12 class was a natural choice to work with. I decided to conduct the research with my own learners as I considered myself competent enough to provide adequate mediation and play the role of the more knowledgeable other as described by Vygotsky (1978). The other reason for choosing to work with my own learners was for convenience. I had limited time and resources for the research, so researching at my own school with my own class allowed me to research and do my work at the same time. And of course, most importantly, I wanted to improve my practice.

3.3.2 Participants

3.3.2.1 Researcher

As stated earlier, I co-designed with my critical friend the main mediation tool, which is the unit of work I used in the teaching of the content. I also played a mediating role during the learners' construction of knowledge.

3.3.2.2 Learners

The learners who participated in this study were in grade 12 in 2015 at the research site. The class had 37 learners. Of these 37 learners, 19 were repeating grade 12, either because they had failed previously or wanted to upgrade their passes. In Phase 1 of this study, which involved administering a diagnostic test, all 37 learners wrote the test. Using the test scores a focus group made up of six learners was selected from the 18 non-repeaters. Repeaters were not included in the focus group for the reason that they were not being exposed to the content for the first time, so their performance could not be entirely attributable to their current learning.

Two top performers, two middle, and two bottom performers were selected. In addition, a seventh learner, who achieved the highest score in the diagnostic test was chosen in order to play a special role in the focus group. This particular learner had passed Physical Sciences at level 4 (50–59%) in the previous year's NCS examinations. During group discussions in Phase 2, which involved the teaching of the unit of work, this learner played the role of a more knowledgeable other (Vygotsky, 1978). The focus group consisted of three girls and four boys.

The school is situated in a small village and all the learners speak *isiXhosa* as their home language. The medium of instruction at the school is English, which is a second language to all the learners. As suggested in Chapter 2, the issue of learning science in a second language was pertinent in this study.

Phase 2 of the study involved teaching and learning using the unit of work. Video recordings were made of group discussions among the seven learners.

3.4 Data gathering

3.4.1 Introduction

Data were generated from the whole class as well as from the focus group, as explained above. The data gathering process started with the whole class when the diagnostic test was administered in order to gain a general impression of the class's prior knowledge. Video-recordings were made of the focus group during selected lessons. Learners in the focus group kept journals in which they regularly wrote down their reflections on the lessons. The selected lessons were those in which the learners were engaged in group activities.

After the teaching of the unit of work described earlier was completed, learners were given a summative test which was analysed for the whole class. Stimulated recall interviews were conducted with learners who gave answers which needed further probing in the diagnostic test as well the summative test.

3.4.2 Data gathering techniques

3.4.2.1 Diagnostic test

As explained by Cohen et al. (2011), a diagnostic test is a test designed to discover particular strengths, weaknesses and difficulties that learners may be experiencing. Treagust (1998) postulates that diagnostic tests can be used to find out about misconceptions held by learners. Prior knowledge that learners have can also include misconceptions. Tests to find out about learners' misconceptions should be used as diagnostic tools to help to begin to address the misconceptions. The diagnostic test in this study sought to explore what relevant prior knowledge this grade 12 class had before the formal learning of work and energy concepts at grade 12 level. From as early as grade 7, under the strand of Energy and Change in the Natural Sciences, the concept of energy is taught. Furthermore, in grade 11 learners learn how to resolve forces into components. This knowledge is used when applying the work-energy theorem to bodies on inclined planes or when forces are applied at an angle.

According to constructivist principles, learning is built upon prior knowledge, a view emphasised by Roschelle (1995). Exploring learners' prior knowledge is therefore important in the use of constructivist principles in teaching and learning. Being aware of learners' prior knowledge helps the teacher, who is the mediator of learning, to design mediation activities with an idea (although not a very precise one) of the learners' Zones of Proximal Development (Vygotsky, 1978). The outcome of the diagnostic test therefore informed the preparation of my unit of work.

3.4.2.2 Lesson observation

To answer the second sub-question of the study I video-recorded learners in the focus group as they performed group tasks. As the teacher of the class I did intervene in the group discussion, as a way of mediating the process of sense making on the part of the learners (see Section 2.8.3).

The purpose of the group tasks was to give learners an opportunity to socially construct knowledge of work and energy concepts, as envisaged in Vygotsky's (1978) social constructivism. In order to analyse the interactions between learners, I video-recorded the focus group in some of the lessons. My critical friend helped in checking the transcriptions for accuracy, especially with the translations from *isiXhosa* to English as my *isiXhosa* is limited.

3.4.2.3 Learner journals

Learners kept journals in which they made entries after every lesson on the work-energy theorem. Audet, Hickman and Dobrynina (1996) contend that analysing what learners have written can provide teachers with insight into how they make sense of the material or concepts they are learning. In this study, journals gave learners the opportunity to use language in the construction of knowledge and understanding of the concepts pertaining to work and energy. Learners were given some simple questions which were meant to focus their reflections and help them write in a structured manner. I collected these journals and wrote responses to the learners' writing whenever necessary.

3.4.2.4 Summative test

After the teaching of the concepts relating to work and energy, all learners in the class were given a summative test. Cohen et al. (2011) state that a summative test is a test given at the end of a programme that is designed to measure achievement. The summative test was a criterion reference test which provided information about the abilities and understandings developed by the learners. This type was chosen because the teaching and learning in grade 12 is focused on preparing for the NSC examination. The criteria used to construct the test items were extracted from the Physical Sciences Examination Guidelines (DBE, 2014). These criteria are set out in Section 2.2.

As proposed by Harlen & James (1997) if understanding is to be assessed the summative test should include items that require learners to use their knowledge of work and the work-energy theorem in solving problems linked to real-life contexts

The questions in the summative test were categorised in order to reflect the knowledge and skills learners need to acquire as guided by the Physical Sciences Examination Guidelines (DBE, 2014). Table 4.3 the foci of questions from the diagnostic test.

Table 3.1: Foci of summative test questions

Foci		**Question number**
A	Identifying forces/drawing free body diagrams	**1,1; 1,2; 2.1; 3.1**
B	Identifying forces that are or are not doing work	**2.2;**
C	Recalling/identifying correct formula for work-energy theorem	**2.6; 3.3**
D	Calculating change in kinetic energy	**1.5; 3.2**
E	Calculating net force or net work	**1,3; 1,4; 2.4**
F	Stating the work-energy theorem	**2.5**
G	Identifying and applying the work-energy theorem	**3.3**
H	Applying work-energy theorem to calculate unknown values for velocity, displacement, applied force	**2.6; 3.4**
I	Using trigonometry	**1,3; 2.4; 3.4**

3.4.2.5 Stimulated recall interviews

As explained earlier, the diagnostic test sought to explore the prior knowledge learners brought with them from earlier grades. Some learners' responses warranted further exploration. In order to acquire an in-depth understanding of these responses, stimulated recall interviews were conducted (Lyle, 2003). The summative test not only measured learners' achievements, it also brought out the kind of mistakes, misconceptions and problems they had after the teaching of the unit of work. Stimulated recall interviews were conducted using learners' responses to test questions as stimuli.

In both sets of interviews, those based on the diagnostic test and those based on the summative test, individual learners' responses were used as stimuli. The interviews were tape-recorded and transcribed verbatim.

3.5 Data analysis

According to Gay, Mills and Airasian (2006), data analysis is the process of making sense of and finding meaning in the data. Qualitative analysis is a relatively systematic process of coding, categorizing and interpreting data to provide explanations of a single phenomenon of interest (ibid.).

In this study, the data gathered were analysed in order to establish themes or issues emerging from it. Data were analysed inductively (Cohen et al., 2011; Betram & Christiansen, 2014) since the themes were not predetermined: rather, I identified them in the process of analysing the data. From the themes I developed three analytical statements. From the diagnostic test I constructed graphs showing the distribution of marks for the whole class as well as for the focus group. Misconceptions and gaps in prior knowledge formed one of the themes that gave rise to analytical statements.

Analysis of learners' journals involved looking for any common themes that emerged from learners' writings and relating them to themes emerging from the video-recording transcriptions. My critical friend checked the transcriptions for accuracy.

3.6 Validity

Since I conducted this research with my own learners and did the data collection myself, issues of validation and trustworthiness are very pertinent. My critical friend, who was also studying for a Master of Education in Science degree, played a key role in validating the data gathered at every stage in the data-gathering process. The diagnostic test and the summative test were sent to my critical friend and another Master of Education student in my class for their input. Both made valuable suggestions relating to suitability, validity, relevance, clarity, and readability level and language appropriateness for the target audience.

Triangulation is another way to ensure the validity of findings. “Triangulation seeks to validate a claim, a process or an outcome through at least two independent sources” (Newby, 2010, p. 112). Data from lesson observations, learner journals and the summative test were used to answer the main research question. Interview schedules and transcriptions from the interviews as well as video clips were analysed with the assistance of the critical friend to ensure accuracy in transcription.

3.7 Ethical considerations

Being both a teacher and researcher to the same group of learners presents challenges as far as power dynamics are concerned. During the research process, learners might act in ways they perceive to be acceptable to me but which are not natural. I made it clear to the learners that they were free to choose not to participate in the data-gathering process.

Informed consent in writing was sought from the principal of the school and the parents of the learners to be involved in the research. Twenty-five learners who took part in this study were over the age of 18 so they signed their own informed consent forms. Cohen et al. (2011) describe informed consent as involving procedures that will allow individuals to choose whether or not to participate in an investigation after being informed of facts that are likely to influence their decision.

In my final report, pseudonyms were used for both the learners and the school to maintain their anonymity and protect their identities. For learners in the focus group learner codes were used (L1, L2 etc.). During the stimulated interviews, learners were asked to choose pseudonyms for themselves.

3.8 Limitations of the study

Being a case study that was chosen mainly for convenience the findings of this study may not be generalised. The topic on Work and Energy was taught by me, the researcher, who also happened to know the learners well. This could have introduced some bias, since I would inevitably have had some preconceived perceptions of the learners at the back of my mind. By video-taping learners engaged in discussions I minimised my bias since the transcriptions were checked by my critical friend. The composition of the class – which influenced the kind of group discussion that took place – is obviously not the same as classes in other schools. This is another limitation of this present study. Notwithstanding this, some valuable insights on how grade 12 Physical Sciences learners make sense of the concepts of work and energy emerged from this study.

3.9 Concluding remarks

In this chapter I outlined the methodology used in gathering data to answer the research questions. The data gathering techniques and the research question that each of the techniques sought to answer were explained. This study was conducted within the interpretive paradigm, employing a case study method. Also described above was the embedded mixed method design, which involved mainly qualitative data analysis, with elements of quantitative data analysis in the forms of percentages and graphs.

The research site and the learners were described in order to give a contextual background to the study. The data will be interpreted in this context as explained. I went on to explain how the data were analysed and how themes and analytical statements were formed and used. I also explained how data collected was validated with the help of a critical friend. I ended with a discussion of the ethical issues taken into account.

In the next chapter, I present and analyse my data.

CHAPTER 4: DATA PRESENTATION AND ANALYSIS

4.1 Introduction

In order to find out how grade 12 Physical Sciences learners at my research site make sense of the concepts of work and energy I gathered data using a diagnostic test, lesson observations, learner journals, summative test and stimulated recall interviews based on the learners' responses in the diagnostic and summative tests respectively. The main objective of this chapter is to present and analyse the data gathered. I start by presenting data on the performance of learners in the diagnostic test as well as a selection of the learners' responses to some of the items in the diagnostic test. Data collected from lesson observation follows and highlights from learner journals are presented. Finally, learners' marks from the summative test and related stimulated recall interviews are presented. I end the chapter with some concluding remarks.

4.2 The Diagnostic Test

The Department of Basic Education's grading system for learners uses levels 1 to 7. Level 1 (0 – 29%) is the failing level. Level 2 (30 -39%) and higher are the passing levels. In this investigation I considered 50% (equivalent to level 4) as the passing mark. In my view, a mark of 30% in a test is too low for one to be considered to have gained any conceptual understanding.

The diagnostic test (Appendix C) which sought to explore the relevant prior knowledge the grade 12 Physical Sciences learners had acquired from their learning in earlier grades was administered to the whole class. The prior knowledge that was tested ranged from definitions of some basic concepts such as force, energy, and velocity to mathematical skills such as resolving a vector into components and using formulae in calculations. A full analysis of the diagnostic test items is presented in in 4.2.1.

As explained in Section 3.4.2.2, this class comprised 37 learners of which 19 were repeating grade 12 either to upgrade low pass marks or because they had failed to get a mark of at least 30% in Physical Sciences the previous year. From the 37 learners a focus group of seven learners was selected. I start by presenting and analysing marks from the diagnostic test and some issues that emerged from a close examination of learners' responses.

4.2.1 Learner Performance

Table 4.1: Question by question analysis of learner performance

Item	Purpose/Content	Learner Performance	Common errors, misconceptions & understandings	Comments on the learners results
1	Giving an example of a scalar and a vector quantity	-17 got it correct -15 both examples wrong or only one correct - 6 did not attempt	- learners just stated 2 quantities without specifying e.g. *Speed and displacement*	50% of the learners could not differentiate between a vector and scalar quantity using own example
2.1	Define/explain '*force'* and give an example	- 12 managed to define and give correct example - 19 defined/explained correctly but incorrect or no example - 6 gave wrong definitions	- *'force is power*' - common error - failure to give examples with the definition 'force is a push/pull ...')	68% of learners could not define force and give a correct example - Learners who failed to give examples with the correct definition could have just memorized without understanding - There could be confusion between terms force and power stemming from home language, i.e. force and power have the same word in *IsiXhosa* (*'force is power'*)
2.2	Define/explain *energy*	- 6 gave both correct definition/explanation and correct example -23 gave correct definition and incorrect or no example -9 got it wrong	- '*ability to do work*' was the definition given - 5 learners wrote, '*energy is power'*	16% could not give correct definition as well as a correct example -Learners who failed to give an example could have memorized definition without understanding - language issue: *'energy is power'* (see comment for 2.1)
2.3	Define/explain *displacement*	- 5 gave correct definition and example - 7 gave correct definition and no example - 20 gave incorrect definition and no example	- all sorts of terms/quantities mixed up e.g. '*displacement is time taken', 'displacement is speed x time', 'displacement is force'*	Only 13% of the learners could correctly explain the concept of displacement and give an example

		-2 did not attempted		
2.4	Define/explain *distance*	- 8 gave correct definition/explanation and correct example -7 correct definition but no or incorrect example - 20 gave incorrect definition/explanation - 3 did not attempt	- distance is '*time taken* ...' common errors (8 learners)	79% of learners failed to explain what distance is, and give an appropriate example
2.5	Defining/explainin g *speed*	- 2 gave correct definition/explanation and example - 19 gave correct explanation but no example - 17 gave incorrect definition/explanation	Learners associate speed with cars	95% of the learners could not explain/define speed and give an example 50% could only give a correct definition with no appropriate example/explanation Most learners could have memorized definition without understanding
2.6	Define/explain *velocity*	- 3 gave correct definition/explanation but no example - 6 related it to speed - 29 incorrect definition/example	'*Velocity is speed...*' common answer	92% of learners could not define velocity and give an example 16% could relate it to speed
3.1	Basic trigonometry	- 25 got all trigonometric ratios correctly - 4 got ratios partly correct - 9 got all of them wrong	-	66% of learners could calculate trigonometric ratios from a right angled triangle
3.2	Resolving forces into components	- 9 got both vertical and horizontal components correct - 17 totally incorrect - 3 did not attempt - 1 used cos θ for both components - 4 cosine and sine switched - 4 used weight (mg) in place of the force applied	- $mg.sin\theta$ used in place of $F.sin\theta$	- 24% of learners could not correctly resolve forces acting at an angle -
3.3	Identifying component of force doing work	- 10 identified correct force with justification		76% f learners could not identify with reason the

	for a force applied at an angle	- 7 made correct choice of component but could not justify choice - 4 did not attempt - 17 got it wrong		force/component causing displacement
3.4	Statement of Newton's 2nd Law	- 10 stated the law correctly - 6 made errors but identified that the law is about 'resultant/net force' - 4 stated 1st law - 2 stated 3rd law - 12 gave completely incorrect statements - 4 did not attempt	- Stating 1st or 3rd laws instead of 2nd law -	26 % of learners could not remember Newton's 3rd law
4	Ability to identify and draw components of weight (F_g) for a body on an inclined plane	- 5 learners identified and drew all forces correctly. -3 learners identified and labeled 1 or 2 forces correctly. - 3 learners drew forces correctly but did not label them. - 5 learners did not attempt the question at all. - 17 learners drew lines on the diagram which did not make much sense at all	No directions shown. Failure to name forces that are otherwise drawn correctly - Normal force show as acting vertically upwards although surface is inclined (i.e. F_n not at 90 degrees to the surface)	89% of learners were not able to identify and draw components of weight for a body on an inclined plane.
5	Calculating Kinetic energy (E_k)and Potential Energy (E_p) and Change in kinetic energy (ΔE_k)	- 4 got all 3 correct - 16 managed to calculate E_k and E_p but failed to calculate ΔE_k - 2 Got only E_k correct - 16 got it all wrong	- Remembered the formula, $E_k = 1/2mv^2$ but failed to use it correctly - Failure to find ΔE_k -	50% of learners could calculate kinetic energy. - only 11% could calculate change in kinetic energy

As shown in the bar graph in Figure 4.1 below, only 6 out of the 37 learners (16%) who wrote the diagnostic test managed to get a mark of at least 50%. The general picture presented here is that the amount of prior content knowledge on concepts relevant to work and energy was insufficient for true understanding at grade 12 level. The marks from this diagnostic test pointed to the fact that the learners were at a conceptual level lower than expected.

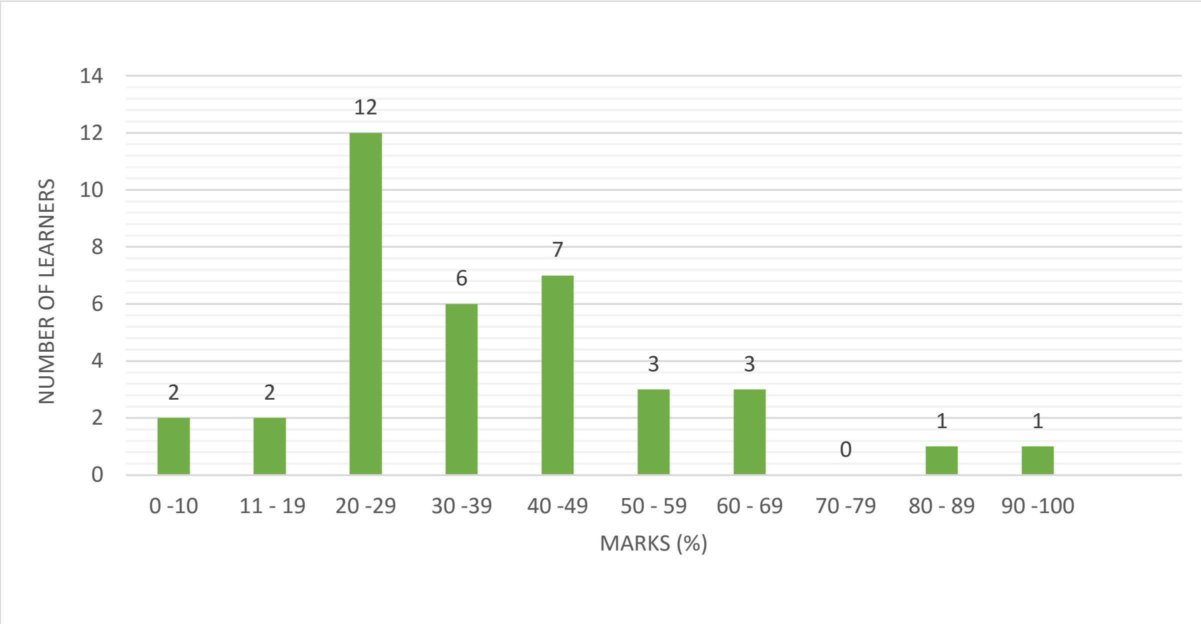


Figure 4.1: Analysis of diagnostic test distribution of marks

Figure 4.1 presents the general picture in terms of the prior knowledge learners have as shown by the marks they scored. Since the data collection that followed the diagnostic test was mainly involved the focus group, I now present Table 4.2 which shows how the learners in the focus group performed in each of the questions in the diagnostic test.

Table 4.2: Detailed scores for diagnostic test

Learners	**Question 1**	**Question 1**						**Question 3**							**Question 4**			**Question 5**		**Total**
		2.1	2.2	2.3	2.4	2.5	2.6	3.1.1	3.1.2	3.1.3	3.2.1	3.2.2	3.3	3.4	4.1	4.2	4.3	5.1	5.2	
Total	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**3**	**3**	**3**	**3**	**2**	**2**	**2**	**3**	**4**	**45**
L1	2	2	2	2	1	1	2	2	2	2	3	3	3	3	2	2	2	2	2	**43**
L2	2	2	2	0	0	2	0	2	2	0	0	0	0	3	0	0	0	3	0	**20**
L3	2	1	1	0	1	0	0	2	2	2	0	0	0	0	0	0	0	1	0	**11**

L4	0	2	2	0	2	2	1	2	2	2	0	0	0	1	2	0	2	3	2	**23**
L5	0	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	**8**
L6	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**
L7	1	2	0	3	2	1	0	2	2	0	0	0	0	0	0	0	0	0	0	**11**

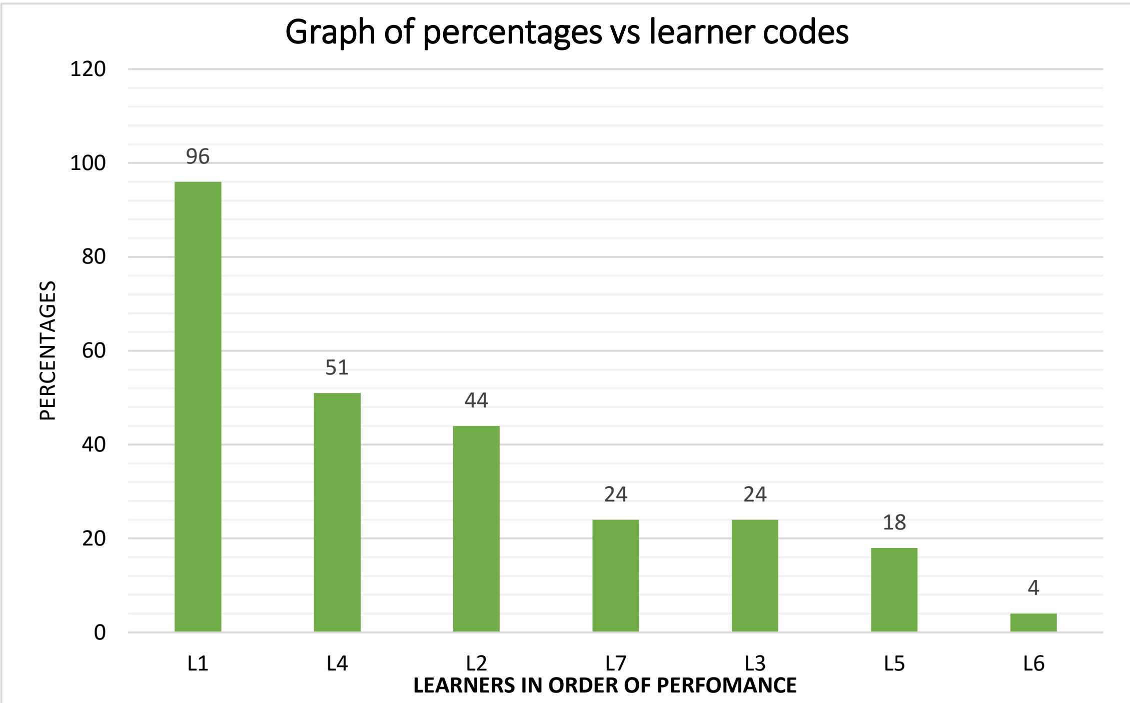


Figure 4.2 shows how learners performed in question 2. Question 2 was made up of 6 sub-questions. Each sub-question required learners to define or explain the meaning of a concept. These concepts are key to the understanding of work and energy concepts at grade 12 level.

For this reason I now present a bar graph showing how learners performed per each sub-question in question 2.

A closer analysis of learner responses to the diagnostic test items revealed some common problems and misconceptions the learners had. I will now discuss some of the more pertinent ones.

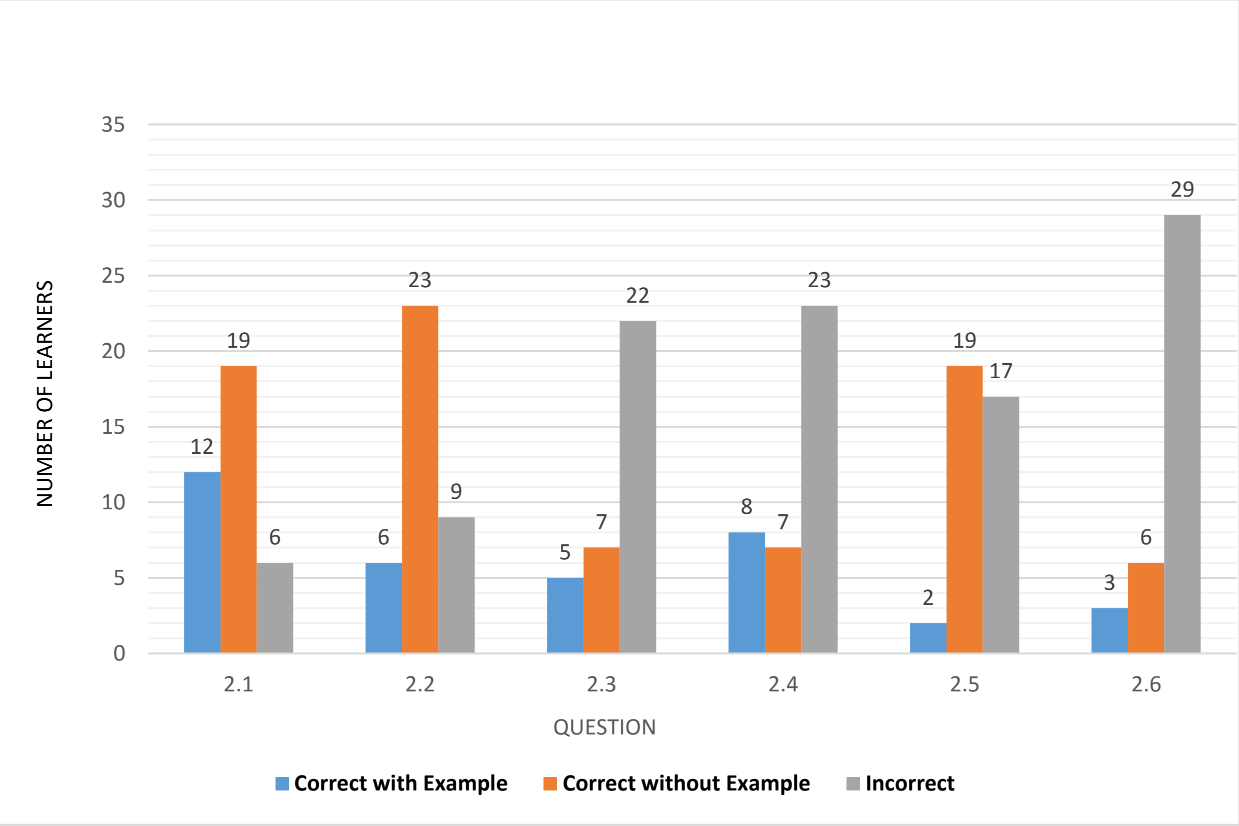


Figure 4.2: Analysis of question 2 marks

4.2.3 Common errors, misconceptions and issues arising from the diagnostic test

Since the scores from the diagnostic test were generally low, this discussion dwells more on what learners could not do, rather than what they could do.

Question 2 of the diagnostic test required learners to define or explain concepts and give an appropriate example. The concepts which were to be defined were as follows:

2.1 Force;

2.2 Energy;

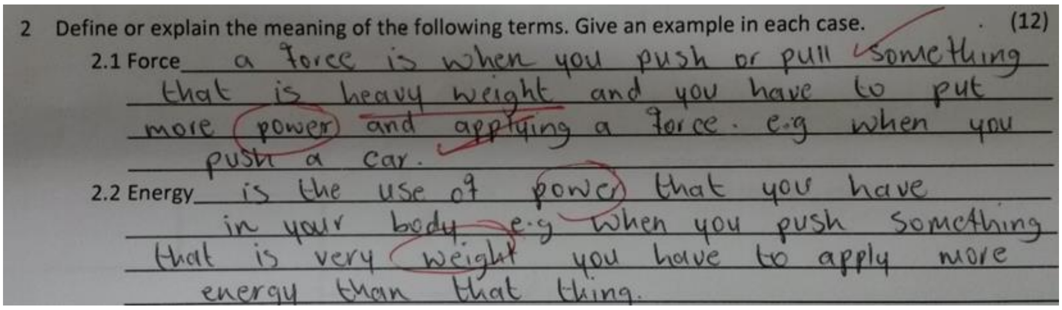
2.3 Displacement;

2.4 Distance;

2.5 Speed; and

2.6 Velocity.

Only 12 learners or 37% of the class managed to define 'force' and gave a correct example. The phrase '*force is power…*' was used by several learners. Figure 4.3 show an example of such a response from a learner. Force and power are different concepts. I later asked the learners who stated that '*force is power*' to explain what they meant by the phrase in the stimulated recall interviews which are presented in the next section of this chapter.


2 Define or explain the meaning of the following terms. Give an example in each case. (12)

2.1 Force a force is when you push or pull something that is heavy weight and you have to put more power and applying a force. e.g when you push a car.

2.2 Energy is the use of power that you have in your body e.g when you push something that is very weight you have to apply more energy than that thing.

Figure 4.3: Extract of learner's responses to questions on force and energy

62% of the learners correctly defined energy as '*the ability to do work'* but only 43% could give a correct example. This could mean that some learners had memorised the definition of energy without conceptual understanding. Six learners wrote, '*energy is power'*. Just as in the case of '*force is power'* I later asked learners to explain their use of the phrase '*energy is power'* during the stimulated recall interviews.

The concept of displacement (question 2.3) is key to the understanding of, and doing calculations on work done on an object. Only 14% of the learners could define displacement and give a correct example. The concept of velocity (question 2.6) was also poorly answered as only 8% of the learners managed to define or explain the concept of velocity and give an appropriate example.

Questions 3 and 4 were based on the application of some basic trigonometry. There was evidence that the majority of learners could calculate trigonometric ratios of sine, cosine and tangent from a right angled triangle as 66% of the learners got the relevant question correct. Resolving components of a force acting at an angle to the direction of displacement of an object was only correctly done by 24% of the learners. After resolving the force acting at an angle into a vertical and horizontal component learners were asked to name the force which was responsible for the indicated displacement of the object. Learners who could not identify that it was the component of the applied force acting in the direction of displacement that was causing the displacement were 76% of the class. Identifying and drawing components of weight for a body on an inclined plane could not be done by 89% of the learners.

In the last question of the diagnostic test, learners were asked to perform some calculations involving kinetic energy. Half the class, i.e. 50% could calculate kinetic energy but only 11% could calculate change in kinetic energy given the initial and final velocities of an object.

As shown in the above paragraphs there were significant gaps in the prior knowledge required for the learners to make sense of work and energy concepts as summed up by the work-energy theorem. This indicated to me that when teaching the unit of work used in the intervention I should not take prior knowledge for granted. As I referred to earlier in this section, I will now present data gathered from stimulated recall interviews based on the learners' responses from the diagnostic test.

4.2.2 Stimulated recall interviews based on the diagnostic test

The names used in all the interviews are pseudonyms which the learners chose for themselves. Pseudonyms were used for learners who were not in the focus group. Those in the focus group were coded L1 to L7 for easier reference since they are referred to several times in this thesis.

Two learners, Given and Zimbini were interviewed about their definition of energy and power respectively. The first vignette is from the interview with Given (I coded it D1-see Appendix L) highlighting his explanation of his response that *'energy is a power done by a person'.*

Extract from Interview D1:

Int: But scientifically energy and power are two different concepts. OK, maybe let's go to vernacular, to Xhosa, neh
Gvn: Yes Sir
Int: What is energy in Xhosa?
Gvn: Energy, *amandla* Sir
Int: And what is power?
Gvn: Power, (he hesitates) *amandla nawo*

(Given went on to state that power is also called amandla in *isiXhosa*)

Int: *Amandla nawo?* **Translated:** *Amandla* also?

The above interview with Given indicated that there is confusion between the concept of energy and power. It appears that the confusion is based on the fact that there is only one term for both energy and power which is *amandla* in the learners' home language *isiXhosa*. This is an aspect of prior everyday knowledge of the concepts of energy and power as they are learnt in the everyday contexts of the learners. I now present a vignette from the interview (see appendix M) Zimbini which was based on her definition of power.

Extract from interview D2:

Zim	**…** *uyipusha…Andiyazi tishala ukubandizawuthini, ndizawuyibeka njani iforce nge* English but *xaupusha iobject uyipusher ngala* force. *So ndiyendayithatha as ukuba iforce* yipower. *Ndiyendohluleka ukudifferentiata iforce ne power*. **Translated**: If you are pushing it, I don't know how to explain force, but if you are pushing an object with that force … So I took it that force is power. I failed to differentiate between force and power.
Int:	Maybe *masithi in iXhosa iforce yinton*? What is the word for a force? **Zim:** *Yhoo tishala* force (Long pause) *ngesi Xhosa tishala. Hayi andiyazi iforce ngesiXhosa*. **Translated**: Oh sir, force in *isiXhosa* sir. No I do not know what it is in *IsiXhosa*.
Int:	Then *ipower*?
Zim:	*Ipower tishala ngamandla.* **Translated**: Power is *amandla* sir

The interview suggests that Zimbini was not sure about the difference between the concepts of force and power. Unlike Given she could only give the *isiXhosa* word for power, *amandla*. The concept of force is an important aspect in the study of work since for work to be done a force needs to be applied.

In the interview coded D3I asked Festo about her answer to calculating components of forces acting at an angle.

Extract from interview D3:

Festo:	So I wanted something just *njee ukuba ndibale ndingatshiyi* blank spaces. I didn't understand the question *manyani.* **Translated:** So I wanted just to have some calculation and not leave blank spaces. I really didn't understand the question.
Int:	*So lo m.g ubusithi umela ntoni*? **Translated**: So what did you think m.g stood for?
Festo:	*Kuba apha sine, sinayo iforce neh. Apha ne angle sinayo. Uyabona. So la m ndaithatha as iforce*. U g ke always 9.8. **Translated:** Since we have force and also the angle I took that m as the force and g is always 9.8.
Int:	So you took m as the force but m is the mass.
Festo:	*Uh uh m is mass but kuba ke ndandifuna ukwenza i*substitution. **Translated**: Yes, m is mass but I just wanted to make a substitution.

Festo failed to resolve a force into components. This is taught in in grade 11 and is part of the assumed prior knowledge for grade 12 learners. She just wrote something so as to "have some calculation and not leave blank spaces".

Interview D4 with Shania was relatively brief so I decided to present the whole transcription.

Interview D4

Int: On question 3.2 you were given a diagram, in this diagram, you were asked to come up with the components of the force F, as you are looking at it. In your answer you wrote $F_x = mgsin\theta$, now my question is, why did you say $mgsin\theta$? Where are you getting the value of m from the information given?

Shania (Sha): *Kalok tishala, ndacinga lo F, le force leyi siyinikiweyo singaisebenzisa as u m*.**Translated:** It Sir, I thought this F, the force we are given can be used as m.

Int: *I force uyuisebenzise as u m?* **Translated:** Using force as m?

Sha: *Ewe tishala. Le siyinikiweyo*, but then *ndabuya ndayazi ukuba irongo leyo lo m* because *akanoba iforce le siyinikiweyo. Bekumele ukuba ndisebenzise u F kula ndawo ka mg.* **Translated:** Yes Sir, the one we are given. But then I now realise that it is wrong to use m because it cannot be a force. I was supposed to use F in that place with mg.

Int: So you knew about it later?

Sha: *Ewe tishala*. **Translated:** Yes Sir.

The interview with Shania, like the one with Festo was based on resolving a force acting at an angle into its vertical and horizontal components. She also used m (mass) and *g* (acceleration due to gravity) incorrectly in trying to calculate the components of force *F*. *Mg* represents the weight of a body, not the force applied at angle on a body. She unlike, Festo did not attribute her mistake to just writing for the sake of filling up space but to misconception of what the symbols *m* and *F* stood for. Shania and Festo are two amongst several other learners who mistakenly used *mg* in the place of applied force, *F*.

Results from the diagnostic test indicated some common errors. Stimulated recall interviews gave me a deep understanding for the common errors.

4.3 Intervention

In order to capture moments when learners were constructing knowledge in social settings, some group discussions were video-recorded and transcribed. I start by presenting some of the transcriptions of those discussions. Thereafter I present data from learner journals and end with data from the summative test.

4.3.1 Lesson observations

During a group discussion based on Activity 1 of the Unit of Work (Appendix G) learners first discussed then drew free body diagrams of all forces acting on a 30kg box lying on a horizontal floor that was pulled to the right by a force of 50N which was applied at an angle of 30 degrees to the horizontal. In this particular discussion the teacher did not intervene. Extracts 1, 2 and 3 below are from the group discussion. (See Appendix H)

Extract 1:

L4: *I*displacement *nayo siyafaka* as *i*force? **Translated:** Do we also put displacement as a force?

L4: Ah, ah

L5: *I*displacement *asiyifaki as i*force *kalok*u but *yona siyayi representer*. **Translated:** We do not put displacement as a force but we represent it.

L4: (shaking his head in disagreement) Ah, ar. Ah ar

Extract 2:

L4: *Jonga L5, yi* component *yalenantsika, yale* 50N. *Yiforce* applied le 50N. **Translated**: Look L5, this is a component of this 50N. It is force applied, this 50N.

(Showing on the diagram) *Enye* icomponent *nantsi.* **Translated:** Here is the other component.

L3: Normal force

L7: Then *ibeyi* gravitational force. **Translated:** Then there is gravitational force

L4: I gravitational force *nantsi yona*. (He draws on the diagram). **Translated:** Here is the gravitational force

Extract 3:

L4: *Yile* component *ka*force applied, *Yi* displacement *kengoku*. (He moves his hand showing the displacement on the diagram.) *I*displacement *mosi iyaacta kule box*. *I*displacement *kukuthatha labox ukusuka apha ukuzaapha*. That 6m *ukusuka*…**Translated:**

This is the component of applied force, then the displacement is taking that box from here to there. That 6m, from …

L5: But *xa sicalculetayo izawufuneka?* **Translated**: But when we are calculating do we include it?

In the above group discussion L5 initially seems to think that displacement is a force and as such it must be included in the force diagram. Other learners, particularly L4 try to explain to her that displacement is not a force. L7 also seems unsure about the forces to be included on the force diagram. L5 shares her incorrect idea that displacement is a force to the other group members who disagree. Through the interaction with other learners the two learners, L5 and L7 seemed to have understood what needs to be included in the force diagram. Figure 4.1a and 4.1b show different extracts from learner L5 and L7s work from the same class activity written individually respectively.

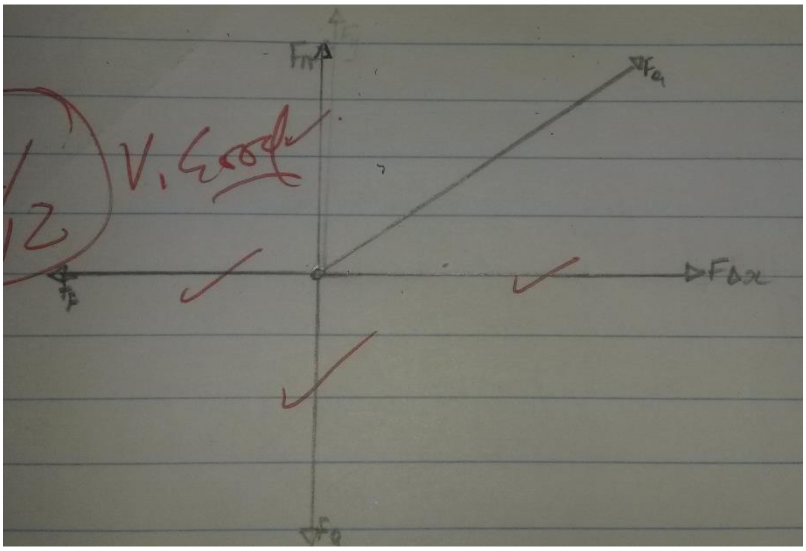


Figure 4.1a: Learner, L5s free body diagram

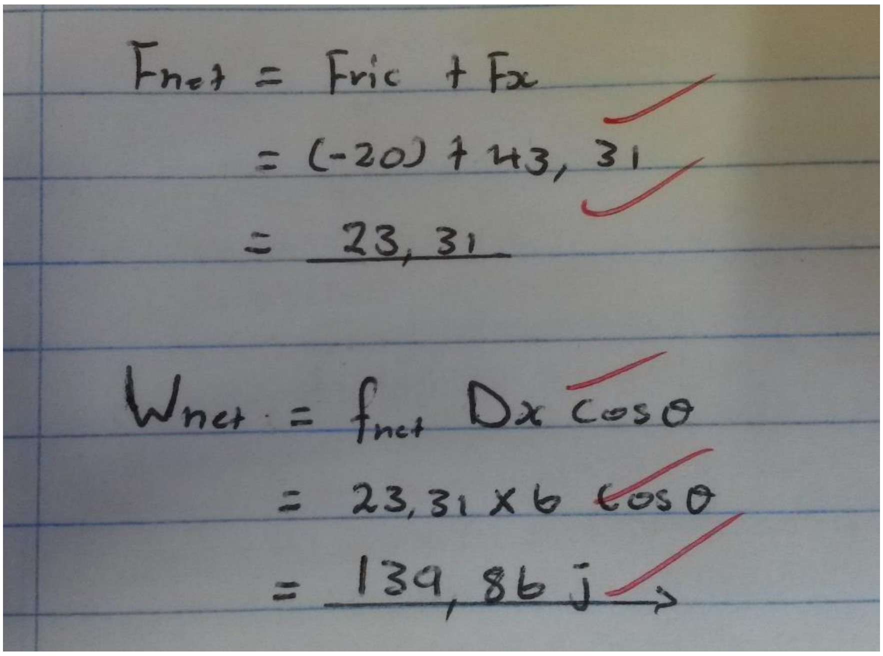


Figure 4.1b: Extract from learner L7s classwork

The next excerpt is from a discussion based on Activity 5 of the Unit of Work (Appendix G). In this group discussion there was teacher (Tr) intervention unlike in Activity 1. Learners are discussing question 5.3. This extract is presented here to show that the teacher also played a role in mediating learners' knowledge construction of knowledge.

L1: (Reading the question.) Name the forces that are responsible for the change in velocity. Explain your answer.

T: Now, can you look at the wording properly. Forces that are responsible for the (putting emphasis) CHANGE IN VELOCITY. Which one is being referred to as the change in velocity? That change (given) at the top. I go back to my question. Is that change an increase or a decrease in velocity?

Several learners: (Chorus answer) – An increase

T: It's an increase right. What does friction do to velocity?

L2: It opposes.

T: So if it opposes, does it increase velocity? Does is help to increase velocity?

L3: No, *iyayi reducer*. **Translated**: No, it reduces it

T: What does it do?

L3: *Ingxaki, handiti i*frictional force *iba ku* opposite (gesturing to the left) direction *yale uyiaplayayo*. That's why *izakuincrease*r. **Translated**. The problem is that frictional force will be in the opposite direction to the applied one.

T: So, are you saying frictional force increases velocity?

L3: Decreases

T: It decreases velocity

L3: (Nodding her head) Yes.

T: L4, you do not seem to agree.

L4: (Shaking his head). *Hayi, Hayi Sir. Andivumi ncam, andivumi ncam Sir*. **Translated:** No, no Sir, I do not quite agree, I do not quite agree Sir.

T: *Awvumi ncam neh.Tetha sive*, tell us, what are you saying? **Translated**: Oh, you do not quite agree, say it out …

L4: *I*friction, *Meneer, iyaincreaser, inancika, i*velocity. **Translated:** Friction, Sir, increases, this thing, velocity.

T: *Iya increaser i*velocity? Now, let's go back to Newton's 2nd law of motion, neh. You said a net force will increase velocity in the direction of the force. Does friction work in the direction of displacement?

L4: No, it opposes

T: It opposes, neh.

Several Learners: Yes

T: So, friction will not increase velocity because it is opposing motion. You see that.

L3: *Nditshilo mna* **Translated:** I said so.

T: So, of the forces that are acting which one is …

L4 & L5: Force applied

T: Force applied neh. Thank you. Its force applied. Yeah. You say force applied, then you explain it. How would you explain it?

L4: It depends with the forces, Sir.

T: It all has to do with the direction. So we are saying that the forces that are in the direction of acceleration are the forces that are responsible for acceleration.

L3: *Niyivile?* **Translated:** Did you get that?

L5: *Kubuzwa i*effect *ezokwenzakala xa kuincreser i*velocity. So which means *ivelocity or imovement or ikinetic* energy *yayo izotshintsha*. **Translated**: The question is about the effect of increasing velocity. So which means the velocity, or movement or its kinetic energy will change.

T: If you say, *izotshintsha*, that is to change hey. A change can be an increase of a decrease. Which change?

L5: Increase

T: It will increase?

L5: Yes.

T: So we can put that down.

In the episode above, the teacher worked collaboratively with learners to construct meaning. One of the learners, L4 thought frictional force helps to increase the velocity of a body. The teacher mediated learning by playing the role of a group member as well as that of a more knowledgeable other. Learners were given an opportunity to disagree with the teacher. By referring learners back to the previous question in which they had stated Newton's second law of motion learners where able to see that a force will cause an increase in velocity only if it is in the direction of displacement. Some meaning was negotiated and eventually the group, including the teacher reached consensus.

4.3.2 Learner journals

As explained in Section 3.6.2.3 the seven learners in the focus group kept journals. They wrote in the journals after every lesson. After realising that learners were not writing much in their journals I gave them the option to use *isiXhosa* in cases they felt that they were failing to express their thoughts or feelings well in English. Journals were collected regularly and I wrote some comments in response to what learners wrote. This was intended to encourage learners in their learning.

Learners were also given the following guiding questions for their journal entries.

1. What did you learn in today’s lesson?
1. Were there any points/concepts/ideas that you found confusing at first?
2. How did you manage to unravel the confusion?
3. Is there something from today’s lesson that is still not clear or you still cannot do?
4. Is there anything else you would like to comment on or say about the lesson in general?

Despite being given the option to write in their home language which is *isiXhosa*, all the learners in the focus group continued to do their journal entries in English as evidenced by the examples quoted below. Although learners generally made short entries in their journals some valuable data pertaining to their views and feelings about the lessons was gathered. Learners commented on the learning method and what they had learned and the challenges they were facing. Below are some extracts from the journals.

4.3.2.1 Learning method

In a journal entry after the lesson from which the discussion reported in section 4.3.1 above was extracted L7 wrote, *“I was a little confused on the free body diagram but as we do it as a group I got it”.* Commenting on the same lesson L5 had this to say, “*The discussions were making clear for me. If we keep on studying as we did that can be helpful”.* From these statements, the two learners who initially struggled with the free body diagram expressed their appreciation for the social constructivist approach used in learning about forces and free body diagrams. These journal entries in which learners stated that group discussions enabled them to learn scientific concepts compliment findings from the lesson observations whereby learners collaboratively solved problems on work and energy.

4.3.2.2 Learning done

In their journals, learners also mentioned some of the main concepts that they learnt that day. For example, after the lesson in which the free body diagrams were discussed L3 stated, “*I am clear about free body diagram …”* After the lesson in which the work-energy theorem was introduced L5 paraphrased the theorem as, “*when net force does work then there is always a change in kinetic energy”.* Writing on the same lesson L4 said, “*On today’s topic on work-energy theorem I learnt that there is no net work done if the forces are balanced”.*

4.3.2.3 Challenges faced

In some of the journal entries learners indicated what they fully understand all of the concepts. Three such entries are listed below.

L5: *"I am not clear about the substitution of 0 in (place of) θ".*

L3: "*I have a little bit confuse about* $F_{net} = \Delta x sin\theta$ *and* W_{net}*. So I need an explanw2ation between this combination*" (It must be noted here that the equation $F_{net} = \Delta x sin\theta$ given by L3 is incorrect.)

L7: *"I was a little bit confused by calculations when you taking left hand side as positive. Xakutheni?* **Translated:** When do you do that?

4.3.3 Summative test

The summative test was set about three weeks after the teaching of the topic on Work, Energy and Power. The test could not be administered earlier since the learners were writing their trial examinations. On reflection, this three week period might have had a negative influence on learner performance since some would have forgotten what they had learned. However, since the topic in question was part of what was examined in the trial examinations I assumed that learners had revised it as part of their trial examination preparation.

4.3.3.1 Performance of learners in the summative test

Figure 4.5 below shows the overall performance of the learners. The test was written out of a total of 50 marks and the scores were converted into percentages for analysis purposes.

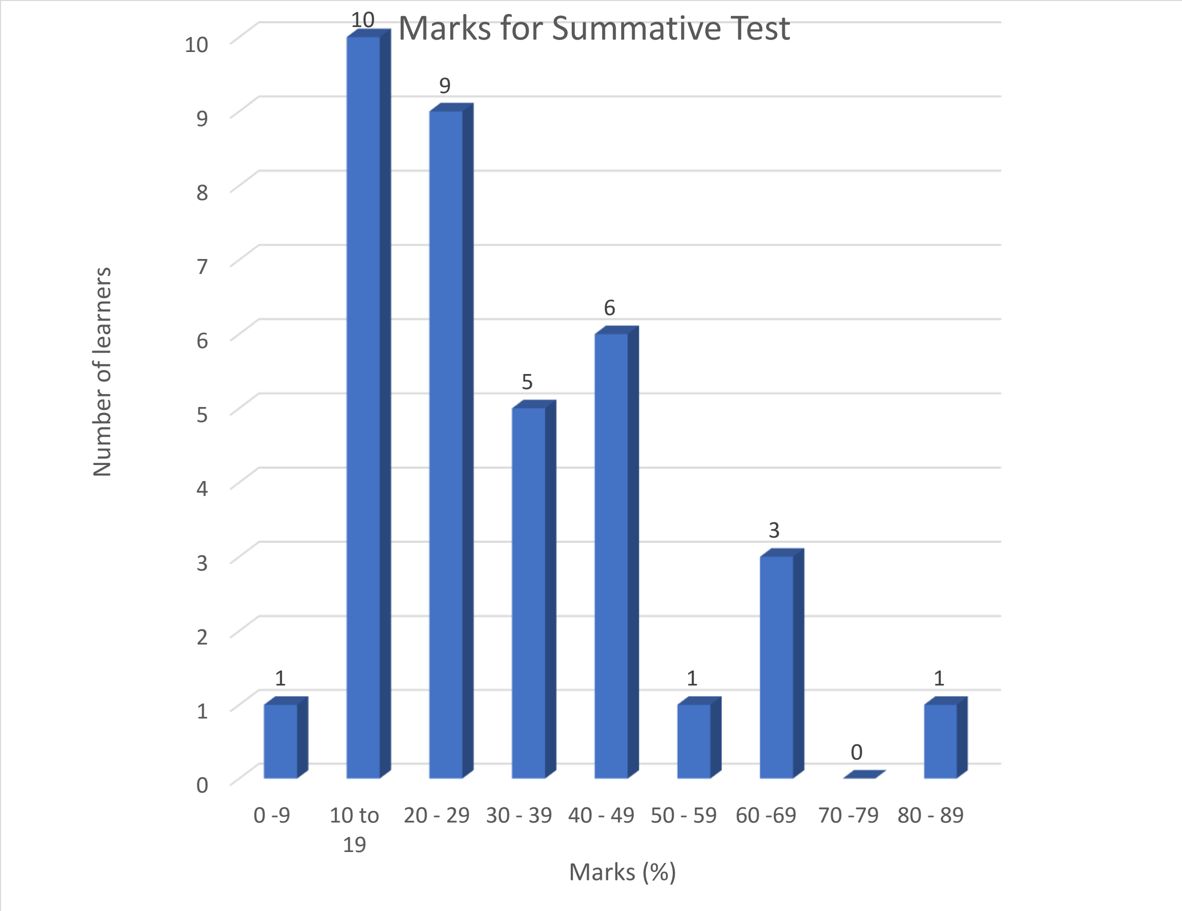


Figure 4.4: Analysis of summative test marks

Thirty six learners managed to write the summative test compared to the 37 who wrote the diagnostic test as one learner was absent from school on the day. Only 5 out of the 36 learners (14%) managed to score a mark of 50% in the summative test. It can be concluded that generally the learners performed poorly in the summative test.

4.3.3.2 Question by question analysis of learner performances

Table 4.3: Question by question analysis of learner performances

Item	Content Tested	General learner performance	Common errors, misconceptions & understandings	Comments/ Conclusions
1.1	Recognition that if speed of a body is constant forces are in equilibrium	1 got correct answer and explanation 19 got correct answer but incorrect explanation	8 learners choose A (force pushing object is zero) 7 choose D (Applied force is greater than frictional force)	47% of learners could not recognise that if speed of a body is constant the forces are in equilibrium

		17 incorrect answer		
1.2	Identify the presence of a horizontal component of a force acting at an angle Use the fact that a net force results in a change in kinetic energy Negative work results in a change of kinetic energy	2 got correct answer and explanation 11 correct answer and incorrect explanation 24 incorrect answer	9 learners failed to recognise presence of parallel component of weight for body sliding up an inclined surface. 11 learners wrongly thought that as body slides up the incline gravitational force decreases	31% of learners held misconception that gravitational force is not constant when body slides up an inclined surface
1.3	Identify and calculate the horizontal component of force acting at an angle Compare magnitudes of forces acting in opposite directions Apply fact that object accelerates in the direction of the resultant force	1 Correct answer and explanation	none	97% of learners failed to recognize that a force applied at an angle has a horizontal component less than that and identical force applied parallel to surface
1.4	If resultant force is opposite displacement the kinetic energy is reduced	9 correct answer and explanation 3 correct answer but incorrect explanation 24 incorrect answers	There seems to be a misconception that if a body is moving its kinetic energy always increases	75% of learners could not recognise that if a resultant force is opposite to displacement it results in loss of kinetic energy
1.5	Apply work-energy theorem Calculating change in kinetic energy	1 correct answer and explanation 13 correct answers and incorrect explanation 22 incorrect answers	None	97% of learners failed to calculate change in kinetic energy when given letters instead of numerical values
2.1	Identify forces acting on an object moving along a horizontal plane and represent them	16 drew and labelled all 4 forces correctly 16 made one or two errors	Learners included components of weight although body was on a horizontal plan	78% could draw a free body diagram although some had one or two errors

	using a free body diagram			
2.2	Knowledge that work is only done by forces parallel to the displacement	18 named both Fg and Fn as not doing work 5 named Fn only 5 named Fg only 8 gave various incorrect responses	None	50% of the learners failed to identify that vertical forces do not do work if displacement is along a surface
2.3	Explain/Justify answers to question 2.1	4 explained that there is no vertical displacement 8 gave partly correct explanations 24 gave incorrect explanations		11% of learner could explain why F_g and F_N do not do any work
2.4	Calculating work done and using component of applied force	2 got it correct 15 got it all wrong 19 partly correct	Not using all forces acting Failure to relate this question to free body diagram in 2.1 Failure to use appropriate angle	6% of learners managed to use formula and correctly calculate net work done. Most learners managed to identify the correct formula
2.5	Stating the work-energy theorem in words	15 got it correct 17 either completely wrong or did not attempt 4 partly correct	Some learners used '*total kinetic energy*' or '*kinetic energy*' in place of '*change in kinetic energy*'	42% of learners could correctly state the work-energy theorem in words.
2.6	Application on work-energy theorem to solve a problem of an object on a horizontal plane	9 got it all correct 21 either all wrong or not attempted 6 partly correct	Learners who got it partly correct made following errors: Just stating the correct formula, $W_{net} = \Delta E_k$ Not using change in kinetic energy but just calculated final kinetic energy	75% of the learners could not correctly applying the work-energy theorem to solve a problem for an object on an inclined plane
3.1	Identify forces acting parallel to the incline for an object moving along an inclined plane and represent them using a free body diagram	3 got all three forces correct 24 got 1 or 2 forces incorrect 9 drew all forces incorrectly	3	92% of the learners could not draw the correct free body diagram

3.2	Calculating change in kinetic energy	10 got it all correct 20 partly correct 6 totally incorrect	Just writing formula and failing to substitute Using $\frac{1}{2}mv$ instead of $\frac{1}{2}mv^2$ Using $E_{ki} - E_{kf}$ instead of $E_{kf} - E_{ki}$	83% failed to calculate change in kinetic energy
3.3	Interpretation of the work-energy theorem for object on a inclined plane	9 gave correct answer and explanation 4 correct answer with incorrect explanation 23 incorrect answers	Some learners attempted to calculate the net work done	64% of learners failed to interpret the work energy theorem by relating answer from 3.2 to 3.3.
3.4	Application on work-energy theorem to solve a problem of an object on a inclined plane	No learner got everything correct 7 use correct formula but made some errors 30 totally incorrect	Failure to recognize that the problem could be solved used the work-energy theorem	83% of the learners could not recognise that the energy principle they were required to use was the work-energy theorem

4.3.3.3 Performance of learners by foci

The next graph, figure 4.6 shows how learners performed in question 1. Question 1 was made up of sub-question 1.1 to 1.5. In each of these multiple choice questions learners were given four options from which to choose their answers. After choosing their answers from the four options learners had to motivate them or show some relevant calculations to show how they made their choice.

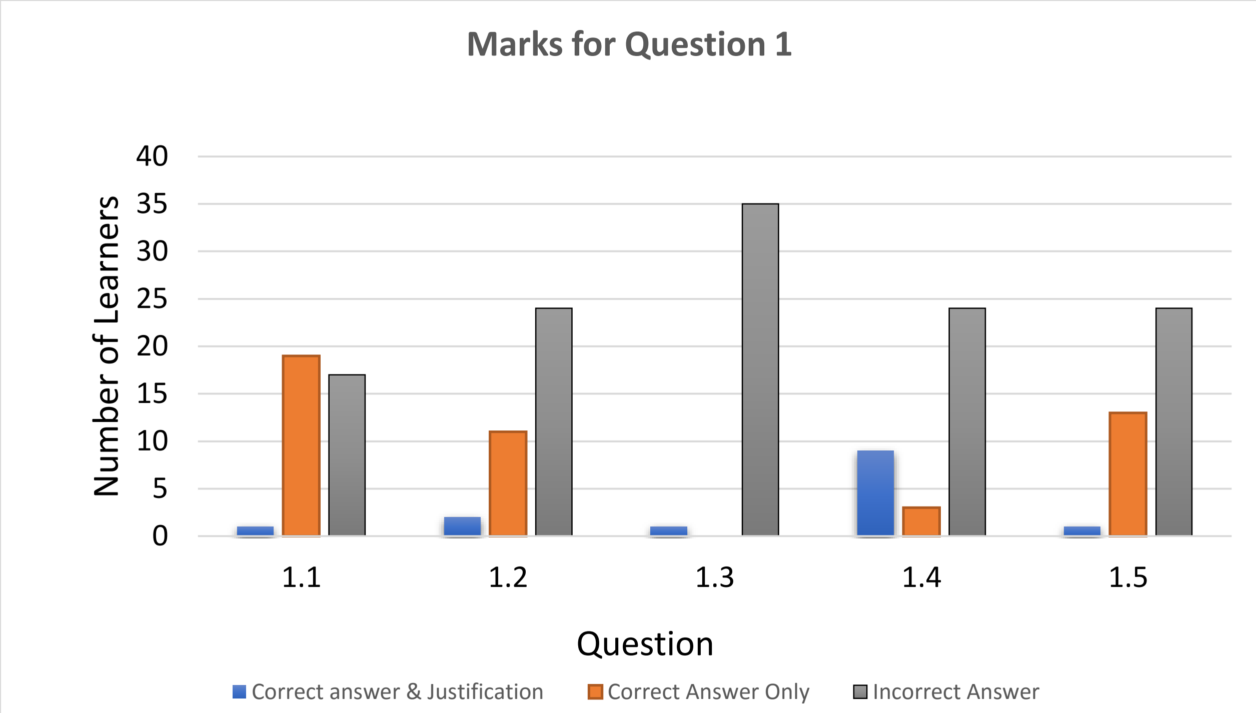


Figure 4.5: Analysis of question 1 marks

As illustrated in the above graph, the general trend in question 1 was that very few learners managed to select the correct option and give the correct explanation or motivation for their choice. The highest number of learners in all the sub-questions except 1.1 was that of learners who failed to choose the correct answer. Once the answer was incorrect the motivation was not considered. The second highest number of learners in all questions except for 1.1 was that of learners who managed to choose the correct answer but failed to justify it.

Table 4.4: Performance of learners in the test questions as categorised in Table 4.1

Category	Question Numbers	Learner performance
A	1.1; 1.3; 2.1 and 3.1	47% of learners could not recognise that if speed of a body is constant the forces are in equilibrium. 78% of learners managed to draw force diagrams for a body moving along a horizontal surface. However, when presented with an object moving along inclined plane learners had problems as only 8% of the learners managed to draw the free body without mistakes
B	2.2	Although 50% of the learners managed to identify normal force and gravitational force as not doing any work on the trolley in question 2 only 14% managed to explain correctly why these two forces do not do any work on the trolley. Learners could have just memorised that those two forces do not do work in such an instance
C	2.4, 2.6; 3.3	Learners had to use the formula for work done on an object by a force to calculate the net work done on the

		trolley. 59% of the learners managed to identify the correct formula to use, $W_{net} = F_{net}\Delta x.cos\theta$ or $W = F\Delta x.cos\theta$(used for each force acting and then combine the results). Most learners were not using a combination of all the relevant force
D	3.2	28% of the learners got the calculation correct. 56% made some errors. Common errors were; (i). Just calculating kinetic energy using the final velocity without considering the change in velocity (ii). Subtraction final velocity from initial velocity instead of the other way round (iii) not squaring the velocity , v in the formula $E_k = \frac{1}{2}mv^2$
E	2.4	Only 2 (6%) learners managed to correctly use the formula for work done to calculate the net work done on the trolley.
F	2.5	The work-energy theorem was only correctly stated by 42% of the learners. 39% wrote something that was completely incorrect or stated the conservation of energy instead. The remaining 19% gave partially correct statements of the work-energy theorem. Using the phrases "*total kinetic energy*" or "*kinetic energy"* in place of *change in kinetic* energy was a common error for those whose got the definition partly correct
G	3.3	17% managed to state the value of change in kinetic energy calculated previously as the network done and explained by making reference to the work-energy theorem.11% managed to give correct value but could not relate it to change in kinetic energy in their explanations. 72% gave incorrect answers.
H	2.6; 3.4	In question 2.6, 25% were able to the unknown velocity using the work-energy theorem. 58% failed totally to apply the theorem and get the unknown velocity whilst the remaining 17% got parts of the calculation correct. Common errors were (i) failure to use change in kinetic energy. Some learners used change in velocity, Δv in place of change in kinetic energy, ΔK. (ii) Some learners just used the final velocity and calculated final kinetic energy which they used in place of change in kinetic energy. In question 3.4 no learner managed to get full marks. 19% got parts of the calculations correct. 81% got it completely incorrect. Leaners were supposed to figure out that they had to use the work-energy theorem. Only 19% managed to figure out that they had to use the work-energy theorem

4.3.3.4 Stimulated recall interviews based on the summative test

The interviews are presented in the order in which they were conducted. The order was not pre-determined. Learners were interviewed according to the times that were convenient to individual learners. Some excerpts from the interviews are presented below.

Interview S1

Int: In question 2.4 you were asked to look at the net work done after being given that diagram and the information in front of you. Right, now my question is you wrote the work done by the applied force. You wrote 20 which is the applied force, multiplied by 5 which is displacement, cos zero, right. Why did you write cos zero?

Lwando (Lwa): Er, I write cos zero Sir because I think applied force was parallel to the, to the displacement of this trolley Sir.

Int: But if you look at the diagram again the applied force is that 20N. Is it parallel to displacement?

Lwa: I thought it is, I know applied force is doing work Sir but I forgot to do the components. I forgot to say the component of the applied force because that 20N is at an angle. I forgot to write that Fg 20 degrees.

Int: Oh, at that particular moment you forgot to write the components but can you say now you are clear on that?

Lwa: Yes Sir.

At the time of writing the test Lwando was unable to recognise and make use of the fact that when a force is applied at an angle to the displacement it is the component parallel to the displacement that causes the displacement. The interview was conducted weeks after the test. Lwando must have learnt this fact in the time between the test being written and the interview.

Interview S2

Int: Question 2.4 was asking you to find the net work done on a trolley … In light of that question can you tell me. Is there a difference between work done and net work?

Steven: Net work and work done?

Int: Yes

Steven: No there is not quite a much difference Sir. Because work net is the…If I can derive net work from the formula it says that work net is the work done on an object which is the change in the kinetic energy of the object.

Int: So what is the difference net work done and work done?

Steven: Net work done. The net work done on the object. It is the work that needs to be done then net work done is the work that has already been done.

The interview with Steven (part of which is presented above) shows the difficulty some learners had in differentiating between the concepts of *work done* and *net work done* on an object. In calculations, learners tended to use work done by one force where they were supposed to use the net work done by two or more forces.

4.4 Concluding remarks

In this chapter I presented and analysed the data gathered from all my data sources in Phases 1 and 2 of the study. The diagnostic test which constituted Phase 1 sought to elicit relevant prior knowledge gained from earlier grades. Some excerpts from transcriptions of the stimulated recall interviews were presented and some salient points from the interviews were highlighted and discussed. The general picture that emerged from the data is that learners did not have any of the necessary prior knowledge for most of the concepts I considered key to the learning of the work-energy theorem and related concepts at grade 12 level. This lack of prior content knowledge identified using the diagnostic test was also evident in the summative when learners had difficulties in calculating change in kinetic energy.

Extracts of the transcriptions from lessons observed whilst learners were engaged in social construction of knowledge were also presented and analysed. Several ways in which learners made sense of concepts on the work-energy theorem and related concepts were identified.

Finally, I presented and analysed data gathered from the summative test. The analysis of this data showed that most of the learners still had not fully understood the concepts of work and energy as required by the grade 12 Physical Sciences curriculum.

In the next chapter, I discuss and interpret the data I presented in this chapter using three analytical statements which I developed based on the existing data.

CHAPTER 5: INTERPRETATION AND DISCUSSION OF FINDINGS

5.1 Introduction

In this chapter I interpret and discuss my findings on how grade 12 Physical Sciences learners make sense of the concepts of Work and Energy which I presented and analyzed in Chapter 4. The data I interpret and discuss were gathered from the data gathering techniques described in Chapter 3, namely, a diagnostic test, lesson observations, learner journals, the summative test and stimulated recall interviews based on both the diagnostic and summative tests. In my discussion of findings I draw on the literature that I reviewed in Chapter 2. The research questions that guided my data gathering process are listed again below for easy reference. 1.

1. What prior content knowledge about Work and Energy concepts do grade 12 Physical Sciences learners have?
2. How do grade 12 Physical Sciences learners make sense of the work-energy theorem during lessons designed using social constructivist principles?
3. What factors enable or constrain grade 12 Physical Sciences learners from solving problems related to the work-energy theorem?

I developed three analytical statements to address these research questions. Table 6 shows the themes that emerged from the data, the analytical statements as well as the research question(s) answered by each of the analytical statements.

Table 5.1: Analytical statements addressing my research questions

Research Questions addressed	Themes	Analytical Statement	Data Sources
1 and 3	Prior knowledge	1. Inadequate prior knowledge from earlier grades is a major constraint to the sense making of the work-energy theorem of grade 12 Physical Sciences learners	Diagnostic test, stimulated recall interviews
2	Knowledge construction in a social setting	2. Interactions between learners or with the teacher in a group enhances sense making of work-energy theorem and related concepts.	Lesson observations, Learner journals
3	Enabling or constraining factors in solving problems	3. Lack of conceptual understanding is a constraining factor in solving problems using the work-energy theorem.	Summative test, lesson observation, classwork, learner journals

5.2 Answering research question1

To answer research question 1 will now draw from analytical question 1:

Inadequate prior knowledge from earlier grades is a major constraint to the sense making of the work-energy theorem of grade 12 Physical Sciences learners

In Section 2.5 I stated that prior knowledge plays a major role in the sense making of new concepts. As Roschelle (1995) postulates, learning proceeds from prior knowledge which acts as a base onto which learners construct new knowledge. The diagnostic test (Appendix C) sought to explore learners' prior knowledge from their formal learning in earlier grades both in the GET and FET phases. Concepts such as force, energy, work done which are used in the statement of the work-energy theorem as well as calculations using the theorem were tested. The results from the diagnostic test presented in Section 4.2.1 suggest that the majority learners in this study did not have sufficient prior knowledge from earlier grades on which to build new concepts on work and energy. This finding supports findings by Lemmer (2011) which I discussed in Section 2.6.2. In his study, Lemmer (2011) worked with grade 10 learners and investigated prior knowledge on the concept of energy from the GET phase. He found that many grade 10 learners do not have sufficient prior knowledge about the notions of energy from the GET phase for them to be able to adequetly learn the concept in the FET phase.

The work-energy theorem states that *the net work done on an object is equal to the change in the object's kinetic energy*. It is expressed mathematically as follows:

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

In order to show the relevence of the prior knowledge tested using the diagnostic test I will now expand parts of the above mathematical expression for the work energy theorem. W_{net} is the net *work* done by all *forces* acting on the object. Furthermore, $W_{net}= F_{net}\Delta x cos\theta$ and F_{net} is the net force, which is the combined effect of all forces acting on the body parallel to the direction of displacement. The angle represented by θ is the angle between the direction of the net force and direction of *displacement* which is represented by Δx.The ΔE_k on the right hand side of the expression represents the change in the object's kinetic *energy*. $\Delta E_k=\frac{1}{2}mv_f^2-\frac{1}{2}mv_i^2$ where *m* is the mass of the object and $v_i$and v_f represent initial and final *velocity* respectively.

The concepts in italics in the above paragraph were supposed to be explained or defined by learners in the diagnostic test. As the results presented in Section 4.2.3 show, the concepts of *force, velocity, displacement* were poorly defined or explained showing a lack understanding of them. The terms force, energy and power were confused. Several learners wrote '*force is power'* and *'energy is power'*. The concepts of dispacement and velocity are key components of the work-energy theorem as shown above. These were also incorrectly defined by learners.

In order to gain a better understanding of the confusion between the concepts of energy, force and power I interviewed some learners after they were reminded of their answers in the diagnostic test. Extracts from two such interviews, D1 (Appendix L) and D2 are presented in Section 4.2.4. Learners' confusion seemed to stem from the use of the same *isiXhosa* word, *amandla* for the terms energy, force and power. Learners failed to differentiate the concepts of force, power and energy due to the prior learning from everyday experiences which used the same word, *amandla* in different contexts to mean force, energy or power. This confusion between the three concepts supports the argument by Driver et al. (1994) that if representations of scientific phenomena learners bring to the formal science class differ from the formal representation learning can become complicated.

This finding from my study also adds weight to the proposal by Msimanga and Lelliot (2014) that teachers need to afford learners the opportunities to learn both scientific concepts and the LoLT which in my study was English. A lack of understanding of the concepts that are encompassed in the work-energy theorem means that the learners fail to make sense of the theorem. This lack of prior knowledge on the basic concepts supports Mchunu's (2012) conclusion that the proper application of the work-energy theorem, the work concept and the kinetic energy concept pose conceptual difficulties to grade 12 learners Physical Sciences.

Resolving forces into components, an aspect of prior knowledge which the learners learned in grade 11, was tested in the diagnostic test. The results that I presented in Sections 4.2.3 and 4.2.4 show that the vast majority of the learners (89%) could not identify and calculate the components of force acting at an angle on a body. The ability to resolve forces into components is necessary in solving many examination questions involving the work-energy theorem. In examinations learners are required to solve problems that involve either a body on a horizontal plane with at least one force on it acting at an angle to the plane or a body that is on an inclined plane. In both these cases the resolution of forces such as the applied force and weight is very important. Learners (see Interviews D3 and D4) mistakely used weight, *mg* in place of the value of the applied force to calculate the component of the applied force.

It can be concluded from the diagnostic test and the follow up stimulated recall interviews that the learners did not have a suffient level of understanding of the following concepts and skills:

- Force;
- Displacement;
- Energy;
- Velocity; and
- Resolving forces into components.

These are vital to the successful application of the work-energy theorem and a lack of understanding can lead to challenges when it comes to making sense of the theorem.

5.3 Answering research question 2

In answering research question 2, I draw from analytical statement 2:

Learner-learner and teacher-learner interactions in a group enhance sense making of the work-energy theorem and related concepts

In Section 2.8.1 I explained that social constructivism proposes that learning is an individual exercise that is facilitated by social interaction with peers and more knowledgeable others (McRobbie & Tobin, 1997). To investigate how learners make sense of work and energy concepts using constructivist principles learners were video-recorded whilst they engaged in group discussions guided by activities in the unit of work.

During the group discussion Tr1 (Appendix H) learners collaboratively identified the forces acting on a box being pulled and drew a free body diagram from Activity 1 in the unit of work (Appendix G). A number of things emerged from the group discussion. First, in identifying forces acting and drawing the free body the learner-learner discussions occurred mostly in their home language, *isiXhosa*. This was despite the fact that the questions and write up were in English. For example, when L4 was explaining to the group he said, "*Jonga*, (indicating on the diagram) *uyabona idisplacement isecaleni. Nantsike ibox. Nazi ke* iforces *eziacta kule* box". [**Translated**: "Look, you see that displacement is on the side. Here is the box and here are the forces acting on the box"].

Msimanga and Lelliot (2014) postulate that reverting to their home language helps learners who lack confidence in English to understand scientific concepts. Learners in the focus group wrote their answers correctly in English after the discussion which was mainly in *isiXhosa* (See figures 4.1 and 4.2 in Section 4.3.1). This suggests that learners make sense of the concepts in their home language, *isiXhosa* and then translate into English when they present their ideas and answer questions. This finding lends support to Zuma and Demster (2008) who concluded that changing the language of assessment from English to home language does not have a significant effect on learner performance. From my study I can conclude that learners can successfully construct scientific concepts by discussing them with their peers in their home language *isiXhosa*.

In group discussions such as those highlighted in Sections 4.3.1 and 4.3.2 learners used their home language, *isiXhosa* and then translated into English, the LoLT when doing written exercises. This is what Probyn (2015) calls translanguaging. The fact that learners managed to answer questions correctly in English after first discussing them in *isiXhosa* supports Probyn (2015) who encourages the use of the learners' home language in exploratory talk and then transferring their understanding to the LoLT. The discussion presented in Section 4.3.1 which I labelled TR1 learners L5 and L7 were not sure about the forces acting on the body and what needed to be included in the free body diagram when the discussion started. Through asking questions and presenting their thoughts to the group the two learners managed to learn to identify the acting forces. In this discussion, learner L4 played the role of the more knowledgeable other (MKO). Throughout the video-recorded lessons there are instances where some learners construct knowledge with the help of other learners in the group.

Learners L5 and L7 could do the task with the help of others. This could mean that the task was in their ZPD. This finding concurs with Thompson (2013) who suggests that learners' development in the ZPD involves social interaction in the form of dialogue between the learners and between the learners and the teacher. The teacher in this case assumes the role of a more capable agent in the group who assists learners in their sense making (Doehler, 2009).

5.4 Answering research question 3:

In answering research question 3 I draw from analytical statement 3:

Lack of conceptual understanding is a constraining factor in solving problems using the work-energy theorem

As the learners try to make sense of the work-energy theorem and related concepts they faced several challenges. These challenges emerged from data collected mainly from the summative test and the stimulated recall interviews that followed. Two chief markers' reports (DBE, 2013, 2014) indicate that learners perform badly in questions based on the use of the work- energy theorem. I now outline the specific challenges that emerged from the data gathered and presented in Chapter 4 (see Sections 4.3.3.4 and 4.3.3.5).

5.4.1 Identifying forces and drawing free body diagrams

The majority of the learners could draw a free body diagram if they were given an object moving along a horizontal surface but had difficulty when the object was on an inclined plane. In solving problems involving the work-energy theorem free body diagrams are critical in the sense that they indicate the forces acting and their directions relative to the displacement and to each other. Also, from the free body diagram, learners are able to identify forces which are not doing work and therefore must not be included in the calculation for work done. For example, for a body moving along an inclined plane the component of the body's weight which is perpendicular to the plane and normal forces do not do any work on the body with respect to its horizontal displacement. A free body diagram helps learners to identify forces to be used in the calculation of net work done

5.4.2 Calculating net work done (W_{net})

Although most learners could correctly identify the formula for calculating net work done ($W_{net} = F_{net}\Delta x. cos\theta$) they failed to use it correctly. The net work is the work done by the combined effect of all forces acting in the direction parallel to displacement. Learners could not recognize that there was more than one force doing work on the object. In both questions 1 and 2 in the summative test there was frictional force as well as applied force on the bodies which needed to be considered when calculating the net force.

Calculating changes in kinetic energy, ΔE_k

Calculating change in kinetic energy, ΔE_k posed a challenge to the learners identified from the diagnostic test as well as from the summative test. Learners failed to include the initial kinetic energy in cases where the body started from rest. The numeric answer would come out the same whether the zero initial kinetic energy was included or excluded from the calculation. Excluding the initial kinetic energy does not demonstrate conceptual understanding of change in kinetic energy of a body. In cases where the numeric value of initial kinetic energy was larger than the final kinetic energy learners subtracted the final kinetic energy from the initial kinetic instead of subtracting the initial from the final kinetic energy ($E_{ki} - E_{kf}$ instead of $E_{kf} - E_{ki}$).

Stating the work-energy theorem in words

As stated in Section 2.3, the work-energy theorem states that, *the net work done on an object is equal to the object's change in kinetic energy.* This is a short statement and one would expert the majority of the learners to be able to learn it off by heart in a short space of time. Only 42% of the learners managed to state the theorem correctly. This contributed largely to the errors made in the application of the theorem to solve problems. Some of the errors made by learners included using the words *'work done'* in place of *'net work done'*. This indicates a lack of contextual understanding. Using expressing, *'work done'* implies that only one force is doing the work whilst 'net work' suggests that more that one force could be doing the work. Other learners used *'total kinetic energy'* instead of '*change in kinetic energy'*. This could lead learner into adding the initial and final kinetic energies instead of subtracting the initial kinetic energy from the final kinetic energy.

5.4.3 Lack of prior knowledge of basic concepts

As I explained earlier in this chapter (see Section 5.2) the work-energy theorem encompasses several concepts namely: *work done; net work done; forces; net force; kinetic energy; change in kinetic energy; displacement* and *resolving forces into components.* All of these components should have been covered in earlier grades and were tested in the diagnostic test. As discussed earlier under research question 1 learners in this study did not have sufficient knowledge of these concepts to be able to make sense of the work-energy theorem and apply it to problem solving.

5.4.4 Interpretation of the work-energy theorem

It is apparent from the analysis of the problem that learners did not understand the work-energy theorem. In question 2.4 of the summative test learners were required to calculate net work done and in Question 2.6 learners were required to solve for the unknown applied force using the theorem. The two calculations were based on the same trolley being pulled along a horizontal surface. Learners failed to see the connection between the net work calculated in question 2.4 and the application of the work-energy theorem application in question 2.5. This also demonstrates a lack of conceptual understanding of the work-energy theorem and its application.

5.5 Concluding remarks

In this chapter I analysed, interpreted and discussed data gathered from the diagnostic test, lesson observation, learners' class work, video-recorded lessons, learner journals, the summative test and stimulated recall interviews. I arrived at three analytical statements from the data sets I collected. Through these three analytical statements the processes learners go through in the making sense of the work-energy theorem and related concepts were revealed. The factors that enable and/or constrain grade 12 Physical Sciences learners to solve problems related to the work-energy theorem were also analysed and discussed.

Lack of prior knowledge on concepts that are part of the work-energy theorem and its application in solving problems were highlighted. Group discussions did help to provide learners with a platform to construct knowledge on the theorem and problem solving strategies using the theorem or other concepts related to it.

In Chapter 6 I summarise my findings and I present my recommendations based on these findings. I also suggest areas for future research. Before critically reflecting on my research process I discuss the limitations of my study.

CHAPTER 6: SUMMARY OF FINDINGS, RECOMMENDATIONS AND CONCLUSIONS

6.1 Introduction

In this chapter I summarise my main findings and discuss the extent to which the findings answer my research questions. I make recommendations on how teachers can provide enabling environments and opportunities for grade 12 Physical Sciences learners to construct knowledge on the work-energy theorem and its related concepts. Recommendations will also be made concerning the use of learners' prior knowledge from earlier grades with some pointers on how to address the challenges learners face in solving problems using the theorem.

The limitations of my study will be discussed before I present my suggestions for areas of further research related to my study. I conclude the chapter with some critical reflections.

6.2 Summary of findings

As I alluded to in Chapters 2 and 4, learning proceeds from prior knowledge. The prior knowledge that this study sort to elicit from the learners concerned concepts and skills learned in earlier grades relevant to the understanding of the work-energy theorem and its application in problem solving. From the diagnostic test I established that most of the learners, at least 66% of the class had sufficient prior knowledge in the following areas:

- Calculating basic trigonometric ratios given a right angled triangle; and
- Calculating kinetic energy using a formula which they were not given.

However, the study also revealed that learners lacked essential prior knowledge in some critical areas. They are as follows:

- Force and net force;
- Displacement;
- Confusing force and power;
- Speed;
- Velocity;
- Resolving forces acting on a body at an angle into components; and

- Resolving the weight of an object on an inclined plane into components.

Analysis of the video-recorded group discussions and learner journals revealed how the learners made sense of the work-energy theorem and related concepts through collaboratively constructing knowledge. The ways in which they made sense of the new knowledge are listed below.

- During discussions learners constructed new knowledge in their home language and were able to then translate the new knowledge and present it in English. This is making use of translanguaging as advocated by Probyn (2015);
- Asking questions in order to get explanations from peers on concepts they did not understand or had partially understood; and
- Through the use of learner journals learners expressed what they had understood and what they were still struggling to make sense of.

Some class exercises, the summative test and the stimulated recall interviews that followed revealed some of the factors that constrain learners in their ability to solve problems using the work-energy theorem. The constraints were:

- Identifying force and drawing free body diagrams for objects on inclined planes;
- Using the formula, $W_{net} = F_{net}\Delta x.\cos\theta$. Learners failed to identify the various forces acting and calculate the net force (F_{net});
- Calculating change in kinetic energy (ΔK). In cases where the final kinetic energy is less that the initial one, learners tended to subtract the smaller value from the bigger value;
- Failure to correctly state the work-energy theorem in words. Errors were made in the '*change in kinetic energy*' section. Learners used '*total kinetic energy'* or '*kinetic energy';* and
- Failure to interpret that the work-energy theorem is the net work done and change in kinetic energy were presented separately for the same situation.

These challenges have the combined effect of making it difficult for learners to solve problems which require the application of the work–energy theorem. This contributes to learners scoring low marks in NSC Physical Sciences paper 1 examination questions as reported in various Chief Markers' reports.

6.3 Recommendations

What follows are some of the critical recommendations from my study.

6.3.1 Eliciting prior knowledge before teaching work and energy concepts at grade 12

The data collected from this research made it appears that learning the work-energy theorem is heavily dependent on learners having the relevant prior knowledge as summarised in Section 6.2 above. In this regard I recommend grade 12 Physical Sciences teachers need to elicit prior knowledge on these concepts before teaching the topic on Work, Energy and Power. Any lack of prior knowledge that is identified needs to be addressed before proceeding with the topic, even if it requires extra time being allocated.

6.3.2 Making use of translanguaging to allow learners to construct meanings of scientific concepts using their home langauge

Translanguaging is the deliberate shift from the LoLT to the learners' home language in bilingual classrooms (Probyn, 2015). This helps to encourage the exchange of ideas and learner particapation which in turn promotes constructivist learning. Findings from this research confirm the claim by Probyn (2015) that learners can successfully construct scientific concepts and solve problems by discussing and sharing ideas in *isiXhosa* and then translating them into English for presentations. In this study, for instance, the learners correctly answered questions in English. I therefore recommend that Physical Sciences educators who are teaching second language learners, to allow them to use their home language in discussions, since this can enhance sense making of the science concepts to be learned.

6.3.3 Development of units of work

In teaching the topic Work, Energy and Power I developed a unit of work which is a tool that contained notes on the concepts to be taught as well as structured group and individual activities. This assisted me in mediating the learning of the concepts using a constructivist approach and for me to serve as a more knowledgeable other (MKO). I recommend that teachers and subject advisors develop units of work for this particular topic as well other topics in Physical Sciences. The development of units of work does not make textbooks obsolete, but instead it complements them. Units of work are developed after taking into consideration the language of the target group as well as other social factors such as the prior everyday knowledge relevant to scientific concepts held by the learners and community in which the school is situated. Language problems such as the use of the same word '*amandla'* for the concepts of *energy*, *force* and *power* in *isiXhosa* can also be addressed if context specific units of work are developed by teachers.

6.4 Limitations of my study

I used a case study approach because it was convenient for me in terms of the available time and resources. The case study provided me with specific insights into how learners make sense of the work-energy theorem which will prove useful, especially to contexts similar to the one in this study. However, the findings from this study may not be applicable to other schools because of the different contexts and so it cannot be generalised.

In any didactic situation the teacher plays a critical role as far as providing the enabling environment for the social construction of knowledge (Vygotsky, 1978). In this study my focus was on the learners only. The teacher who played a mediatory role and scaffolded the learners was not the focus of attention and scrutiny. This limited the depth of the analysis of how learners make sense of the work–energy theorem and related concepts as the lack of relevant prior knowledge identified as one of the major constraining factors could have been due to poor teaching of this particular group of learners which may not be the case with learners in different contexts. My recommendation of the use of translanguaging as proposed by Probyn (2015) only works if the teacher is conversant in the learners' home language. In many cases the science classes are multilingual and translanguaging will then not be feasible.

6.5 Areas for further research

The following areas are proposed for future research:

- A similar study with a wider sample and different language context;
- The use of diagnostic testing in eliciting prior knowledge and the development of context specific units of work in order to reveal how teachers mediate the constructivist learning of the work-energy theorem; and
- The use of translanguaging in the teaching and learning of the work-energy theorem.

6.6 My critical reflections

This research journey was an awesome learning experience. Looking back to the time I was working on my research proposal to the time of compiling the final thesis I see a lot of academic growth. In the initial stages I just had this idea that I would like to find out why grade 12 Physical Sciences learners are performing poorly in questions which needed the use of the work-energy theorem in paper 1.

The research journey took me through a body literature related to my study. The more I read about research methodologies, my chosen theoretical framework, other studies related to mine and various reports about learner performance in science in general and on work and energy concepts in particular, the more I realized that I still needed to read some more. This was a frightening but exciting and fulfilling journey.

Data gathering started with the diagnostic test. The data that emerged from it was so valuable, and exceeded the purposes of this particular study. A diagnostic test is a tool that is valuable in everyday teaching and learning. As teachers we tend to sheep-like just stick to the prescribed teaching programmes guided by the pacesetters. These pacesetters strictly prescribe the topics to be taught on the given dates. There is no room for teachers to deviate from the pacesetters. The use of diagnostic testing would require a situation where teachers are allowed to go back and re-teach or revise the prior knowledge from earlier grades that the learners need in order to learn new concepts successfully. This would mean deviating from the pacesetters and possibly failing to finish the prescribed topics in the allocated time. In my view it is better to spend some time doing a diagnosis to ascertain the level of conceptual understanding of the learners than to just start teaching new content without any idea of the learners' prior knowledge.

From the diagnostic test, data collection moved to lesson observation. Playing the dual role of the researcher and teacher put me in precarious position. Recording the lessons I was teaching was not easy. I had to mediate the learning guided by my unit of work whilst at the same time hoping that the recording was successful. In most of the lessons I had the camera positioned and focused on the focus group. It became a little awkward since once in a while I had to go and check if all was going well with the recording. In the last two recordings I was lucky that one of my colleagues agreed to do the recording for me. If I were to do it all over again I would find someone to record and also use more than one camera to record the group activities from different angles simultaneously. Using different angles would help capture some valuable data including non-verbal behaviour of the quieter members of the group. Nonetheless, zooming on the focus group was useful.

The administration, marking and analysis of the summative test was another great learning experience. Much was revealed from the analysis in terms of challenges faced by learners in using the work-energy theorem. If only as a teacher I could analyse all the end of topic tests for my learners I would be a much better teacher. It is not enough to just allocate a mark after a test. In-depth analysis and feedback to the learners after the analysis is very valuable to both teachers and learners.

The final write up of this thesis was probably the most challenging part of the journey. It was a time where I had to put all the pieces of my jigsaw puzzle into one coherent and meaningful unit. I found myself going forward and backwards through the chapters. It was far from being a linear progression from Chapter 1 to Chapter 6 but instead an iterative process which required me to be reflexive all the time. For example, when I was analysing my data in Chapter 4 I realised that the issue of learning science using *isiXhosa* and English was coming up quite strongly. Yet, I had not reviewed literature on this aspect so I found myself having to revisit my literature review in Chapter 2.

6.7 Conclusion

In this study I investigated how grade 12 learners make sense of the work-energy theorem using constructivist learning principles. Construction of knowledge is based on relevant prior knowledge and I established that the grade 12 learners did not have sufficient prior knowledge of the concepts related to the work-energy theorem for them to make sense of, and apply it to solving problems. Learners in this study lacked conceptual understanding of basic concepts such as force, net force, energy, work done, net work done, and displacement.

In constructing knowledge learners used both English and *isiXhosa* (their home language) quite successfully especially in group discussions where learners asked each other questions on aspects of the work that they did not understand or needed clarification on. Other learners, referred to as the MKOs in this study were always willing to explain and assist the other learners and I observed that the role of MKO switched from time to time in a group. Through journal writing learners were able to express their feelings about the learning process, the actual learning that they experienced and the challenges that they faced.

Finally, the learners had the most difficulty in solving problems that involved a body moving along an inclined plane. The problem stemmed partly from the learners' failure to recognise the direction in which the forces acting on the body faced. Failure to state the theorem correctly, using one force instead of the combined effect of the forces, and the interpretation of the work-energy theorem all added to their failure to perform well.

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Appendices

Appendix A: Letter to principal

1243 Zone 1
Ekhupumleni
Whittlesea

5360

10 February, 2015

The Principal
Yona Yethu High School
Whittlesea

Dear Sir,

Re: Request for permission to conduct research in the school

I, Alfred K. Mapfumo am a part-time Master of Education (Science) student with Rhodes University. I am hereby requesting permission to conduct research in your school. My research is on how grade 12 Physical Sciences learners make sense of the work- energy theorem. The work-energy theorem is one of the problematic Physics concepts to learners. Chief markers have reported from several years that learners generally score low marks in the National Senior Certificate examinations.

My data gathering will involve giving tests, video-recording some lessons and interviewing learners. Informed consent will also be sought from the parents of learners who are below the age of 18 years and from the learners for those above the age of 18.

For ethical reasons I will use pseudonyms for the school and all learners. Data collected in this study will be used exclusively for academic purposes.

Your cooperation in this regard will be greatly appreciated.

Yours sincerely

Alfred K. Mapfumo

I________________________________ (Principal) hereby grant you permission to proceed with your research in this school.

______________________ Date: ____________________

Signature

Appendix B: Letter to parents

1243 Zone 1

Ekhupumleni

Whittlesea

5360

10 February, 2015

Dear Parent

Re: Consent letter

I, Alfred K. Mapfumo am a part-time Master of Education (Science) student with Rhodes University. I am asking for your consent to allow your child_________________________ to participate in my study. My study is on how grade 12 Physical Sciences learners make sense of the work- energy theorem. The work-energy theorem is one of the problematic Physics concepts to learners. Chief markers have reported from several years that learners generally score low marks in the National Senior Certificate examinations.

My data gathering will involve giving tests, video-recording some lessons and interviewing learners. For ethical reasons I will use pseudonyms for the school and all learners. Data collected in this study will be used exclusively for academic purposes.

Your cooperation in this regard will be greatly appreciated.

Yours sincerely,

Alfred K. Mapfumo

(Physical Sciences Teacher)

I___________________________________being the parent/guardian

of_________________________ grant you the permission to involve my child in your study.

__________________________ Date: ________________________

Signed

Appendix C: Diagnostic Test

WORK and ENERGY

Diagnostic Test

Time: 1 hour **Marks: 45**

INSTRUCTIONS TO LEARNERS

I. Answer ALL questions in the spaces provided.
II. Show full working whenever necessary.
III. Scientific calculators may be used

QUESTIONS

1 Give one example of a scalar quantity and one example of a vector quantity. (2)

____
____
____

2 Define or explain the meaning of the following terms. Give an example in each case. (12)

2.1 Force____
____
____
____
____

2.2 Energy____
____
____
____
____

2.3 Displacement____
____
____
____
____

2.4 Distance____
____
____
____

2.5 Speed____

____

____

____

2.6 Velocity____

____

____

____

3. Study the right angled triangle, ABC in Fig. 1 below.

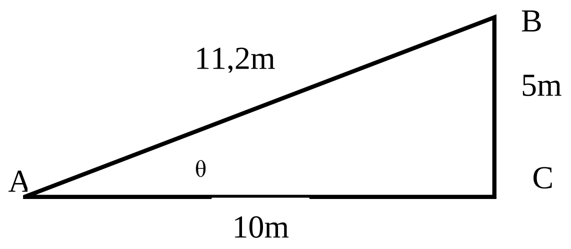


Fig. 1: A right-angled triangle

3.1 Calculate the following: (6)

i. Tan θ

____

____

____

ii. Sinθ____

____

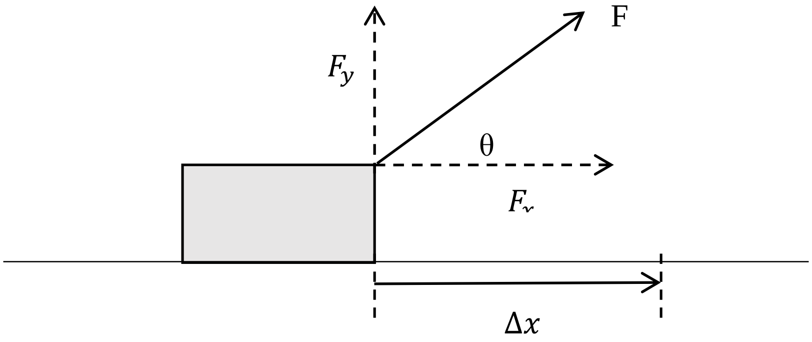
____

iii. Cosθ____

____

____

3.2 A force F, acts on the box at an angle θ as shown in Fig. 2



Force, F of 100N acts at angle of 37° to the horizontal. Its vertical and horizontal components are

Fig. 2: Force applied at an

Calculate:

3.2.1 The horizontal component of F, F_X
(3)

____
____
____
____

3.2.2 The vertical component of F, F_y
(3)

____
____
____
____

3.3 Which of the forces, F, F_x or F_y is causing the displacement, Δx? Justify your choice. (3)

____
____
____
____
____

3.4 State Newton's 2nd Law of motion
(3)

____
____
____
____
____
____

4 A box is stationary on an inclined surface that is tilted at an angle θ as shown in Fig. 3.

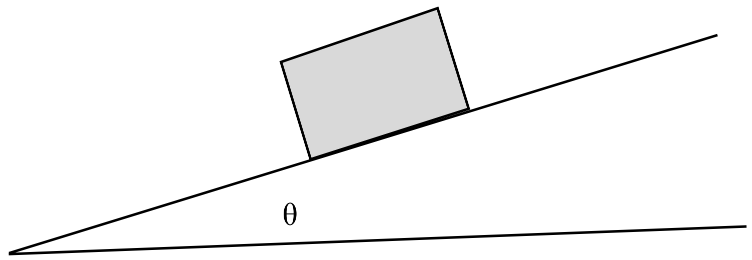


Fig. 3: Box on an inclined plane

On Fig. 3, indicate, using arrows, the following:

4.1 The component of the weight perpendicular to the plane. (2)

4.2 The component of the weight parallel to the plane. (2)

4.3 The normal force. (2)

5 A car moves from a traffic light and accelerates to a speed of $20 m.s^{-1}$.

5.1 Calculate its kinetic energy. (3)

____

____

____

____

5.2 The car accelerates further to a speed of $25 m.s^{-1}$. Calculate the change in the kinetic energy of the car. (4)

____

____

____

____

Total: 45 Marks

Appendix D: Diagnostic Test Memorandum

WORK and ENERGY

Diagnostic Test Memorandum

Time: 1 hour **Marks: 45**

INSTRUCTIONS TO LEARNERS

I. Answer ALL questions in the spaces provided.
II. Show full working whenever necessary.
III. Scientific calculators may be used

QUESTIONS

1. Give one example of a scalar quantity and one example of a vector quantity. (2)
   Any 2 appropriate examples (learners have to specify which one is vector and which one is a scalar)
2. Define or explain the meaning of the following terms. Give an example in each case. (12)
   - 2.1 Force
     -A push or pull on a body
     -e,g A force of 100N used to push a box/ gravitational force pulls objects towards the centre of the Earth, etc
   - 2.2 Energy
     The ability to do work
     e.g. kinetic energy, the energy possessed by moving objects, potential energy, the energy of objects due to height above the ground
   - 2.3 Displacement
     A vector quantity that refers to change in position
     E.g. The displacement of the car from the traffic light was 30m due South
   - 2.4 Distance
     The distance of an object is a scalar quantity the refers to the length of the path it takes
     E.g the car moved 5km through the streets of the city
   - 2.5 Speed
     A scalar quantity that refers to the change in position with respect to time
     E.g. the car was moving at a speed of 90km.h^{-1}
   - 2.6 Velocity
     Speed in a specified direction

E.g. the ball had a velocity of 10m.s^{-1} towards the batsman

3. Study the right angled triangle, ABC in Fig. 1 below.

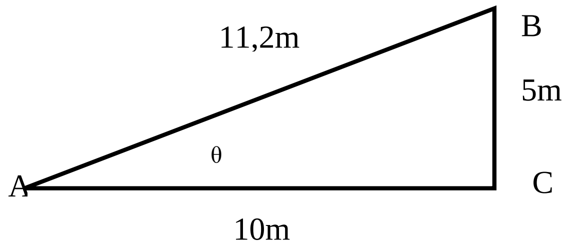


Fig. 1: A right

3.1 Calculate the following: (6)

3.1.1 Tan θ

$$Tan\ \theta = \frac{5}{10} = 0,5$$

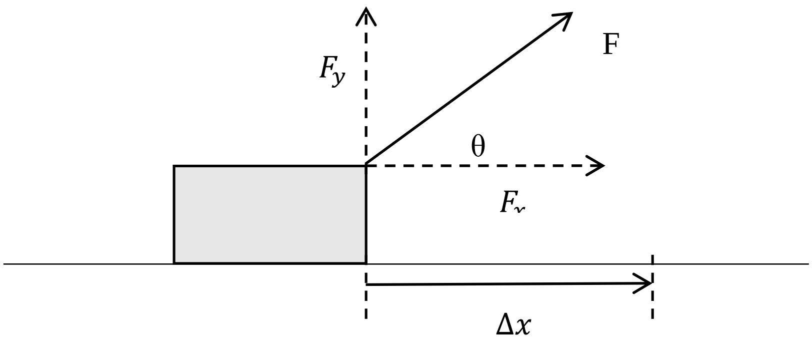
3.1.2 Sinθ

$$\sin\theta = \frac{5}{11,2} = 0,4464$$

3.1.3 Cosθ

$$Cos\theta = \frac{10}{11,2} = 0,8929$$

3.2 A force F, acts on the box at an angle θ as shown in Fig. 2



Force, F of 100N acts at angle of 37° to the horizontal. Its vertical and horizontal components are

Fig. 2: Force applied at an

Calculate:

3.2.1 The horizontal component of F, F_X (3)

$$\begin{aligned} F_x &= F.cos\theta \\ &= 100 \times cos37 \\ &= 79,86N \end{aligned}$$

3.2.2 The vertical component of F, F_Y (3)

$$F_y = F.sin\theta$$

$$= 100 \times sin37 = 60{,}18N$$

3.3 Which of the forces, F, F_x or F_y is causing the displacement, Δx? Justify your choice. (3)

F_x, *because it is the one in the direction of displacement*

3.4 State Newton's 2nd Law of motion (3)

If a net force acts, on a body it causes the body to accelerate in the direction of the body. The acceleration is directly proportional to the force and inversely proportional to the mass of the object

4. A box is stationary on an inclined surface that is tilted at an angle θ as shown in Fig. 3.

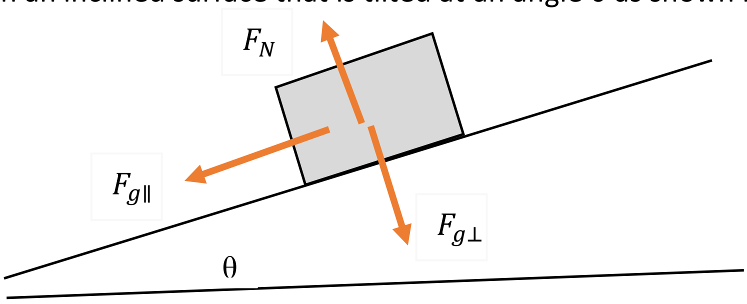


Fig. 3: Box on an inclined plane

On Fig. 3, indicate, using arrows, the following:

4.4 The component of the weight perpendicular to the plane. (2)

4.5 The component of the weight parallel to the plane. (2)

4.6 The normal force. (2)

5. A car of mass 1000kg moves from a traffic light and accelerates to a speed of 20m.s^1.
   a. Calculate its kinetic energy. (3)

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

$$= (0{,}5)(1000)(20)^2$$

$$= 200\ 000J$$

   b. The car accelerates further to a speed of 25m.s^{-1}. Calculate the change in the kinetic energy of the car. $\Delta E_k = E_{kf} - E_{ki} = \frac{1}{2}mv_f - \frac{1}{2}mv_i$

$$= (0{,}5)(1000)(25^2) - 200\ 000 = 112\ 500J$$

Total: 45 Marks

Appendix E: Summative Test

Yona Yethu High School
Grade 12
Physical Sciences Test
Work and Energy Test

Time: 1 hour
Marks: 50

Name:________________________________Date:____________________

Information and Instructions

1. Answer ALL questions.
2. For Question 1, use the separate answer sheet provided. Cross out the box with the best option (answer) and use spaces below the options to motivate, explain of do calculations to support your choice.
3. Round off final answers to two decimal places where applicable.
4. Write neatly and legibly.

Question 1

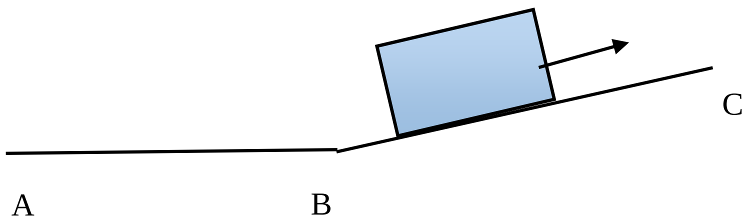
1.1 A force applied on an object moves it in a straight line on a ROUGH horizontal surface. If the speed of the object remains constant during the object's motion then....

A. The force pushing the object forward is zero.
B. The applied force is equal to frictional force.
C. The applied force is less than frictional force.
D. The applied force is greater than frictional force

(3)

1.2 In the diagram below, a wooden crate is pushed between points A and B. It is let go at point B when its speed is $7 m.s^{-1}$. It then slides up the slope until it stops at C. ABC is a frictionless surface.

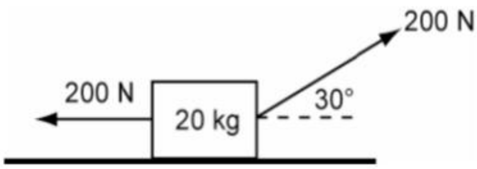
Which one of the following statements about the crate when it moves between points B and C is true?



A. The gravitational force does negative work on the crate.
B. There is no force acting on the crate and no work done on it.
C. There is no change in the kinetic energy.
D. The gravitational force acting on it gets less and less, hence crate stops

(3)

1.3 Two forces, each of magnitude 200N, are simultaneously applied to a crate at rest on a horizontal frictionless surface as shown in the diagram below.
(3)



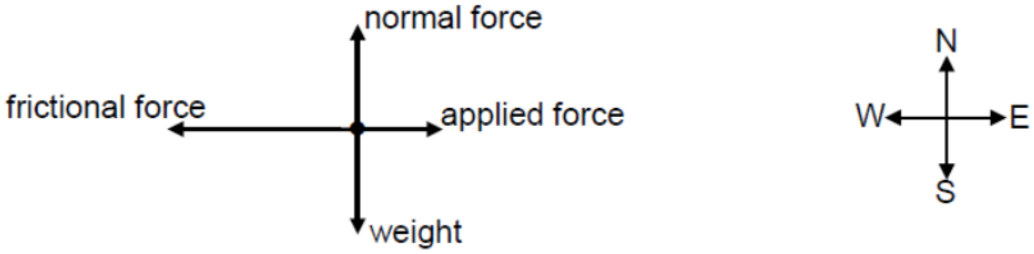
Work will be done by the net force on the crate because the crate will …

A. be lifted off the ground

B. accelerate to the right
C. accelerate to the left
D. remain at rest

(3)

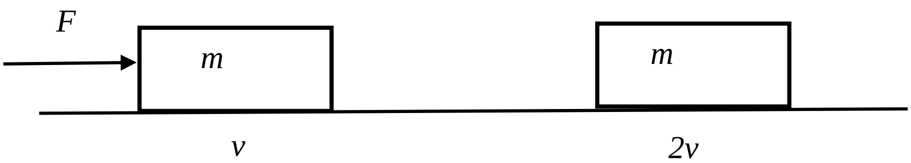
1.4 The free-body diagram below shows the relative magnitudes and directions of all the forces acting on an object moving horizontally in an easterly direction.



The kinetic energy of the object...
A. is zero.
B. increases.
C. decreases.
D. remains constant.

(3)

1.5 An applied force, *F* accelerates an object of mass, *m* on a horizontal frictionless surface from a velocity of *v* to a velocity of *2v*.



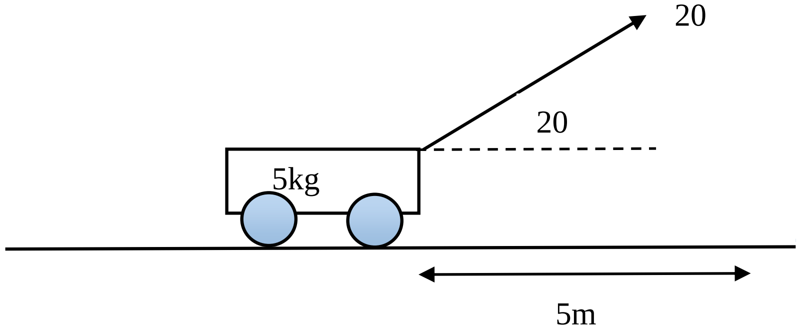
The net work done on the object is equal to….
A. $\frac{1}{2}mv^2$
B. mv^2
C. $\frac{3}{2}mv^2$
D. $2mv^2$

(3)

[15]

Question 2

A trolley of mass 5kg is pulled from rest on a rough surface by a force of 20N as shown in the diagram. A constant frictional force of 5N acts between the trolley's wheels and the rough surface. The constant force pulls the trolley over a distance of 5m.



2.1 Draw a free body diagram showing ALL the forces acting on the trolley. (4)

2.2 Name TWO forces that are not doing work. (2)

2.3 Explain why the forces named in 2.2 do NO WORK on the trolley. (2)

2.4 Calculate the net work done on the trolley. (5)

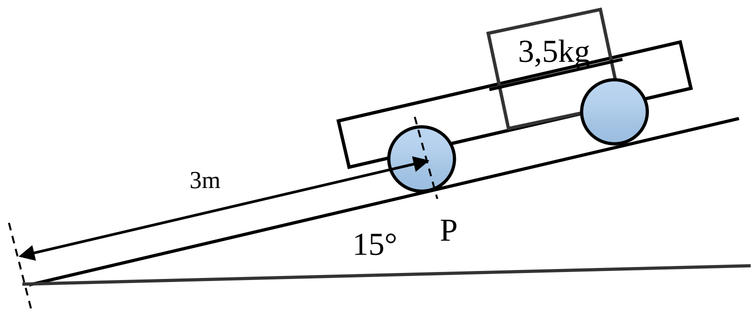
2.5 State the work - energy theorem in words. (2)

2.6 Use the work - energy theorem to calculate the velocity of the trolley after it is displaced for 5m. (5)

[20]

Question 3

In the diagram below a motor driven toy truck of mass 3,5kg accelerates up an inclined ramp. The toy truck starts from rest at the foot of the ramp and moves up to a point, P, a distance of 3m up the ramp. It reaches point P at a velocity of 3,8 $m.s^{-1}$. The toy truck experiences a constant frictional force of 3N.



3.1 Draw a free body diagram of all forces acting ALONG THE RAMP.

(3)

3.2 Calculate the change in kinetic energy of the toy truck between the foot of the ramp and point P. (4)

3.3 What is the work done on the toy truck? Explain your answer. (3)

3.4 Using energy principles only, calculate the force applied by the motor of the toy car. (5)

[15]

TOTAL: 50 MARKS

Useful information

g = 9,8 m.s⁻²

$g = 9{,}8\ m.s^{-2}$

$W = F\Delta x\cos\theta$

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

$E_p = mgh$

$W_{net} = \Delta E_k$

$\Delta E_k = E_{kf} - E_{ki}$

Appendix F: Summative Test Memorandum

SUMMATIVE TEST MEMO

QUESTION 1

1.1. B

The force applied is equal to friction so there is no net force to cause acceleration (3)

1.2. A

The velocity decreases to zero, so there is a decrease in kinetic energy Also because the force causing change in velocity ($F_{g\parallel}$) is opposite to the displacement. (3)

1.3. C

Force to the right is less than force to the left, i.e. the resultant force is to the left

$$F_{net} = (+200) + (-200cos30)$$
$$= 200 - 173{,}21$$
$$= 26{,}79N \text{ to the left}$$

(3)

1.4 C

Frictional force is greater than applied force, so negative work which decreases kinetic energy is done

(3)

1.5 A

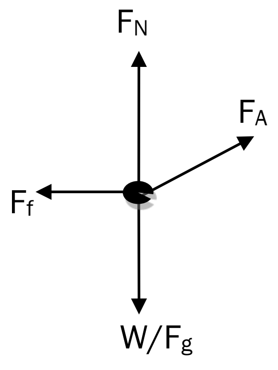
$$\Delta E_k = E_{kf} - E_{ki}$$
$$= \tfrac{1}{2}m2v^2 - \tfrac{1}{2}mv^2$$
$$= \tfrac{1}{2}mv^2$$

(3)

[15]

QUESTION 2

2.1.



(4)

2.2. F_N and W/F_g (2)

2.3. - They are acting perpendicular to displacement.
- There is no vertical displacement
(2)

2.4 $F_{net} = F_x + F_f$ (to the right is positive)

$= 20\cos 20 - 5$

$= 13{,}79N$

$$W_{net} = F_{net}\Delta x cos\theta$$
$$= (13{,}79)(5)(cos0)$$
$$= 68{,}97N$$ (5)

2.5 The network done on an object is equal to the change in the kinetic energy of the object. (2)

2.6. $W_{net} = \Delta E_K$

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

$68.97 = \frac{1}{2}x5v_f^2 - \frac{1}{2}x5x0^2$

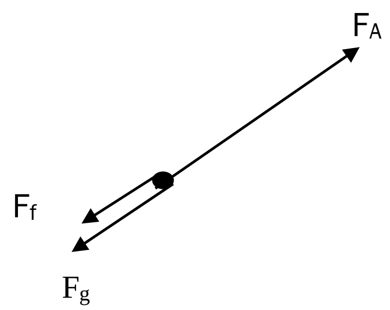
$v_f = \sqrt{\frac{68{,}97}{2{,}5}}$ (5)

$v_f = 5{,}25 m.s^{-1}$

[20]

QUESTION 3

3.1.



(3)

3.2. $\Delta E_k = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$

$= (0.5)(3{,}5)(3{,}8)^2 - (0{,}5)(3)(0)^2 = 25{,}27J$ (4)

3.3. 25,27J

According to the Work- Energy theorem the network done is equal to ΔE_K
(3)

3.4. $W_{net} = \Delta E_k$ (up the incline is positive)

$F_{net}.\Delta x.cos\theta = \Delta E_k$

$(F_A - 3.9059)(3)(\cos 0) = 25,27$

$3F_A - 11,7177 = 25,27$

$F_A = 12,33N$

$F_{net} = F_A + F_f + F_{g\parallel}$

$= F_A - 3 - 3,5sin15$

$= F_A - 3.9059$

[15]

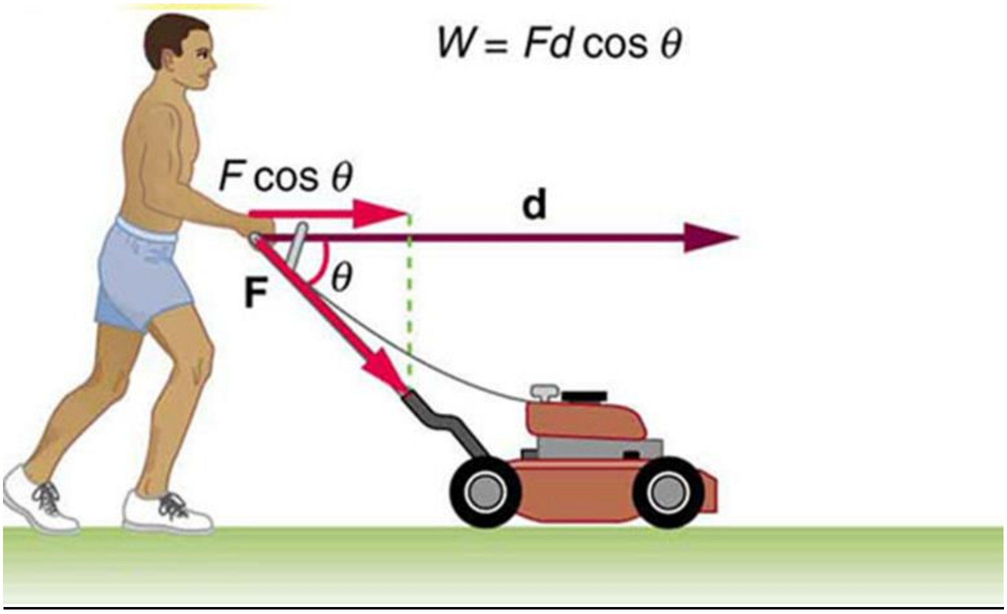
Total: **50 Marks**

Appendix G: Unit of Work

Work, Energy & Power

<u>Grade 12</u>

<u>Physical Sciences</u>



A.K. Mapfumo

Before you do this unit you are expected to have done the following:

1. Vector and scalar quantities
2. Components of vectors/forces
3. Newton's Laws of Motion
4. Gravitational potential energy. ($E_p = mgh$)
5. Kinetic energy. ($E_k = \frac{1}{2}mv^2$)
6. Mechanical energy, i.e. the sum of kinetic and gravitational energy of a body
7. Principle of conservation of mechanical energy, ($E_{ki} + E_{pi} = E_{ki} + E_{pf}$)

By the end of this unit you will be able to:

1. Define the work done on an object by a force
2. Give examples of when an applied force does and does not do work on an object
3. Calculate the work done on an object when a force *F* applied at an angle θ to the direction of motion causes the object to move distance Δx, using $W = F\Delta x cos\theta$
4. Know that an object with greater potential energy has a greater capacity to do work
5. State the Work-Energy theorem in words
6. Solve problems involving the work-energy theorem, $W = \Delta E =$ E_{kf} - E_{ki}, on flat and on inclined planes
7. Define conservative and non- conservative forces and give examples.
8. Solve problems using , $W_{nc} = \Delta E_k + \Delta E_p$
9. Define power as the rate at which work is done or energy is converted from one form to another
10. Calculate the power involved when work is done
11. Calculate the average power using $P_{av} = Fv_{av}$
12. Apply the concepts of work, power and energy to real-life examples

Work

Work is said to be down when a **force** moves the body or point of application in a **direction parallel to the force.**

Work is defined as a product of the force acting on an object and the displacement of the object in the direction of the force. $W = F\Delta x\, cos\theta$

- $W = work\ done\ in\ Joules\ (J)$
- $F = force\ applied\ in\ Newton (N)$
- $\Delta x = displacement\ IN\ THE\ DIRECTION\ OF\ FORCE\ , F\ in\ metres\ (m)$
- $\theta =$

According to our definition, the following situations do not involve work being done. Can you explain why?

- You sit on your desk studying Physics
- You hold a 25kg box of potatoes
- You push very hard on the wall

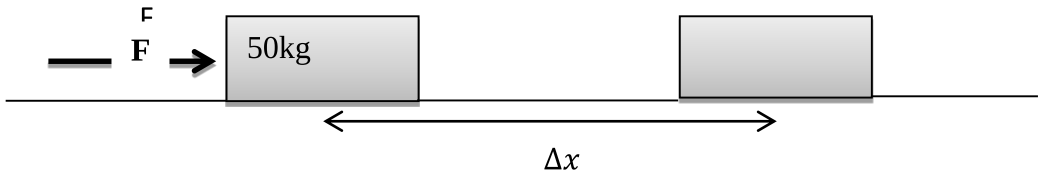
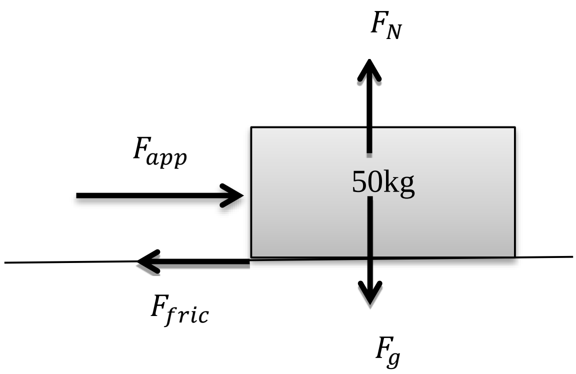


Fig. 1: Box being pushed

Force F, of 100N is applied on the 50kg box and the box moves a distance of 2m to the right on a rough floor. Fig. 2 below shows all the forces acting on the 50kg box as it moves to the right.

$$W = F\Delta x cos\theta$$

$$= 100 \times 2 \times \cos 0 = 200J$$



1 *Fig. 2: force diagram of a box being*

shown in Fig. 3 below:

- F_g is the gravitational force on the box (its weight)
- F_N is the Normal force. It is equal to the weight but acts upwards
- F_{app} is the applied force. This is the force causing the box to move to the right.
- F_{fric} is the frictional force. It always exists whenever two surfaces rub against each other. Friction ALWAYS **acts opposite to the direction**

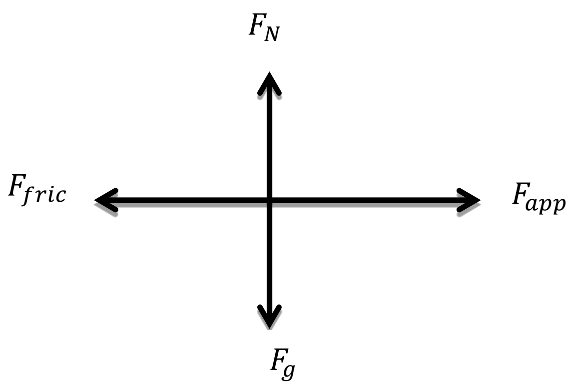


Fig.3: Free body diagram for a box being pushed

The box is now being pulled with a force acting at an angle θ as shown in Fig.4 below

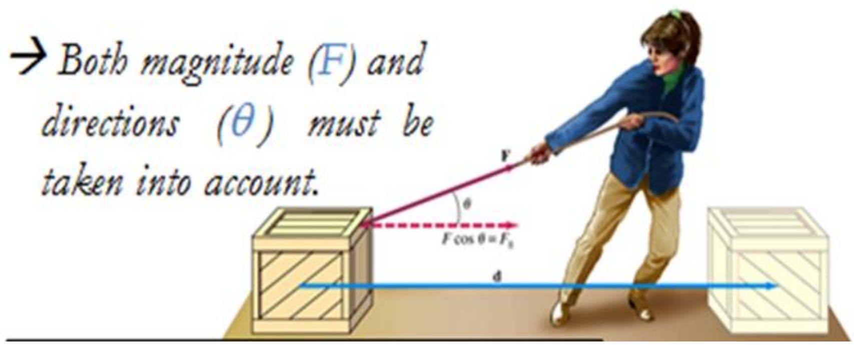
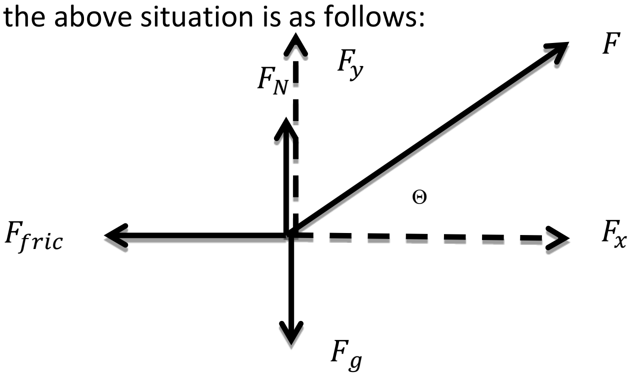
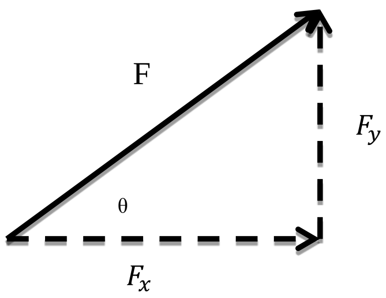


Fig 4: A lady pulling a box with a force at an angle

The applied force, F is at an angle of θ to the direction of motion of the box as shown in the picture. The box does not move in the direction of F, so it is NOT force F that is responsible for the displacement, Δx. It is the F_x the horizontal component of force F, that does work. The free body diagram for the above situation is as follows:



F_{app} can be considered as the resultant force of F_y andF_x. The triangle of forces below can be used to find F_y andF_x.



$cos\ \theta = \frac{F_x}{F}$ And $sin\ \theta = \frac{F_y}{F}$

$F_x = F cos\ \theta$ And $F_y = F sin\theta$

Note the following:

- W is maximum when force is exactly parallel to the displacement ($\theta = 0° \ or\ 180°$)
- If an object gains energy under the action of the force (e.g. the box accelerates) , work done, W is positive i.e. $W > 0$
- If an object loses energy under the action of the force(e.g. a moving crate is slowed down), work done is negative i.e. $W < 0$
- If more than one force acts on a body simultaneously (at the same time), then the net (W_{net}) is the work done by the net force, so $\boldsymbol{W_{net} = F_{net}\Delta x \cos\theta}$
- Referring to Fig. 2 : $\boldsymbol{F_{net} = F_x + F_{fric}}$
- **If the forces acting simultaneously those in opposite direction must be allocated opposite signs. If to the left is positive and to the right is negative then we have $+\boldsymbol{F_x}$ and $-\boldsymbol{F_{fric}}$**

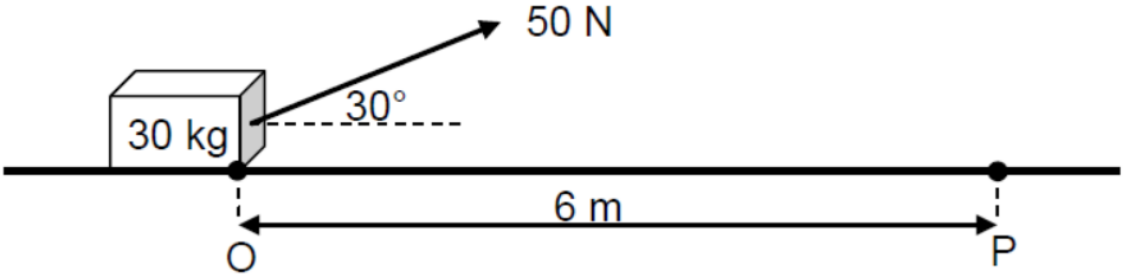
$$\therefore\ \boldsymbol{F_{net} = F_x - F_{fric}}$$

- **If $\boldsymbol{\theta\ is\ 90°\ or\ 270°\ cos\ \theta = 0}$ so the work done by a force acting at an angle θ will be zero.**

Activity 1

Question 1 (Adapted from November 2008, paper 1)

A worker pulls a crate of mass 30 kg from rest along a horizontal floor by applying a constant force of magnitude 50 N at an angle of 30° to the horizontal. A frictional force of magnitude 20 N acts on the crate whilst moving along the floor.



1.1 Draw a labeled free-body diagram to show ALL the forces acting on the crate during its motion.
(4)

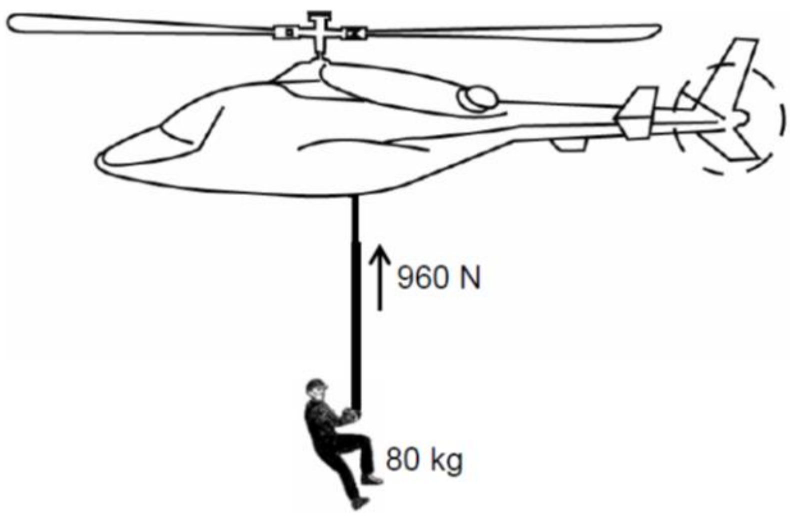
1.2 Give a reason why each of the vertical forces acting on the crate do NO WORK on the crate. (2)

1.3 Calculate the net work done on the crate as it reaches point P, 6 m from the starting point O. (4)

[10 marks]

Activity 2 (Adapted from November 2011, paper 1)

A rescue helicopter is stationary (hovers) above a soldier. The soldier of mass 80 kg is lifted vertically upwards through a height of 20 m by a cable at a CONSTANT SPEED of 4 $m \cdot s^{-1}$. The tension in the cable is 960 N. Assume that there is no sideways motion during the lift. Air friction is not to be ignored.



2.1 Draw a labeled free-body diagram showing ALL the forces acting on the soldier while being lifted upwards.
(3)

2.2 Write down the name of a non-contact force that acts on the soldier during the upward lift.
(1)

2.3 Calculate work done by air friction on the man.
(6)

[10 Marks]

Positive and negative work

- When the force causing the displacement of a body results in an increase in the energy of the body it does **positive work**. This happens when the force applied is parallel to the direction of displacement of has a component parallel to direction of displacement.
- If the force causing displacement or its component is in a direction opposite to the displacement of the body it results in the decrease in the energy of the body. It does **negative work.**

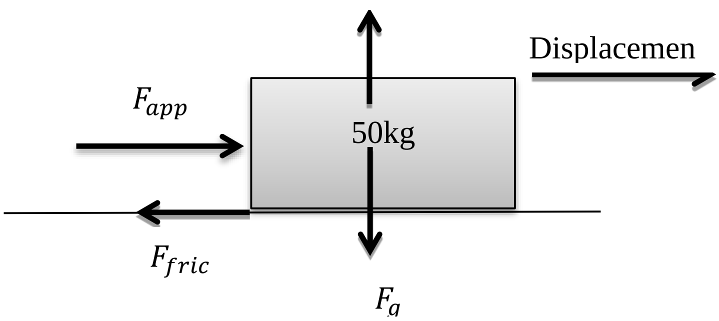
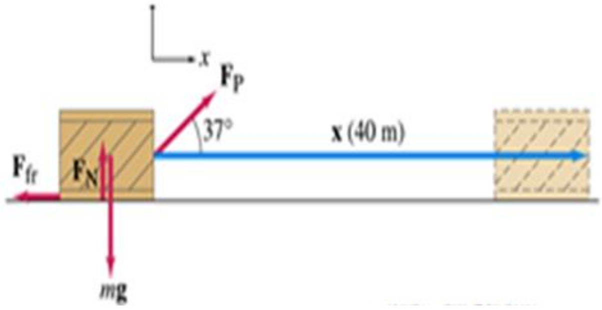


Fig. 6: A force diagram of a box being pulled along a horizontal surface

- F_g and F_N are perpendicular to the direction of displacement. They do **NO WORK** (there is no vertical displacement)
- F_{app} is parallel to the direction of displacement ,it does **POSITIVE WORK**
- F_{fric} is in a direction opposite to displacement. It does **NEGATIVE WORK**

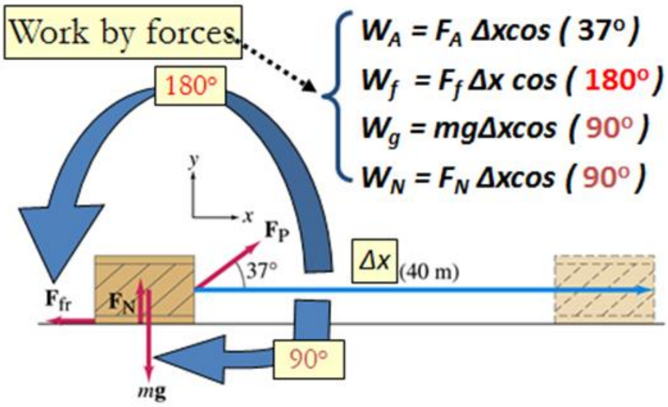
Example 1

A 50kg crate is pulled over a distance of 40m by a constant force, F_P of 100N applied at an angle of 37° to the horizontal. A frictional force of 50N acts between the crate and the floor.



a) Determine the work done by each force acting on the crate.
b) Calculate the net work done on the crate.

Solution



a) $W_p = 3\,194.54J$

$W_f = -2\,000J$

$W_g = 0J$

$W_N = 0J$

b) $W_{net} = W_A + W_f + W_g + W_N$

$= 3\,194.54 + (-2000) + 0 + 0$

$= 1\,194.54\ J$

- fictional force, *f* does negative work
- Gravitational force, *mg* and normal force do not do any work since they act perpendicular to the direction of displacement.

Objects on inclined planes

Activity 2 – Group work

So far we have looked at objects on horizontal planes. Fig 7 shows a box that is sliding down a plane that is inclined at an angle θ to the horizontal.

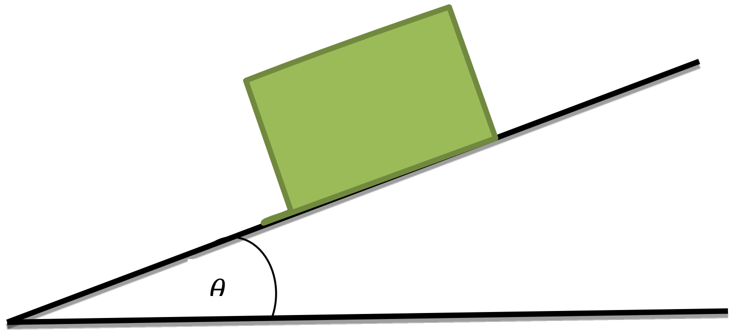


Fig 7: A diagram of a box being pulled up an inclined plane

2.1 State Newton's First Law of Motion

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2.2 Explain why the box slides down the plane, whilst there is apparently no force being applied. Refer to Newton's First Law of motion in your explanation.

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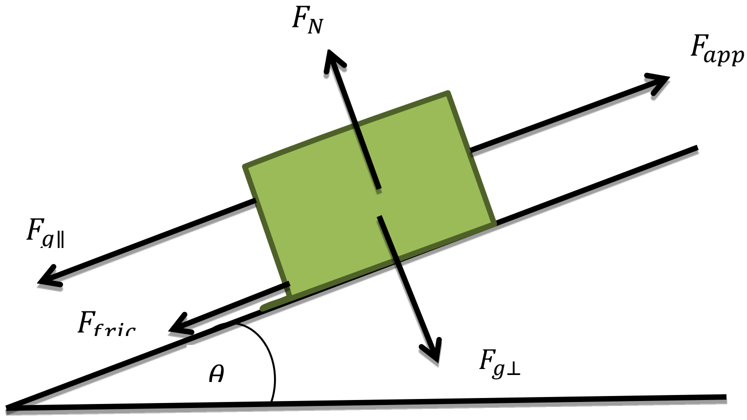


Fig 8: A force diagram of a box being pulled up an inclined plane

The weight of the box has a component down the slope, $F_{g\parallel}$ which tends to pull the box down the slope. The weight also has a component which acts perpendicular to the surface of the incline, $F_{g\perp}$. $F_{g\perp}$ is equivalent to the normal force, F_N since there is no motion in a direction perpendicular to the surface of the inclined plane. The parallel component of weight, F_g is given by:

$$\boldsymbol{F_{g\parallel} = F_g sin\theta}$$

Determining the net work done

The net work is done by the net force parallel to the surface (there is no work done perpendicular to the surface since there is no displacement perpendicular to the surface).

$$\therefore\ \boldsymbol{F_{net} = F_{app} + F_{fric} + F_{g\parallel}}$$

$$\boldsymbol{and\ \ W_{net} = F_{net}\Delta x cos\theta}$$

Activity 3 (Group Exercise)

A car of mass 900kg is driven up an inclined plane at a constant velocity, as shown in figure 9 on the next page.

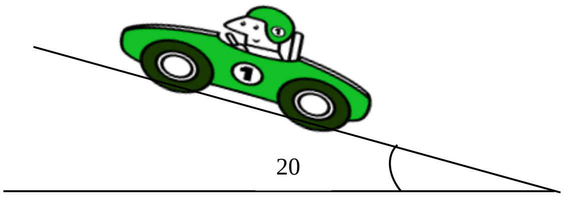


Figure 9: A car being driven up an inclined

3.2 Name the three forces that act on the car parallel to the inclined plane. (3)

3.3 Which of the force(s) is doing positive work? Give a reason for your answer (2)

3.4 Which of the 2 forces is doing negative work? Give a reason for your answer (3)

3.5 What is the net force on the car? Explain your answer. (2)

3.6 Suppose the car now accelerates for 80m up the inclined plane. The car engine exerts a forward force of 7 000N and the car experiences a frictional force of 2500N. Calculate the net work done on the car. (6)

[16 marks]

Energy

- Energy is usually defined as the ability to do work. From this definition it follows that whenever work is done energy is used.
- It also follows that amount of energy used is equal to the amount of work done. The un
- The Law of Conservation of Energy states that:

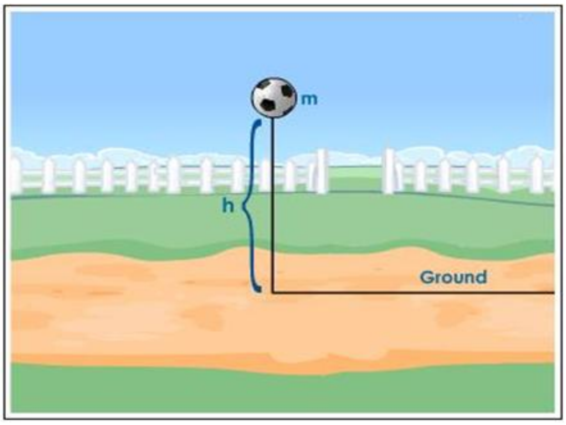
Energy cannot be created or destroyed. It can only be transformed from one for to

- The energy we are dealing with in this unit is mechanical energy

Mechanical energy is the total amount of gravitational potential energy plus kinetic energy in a system.

Gravitational Potential Energy, E_p

- Gravitational potential energy is the energy stored in an object as the result of its vertical position or height. The energy is stored as the result of the gravitational attraction of the Earth for the object.
- The gravitational potential energy is dependent on two variables - the mass of the ball and the height to which it is raised.
- Consider a ball of mass, m raised to a height, h above the ground.



$E_P = m \cdot g \cdot h$

E_p – Gravitational potential energy (J)
m – Mass of object (kg)
g – Acceleration due to gravity $(9.8 m.s^{-1})$

Figure10: A ball raised above the ground

To determine the gravitational potential energy of an object, a zero height position must first be chosen. The ground is usually chosen as the zero height.

Kinetic Energy, E_k

- Kinetic energy is energy of motion. The kinetic energy of an object is the energy it possesses because of its motion.
- A moving body can do work on anything it hits

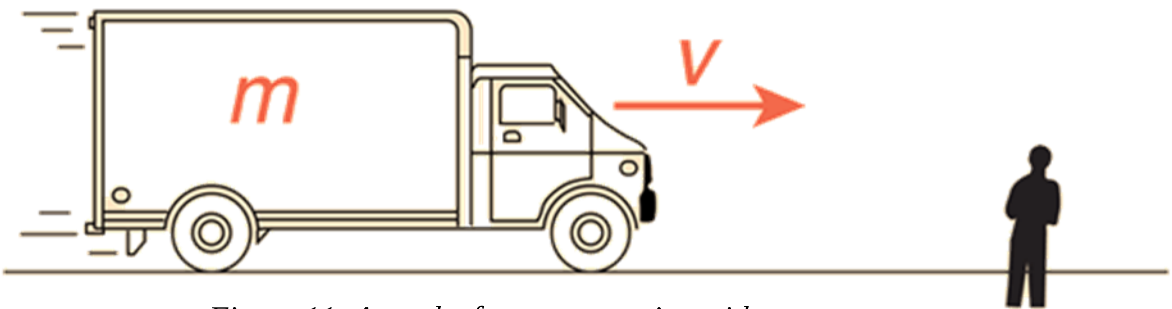


Figure 11: A truck of mass m, moving with a velocity of v (Source: www.

Consider a truck of mass, m that is moving with a velocity of v. Its kinetic energy, E_k can be calculated by:

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

E_k – kinetic energy (J)
m – mass (kg)

Activity 4 – (individual)

Name:____________________________________ **Date:**________________________

Adapted from: http://www.helpteaching.com/tests/160295/mechanical-energy

4.1 A car of mass 1200kg is moving at a speed of 20m.s^{-1}. Calculate its kinetic energy. (3)

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4.2 The car slows down to a speed of 15m.s^{-1}. Calculate the change in the kinetic energy of the car. (4)

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4.3 Is there any work done in slowing down the car? Explain your answer in full.

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____(3)

Activity 5 – Group Discussion

5.1 State Newton's Second law of motion

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5.2 If a car travelling on a tarred road increases its speed from 23m.s^{-1} to 27m.s^{-1}, what effect, if any does this have on the kinetic energy possessed by the car.

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5.3 Name the force(s) that is/are responsible for the change in velocity. Explain your answer

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The work-energy theorem

When a **net force does work** on an object, then there **is always a change in the kinetic energy** of the object.

The work- energy theorem states that:

The net work done on an object is equal to the change in the object's kinetic energy.

In symbols:

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

Where:

W_{net}= the net work done on the object, measured in Joules (J)

ΔE_k =the change in the kinetic energy of the object

From the work – energy theorem:

- The **net positive work** done will be equal to the increase in the kinetic energy of the object.
- The **net negative work** done on the object will be equal to the decrease in kinetic energy of the object.

Example 3

A Formula 1 racing car of mass 640kg is travelling at $30 m\cdot s^{-1}$.It then accelerates in a straight line as shown in figure 9 below. The engine of the car exerts an average forward force of 12 000N and the racing car experiences an average frictional force of 3 000. Using the work-energy theorem, calculate the speed of the racing car after it has travelled 30m

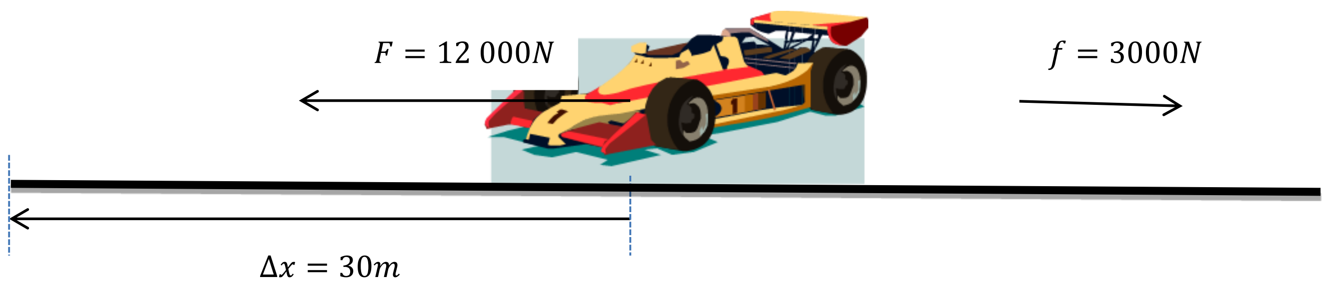


Fig 9: A formula 1 car accelerates to the

Solution:

Data given: (Taking direction *to the left* as positive (+))

- $V_i = 30m \cdot s^{-1}$
- $F = 12\ 000N$
- $V_i = 30m \cdot s^{-1}$
- $\Delta x = 30m$
- $f = 3000N$
- $V_f = ??$

1st: $F_{net} = F + f$

$= (+12\ 000) + (-3\ 000) = +9\ 000N$

2nd: $W_{net} = F_{net} \Delta x cos\theta$

$= (+9\ 000)(30)cos0$

$= 270\ 000N$

3rd: Apply the work –energy theorem

$$W_{net} = \Delta E_k = E_{kf} - E_{ki}$$

$$270\ 000 = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$270\ 000 = \frac{1}{2} \times 640 \times v_f^2 - \frac{1}{2} \times 640 \times 30^2$$

$$270\ 000 = 320v_f^2 - 288\ 000$$

$$\boldsymbol{v_f = 41,76m.s^{-1}}$$

The speed of the racing car after it has travelled 30m is $\boldsymbol{41,76m.s^{-1}}$

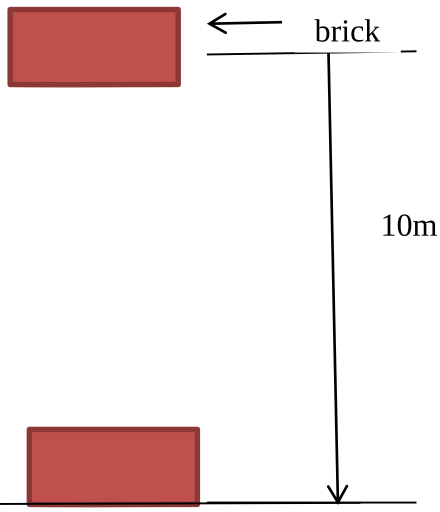
Work- Energy Theorem applied vertically

Example 5

A 1 kg brick is dropped from a height of 10 m. Calculate the work that has been done on the brick between the moment it is released and the moment when it hits the ground. Assume that air resistance can be neglected.

$\boldsymbol{E_p}: mgh = 1 \times 9.8 \times 10 = 98\text{J}$

$\boldsymbol{E_k}: \frac{1}{2}mv^2 = \frac{1}{2} \times 1 \times 0^2 = 0J$



Data given:

- Mass(m)= 1kg
- Initial height = h_i
- Final height = h_f

We need work done on the brick as it hits the ground

$\boldsymbol{E_p}: mgh = 1 \times 9.8 \times 0 = 0\text{J}$

$\boldsymbol{E_k}: \frac{1}{2}mv^2 = 98J$

Solution:

Applying the work –energy theorem:

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

$$= \frac{1}{2}\mathrm{mv_f}^2 - \frac{1}{2}\mathrm{mv_i}^2$$

$= 98 - 0 = 98\text{J}$ $\therefore$ **the work done on the brick is 98J**

Applying work- energy theorem on inclined planes

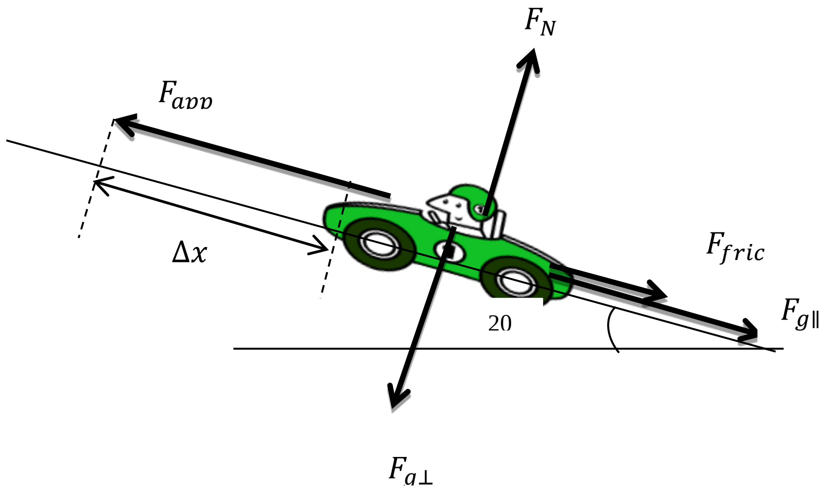


Figure 10: Force diagram of car being driven up an

A car of mass, m is accelerated up a road inclined at an angle of 20^0 to the horizontal by a constant force, F_{app} from its engine. It moves a distance, Δx up the inclined road.

Points to be noted:

- The symbol, θ, is used twice. Firstly in the work formula, $\boldsymbol{W = F\Delta x cos\theta}$, where is represents the angle between the direction of force and displacement. In the situation represented above the forces doing work parallel to the plane are all in the same direction as displacement and hence θ = 0°

- Secondly it is used for the components of the weight of the car, F_g , i.e the vertical component, $\boldsymbol{F_{g\perp} = mgcos\theta}$,as well as the parallel component, $\boldsymbol{F_{g\parallel} = mgsin\theta}$ .In this case θ is the angle of incline, i.e., 20°
- Forces that are perpendicular the road, i.e. F_N and $\boldsymbol{F_{g\perp}}$ are not doing any work on the car as far as displacement, Δx is concerned so they are not used in the application of the work-energy theorem.

Net force action on the car:

$$\boldsymbol{F_{net}} = (+\boldsymbol{F_{app}}) + (-\boldsymbol{F_{g\parallel}}) + (-\boldsymbol{F_{fric}})$$ (Taking up the incline as positive, +)

Net work done on the car: $\boldsymbol{W_{net} = F_{net}\, \Delta x \cos\theta}$

Example 4

A dynamics trolley of mass 2kg is held at the top of a plane of a plane inclined at 30° to the horizontal, as show in fig.11 below. The trolley is released and rolls down the inclined plane while experiencing a constant frictional force of 6N. Use the work-energy theorem to calculate the speed of the trolley after it has rolled 1,5m down the incline.

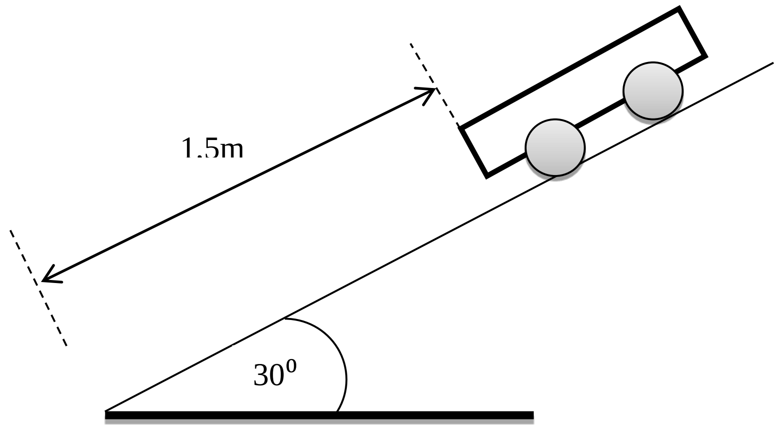


Fig. 11: A trolley rolls from rest down an inclined plane

Solution:

Draw a force or free body diagram to identify forces doing work on the trolley (fig. 12). Take the direction down the slope as (+).

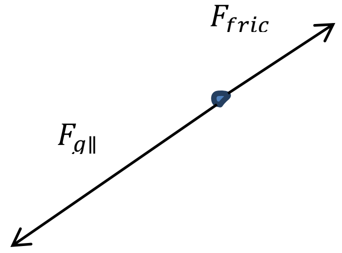


Fig. 12: Free body diagram of forces doing work on the trolley

1st: Net work done on the trolley

$$W_{net} = F_{net}\, \Delta x \cos\theta = (F_{g\parallel} + F_{fric})\Delta x cos\theta$$

$$= [(+mgsin\theta) + (-F_{fric})]\Delta x cos\theta$$

$$= [(2 \times 9{,}8 \times sin30) - (6)] \times 1{,}5 cos0$$

$$= 5.7\, J$$

2nd: Apply the work-energy theorem

$$W_{net} = \Delta E_k = E_{kf} - E_{ki}$$

$5{,}7 = E_{kf} - 0$ (Trolley is released from rest so initial kinetic energy is zero)

$$5{,}7 = \tfrac{1}{2} m v_f{}^2$$

$$5{,}7 = \frac{1}{2}(2) v_f{}^2$$

$$v_f = \sqrt{5{,}7} = 2{,}39 m \cdot s^{-1}$$

The speed of the trolley after it has rolled 1,5m is 2,39 m·s^{-1}

Activity 6

In fig. 13, a 75kg skateboarder skates down a slope while experiencing a frictional force of 60N. The slope forms an angle of 25˚ with the horizontal. The skateboarder covers a distance of 36m before reaching the end of the slope at a velocity of 16m.s^{-1}.

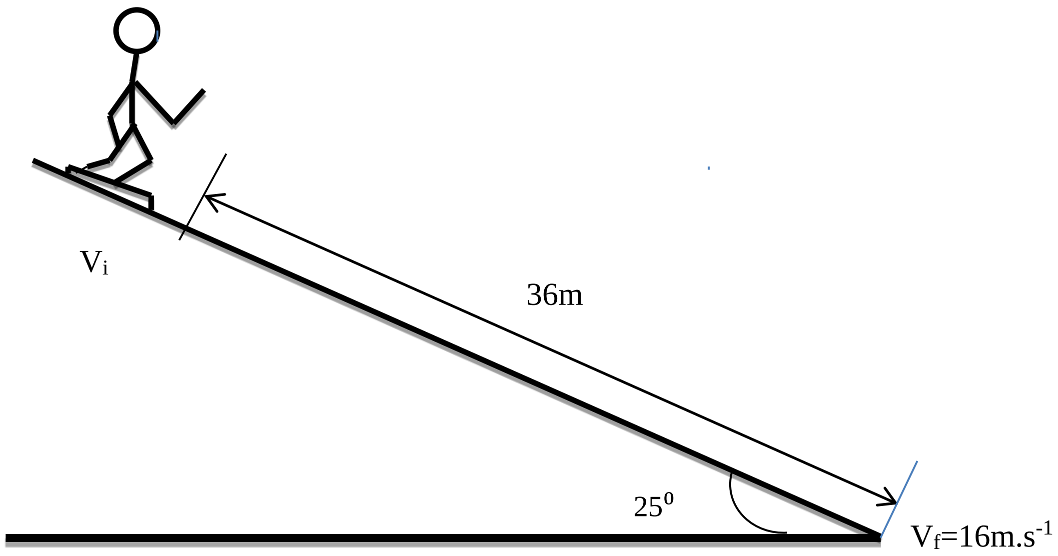


Fig. 13: A skateboarder skates down an inclined plane

a) Draw a labelled free body diagram of all the forces acting on the skateboarder, at the top of the slope. (4)

b) Calculate the net force that acts on the skateboarder as he moves down the slope. (3)

c) Calculate the work done by the net force, as the skateboarder moves 36m down the slope. (4)

d) Use the work- energy theorem to calculate the initial velocity of the skateboarder near the top of the slope. (4)

[15 Marks]

Conservation of Energy

Conservative forces

- A conservative force is a force for which work done in moving an object between two points is independent of the path taken. An example of a conservative force is the **gravitational force.**

The total mechanical energy of an object is conserved, only when conservative forces are present

words total mechanical energy is conserved. So we can say conservative forces 'store' energy.

If points 1 and 2 represent any two points in the path of a ball that is thrown into the air, then the mechanical energy at point 1 is equal to the mechanical energy at point 2:

$$E_{k1} + E_{p1} = E_{k2} + E_{p2}$$

Non-conservative forces

- A non-conservative force is a force for which work done depends on the path taken. Whenever a non-conservative force acts on a body the mechanical energy of the body is NOT conserved. **Friction** is the most common non-conservative force
- Friction is known as a dissipative force. Dissipative forces convert mechanical energy into heat and other forms of energy
- Applied forces are also non-conservative, the can do positive work, which increases mechanical energy or they can do negative work which reduces mechanical energy

Work done by non-conservative forces, W_{nc}

- Forces acting in the direction of motion increase the mechanical energy whilst forces acting in the direction opposite to motion decrease the mechanical energy.
- Suppose a trolley rolls down a slope from point A to point B as shown in fig. 14

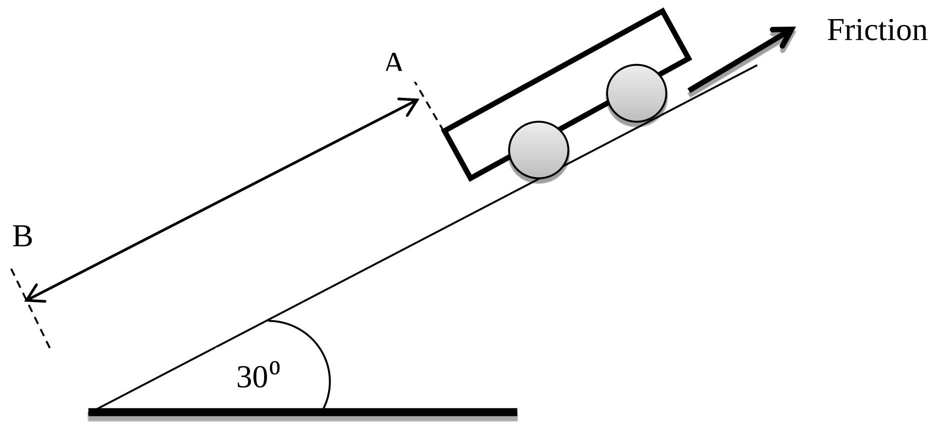


Fig. 14: A trolley rolls down a slope

Negative work is done by the non-conservative force (friction), W_{nc} and some of the mechanical energy is dissipated to the surroundings. This means that mechanical energy at A is greater than at B.

$$E_{ki} + E_{pi} > E_{kf} + E_{pf}$$

To obey the law of conservation of energy we need to include the work done by the non-conservative force, W_{nc} (friction).

$$E_{ki} + E_{pi} = E_{kf} + E_{pf} - W_{nc} \qquad \text{(Equation 1)}$$

From Equation 1: $\boldsymbol{W_{nc} = E_{kf} - E_{ki} + E_{pf} - E_{pi}}$

(Equation 2)

But: $\boldsymbol{E_{kf} - E_{ki} = \Delta E_k}$ **and** $\boldsymbol{E_{pf} - E_{pi} = \Delta K_p}$

So equation 2 becomes:

$$\boxed{\boldsymbol{W_{nc} = \Delta E_k + \Delta E_p}}$$

This is another form of the work-energy theorem. We can state the equation in works as:

The work done by all non-conservative forces equals the change in the total mechanical energy of the system.

Example 5

Fig. 15 shows a 70kg skateboarder who skates down a slope whilst experiencing a constant frictional force of 190N. The slope forms an angle of 30^0 with the horizontal. The skateboarder covers a distance of 10m between points A and B. Point A is 5m higher than B. The speed of the skateboard at A is $6 m{\cdot}s^{-1}$.

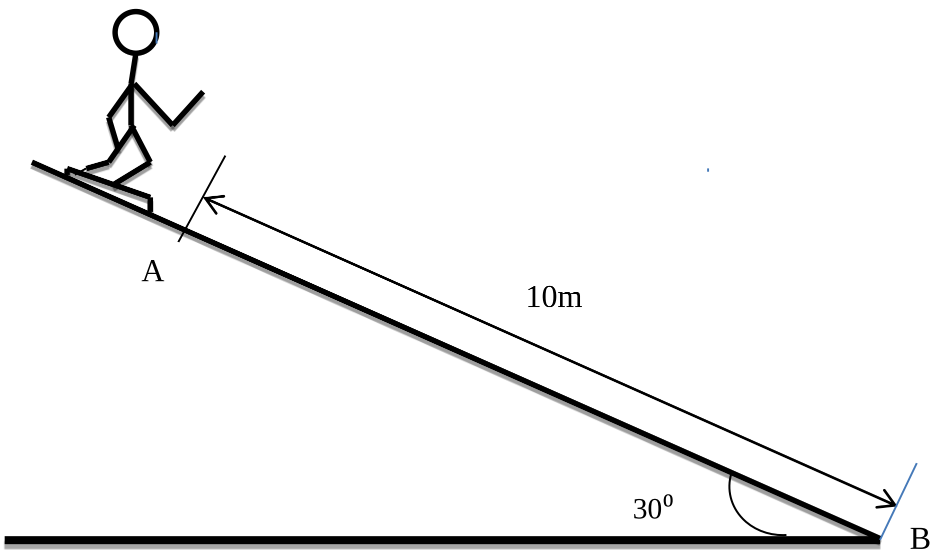


Fig. 15: A skateboarder skates down an inclined plane

a) Calculate the gravitational potential energy of the skateboarder at point A.
b) Calculate the speed of the skate boarder at point, the bottom of the slope.

Solution:

a) $E_{pA} = mgh = (70)(9{,}8)(5) = 3\ 430J$
b) Mechanical energy of the skateboarder is not conserved since there is friction, a non-conservative force acting. $\therefore\ W_{nc} = \Delta E_k + \Delta E_p$

1st: Work done by friction: $W_{nc} = F\Delta x cos\theta$

$= (190)(10)cos180° = -1\ 900J$

2nd: Change in gravitational potential energy, (ΔE_P):

$$\Delta E_p = E_{pf} - E_{pi} = 0 - 3\ 430 = -3\ 430J$$

3rd: Change in kinetic energy, (ΔE_k):

$$\Delta E_k = \frac{1}{2}mv_f{}^2 - \frac{1}{2}mv_i{}^2 = \frac{1}{2}(70)v_f{}^2 - \frac{1}{2}(70)(6)^2$$

$$= 35v_f{}^2 - 1\ 290$$

Finally: $W_{nc} = \Delta E_k + \Delta E_k$

$$-1900 = (35v_f{}^2 - 1260) + (-3430)$$

$$v_f{}^2 = 2790$$

$$v_f = 8{,}93 m.s^{-1}$$

References

du Plessis, D., Gray, F., McLaren, C., & Nozaic, B. (2013). *Physical Sciences: Learner's Book 12.* Northlands: Macmillan South Africa.

Kelder, K. H. (2012). *Physical Sciences: Grade 12 Learner's Book.* Cape Town: Cambridge University Press.

Appendix H: Transcript Tr1 – Group Discussion 1

ACTIVITY 1 (Unit of work)

L5: Then thina sine displacement Yethu, then yifrictional force, ibe yigravitational force, ibe yinormal force, ibe yi force applied. **Translated**: Then we have our displacement, then it's normal force, then applied force

L4: Idisplacement nayo siyafaka as iforce? **Translated:** Do we put displacement as a force?

L4: Ah, ah

L5: *Idisplacement asiyifake as iforce kalok* but *yona siyayirepresenter*. **Translated:** We do not put displacement as a force but we represent it. L4: (shaking his head in disagreement) Ah, ar. Ah ar

L5: Because, *kalok* guys *jonga, L1, ukusuka apha kule* force *ukuya kweli cala.* (Pointing on the diagram*)* **Translated:** Look guys. L1, from this force to this side…

L4: *Jonga*, (indicating on the diagram) *uyabona idisplacement isecaleni. Nanci ke ibox*. Nazi *ke* iforces *ezi acta kule* box. **Translated**: Look, you see the displacement, it's on the side. Here is the box. Here are the forces acting on the box.

L5: Yes. *Then apha kalok jonga, sino, sino*… **Translated**: Here, look. We ha, we have….

L7: *Sino 30*. **Translated:** We have 30.

L5: Ngu30 okanye ngu cos30 **Translated:** Is it 30 or cos 30?

L7: Ngu theta **Translated:** It's theta (θ)

L5: *So if thina sizorepresenter lo F-net wethu, uyabona apha ezantsi, uyabona kule ndawo ne, ikule ndawo I, u cos30 wethu. So if ayizubakho lendawo which means asizubanaye u cos*… **Translated:** So we will represent F_{net}. You see down here, you see here, it is here. Our cos 30.

L4: *Jonga L5, yi* component *yale nancika, yale* 50N. *Yiforce* applied le 50N. **Translated**: Look L5, this is a component of this 50N. It is force applied, this 50N.

(Showing on the diagram) *Enye* icomponent *nanci.* **Translated:** Here is the other component.

L3: Normal force

L7: Then ibe yi gravitational force. **Translated:** Then there is gravitational force

L4: I gravitational force nanci yona. (He draws on the diagram). **Translated:** Here is the gravitational force

L7: Then, Le? (Pointing on the diagram). **Translated:** Then this one.

L4: Yile component ka force applied, Yi displacement ke ngoku. (he moves his hand showing the displacement on the diagram.) I displacement *mos iya acta kule box.* I displacement *kukuthatha laboix ukusuka apha ukuza apha*. That 6m *ukusuka*…**Translated:** This is the component of applied force, then the displacement. Displacement is taking that box from here to there. That 6m, from….

L5: But *xa sicalculetayo izawfuneka?* **Translated**: But when we are calculating do we include it?

L1: *Ibisithini kuqala*? *Ithi* **Translated:** What did it say in the first place? It says**…**show all the forces acting on the crate during its motion.

L5: So all in all…..?

L5: Let me see. *Sine* forces *ezingaphi*? *Yi* frictional force, *ibe yi* height. *Yi* height *phofu* le, *le* force *uksuka kule* box *ukuya kule cala*….*Yi* displacement? **Translated:** How many forces do we have? Its frictional force, then height. Is this height, this force from the box to that side…it is displacement?

L7: Yi displacement. **Translated**: It is displacement

L4: Ewe yi displacement. Translated: Yes it is….

L7 Ngulo 6. Translated: It is this 6 (metres)

L4: I displacement *ayi acti kulabox*…

L7: *Ingaphandle*

L4: Er..

L5: Now, which means *asizuba nayo* le normal force Yethu

L4: *Hayi*

L6: *Ayikho apha*

L5: *Asizuizoba kwi* free body diagram

L6: Ah, ah

L3: *Intoni*

L5: I normal force

L3: *Haibo, uzawthini ungayizobi?*

L5: That's why *ndisitsho kalok siyibeke le landuza*

L7: *Siyayibeka phi*? *Siyayibeka?*

L2: *Idisplacement ayiyo* force

L4: *Mamela, kuthini uku displacer kuqala? Ukudisplacer kususa lengcwadi ngapha uibekhe ngapha due to the body.* (He takes a book from one point to another on the table) *Uyabo? Siyi displacile kengoku*

L5: um

L4: *So siyidisplesile ke ngoku. So ayiyo* force *le* displacement. Sizoba iforce lule diagram. Yiforce ukususa lengcwadi apha siyizise apha?

L7: Ayiyo, yi displacement. OK ndiybonile ke ngoku (She takes papers and starts drawing free body diagram)

L1: (Reading the next question on the same exercise) - Give a reason why each of the vertical forces acting on the crate do NO WORK on the crate.

L3: Yile bendibuza, kutheni why uF_y noF_x befumaneka always bengu zero

L1: Uban?

L3: uF_y noF_x befumaneka always bengu zero. Kodwa into onoiqonda ifana ukuthi u F_y unayo, ikhona iforce eyenzekhayo handiti

L1: Uthetha ngo F_y…(inaudible)

L4: Akahethi ngee componentsze F applied

L1: F applied

L3: Ewe ze force applied

L1: Phinda, uthi F_y…..

L3: Ewe. Ndithi uF_y ubangu zero no F_x ne. Ndibuza ke ngoku kutheni ezakuba ngu zero kodwa wenza I force?

L1: Yima, Ndiyabuza ke ngoku ukba siyangqinelana na ukba uFy no Fx baba ngu zero?

L7: Uyakhumbula utishala kulanto ebeilinganisa izolo yesithulo? Xa uphethe isithulo. Xa usithatha pantsi handiti la force ayifani nale xa usithatha pantsi uhamba naso. Ebetshilo ndiya kumbula kulanto ebethe u F no Y always babangu zero kuba iyafana ngathi awenzinto xa uthathe I desika uyoyibeka pha. I force iyenzeka the minute uyithatha la desika uyoyibeka phantsi. Andiyazi noba be ndive right…

L1: Imake, ndibuza ku Fx zeziphi icomponents apha

L7: Inormal force, ne lenduza

L1: Imake…(Inaudible)

L7: Ewe, u Fy. Nangu u Fy (She points at the diagram)

L4: Xa uhamba nayo

L7: Akhonto eyenzekhayo xa uhamba nayo?

L4; Ewe, uyibambile. Ebe tshilo uMeneer. Ebetshilo

L3: Yima. Mna ndifuna I explanation

L1: Ebethentha nge normal force. Wena uthetha ngantoni?

L3: Nge components zikha force applied. Ndithetha ngazo mna.

L1: (Raises the work sheet and explains something to the group. Recording not audible)…Noba siyavumelana nah?

L4: Ikhona mos I displacement pha

L1: Uhu

L4: Xa ikhona I displacement ikhona iwork

L7: Iyenzeka

L4: Ikhona

L3: So aingo zero?

L7: Haai

L1: Kutheni sizo qala ngo zero?

L3: Kalok, Handiti mos xa (inaudible)….akomsebenzi oyennzekhayo, so yiyo le ibingu zero.

L1: OK. Umthathaphi lo zero

L3: Ndimathatha kuwe kaloko kulento ibithethwa ngu tishala

L7: Unyanisile. Simthatha lulamzekelo ubuyenziwe ngu tishala

L1: Ebethani utishala zeathi nguzero

L6: Kalok uthe u tishala

L3: Yile ndiyifiunayo, yile ndiyibuza

(Several learners laugh)

L1: Yabona, anithethi nge force eyi one lo uthetha ne force of gravity lo nge normal force

Appendix I: Transcription Tr2- Group Discussion 2

Group discussion on Activity 4 (Unit of work)

(Learners trying to state Newton's 2nd Law – Question 4.1)

Tr: "Is it the direction of motion? Are you sure it is the direction of motion?"

L3: "*Utheni Chumani?"* Translated: "What did you say Chumani?"

L2: "*Nditheni mna*?" Translated: "What did I say?"

L3: *"Ndithe*." Translated: "I said. When a net force is applied on an object it means that the object it means that the object will accelerate in the direction of what? Of motion."

L3: "In the direction of a motion?"

L4: In the direction of net force.

L2: *Ewe*. Translated: Yes. In the direction of net force.

L4: Acceleration *Injani kwinet force?* Translated: How is acceleration to net force?

L6: Directly (proportional)

L4: *Ibe* inverse *kwimass.* Translated: And it's inverse to the mass.

(Unclear talking as learners write down the agreed statement of Newton's 2nd Law on their respective worksheets.

L3: (Apparently seeking clarity from group). *"Yima*, I inversely proportional to mass then *ibe njani*?" Translated: Wait. It's inversely proportional to mass then what else?"

L1: "Net force, uthi itheni ke" Translated: "Net force. What about it?"

L3: *"Anditi* net force is inversely proportional to the mass of the object. Uphinde uthini? Uthi it is directly proportional…" Translated: Isn't it net force is inversely proportional to the mass of the object. Then what do you say? You say, it is directly proportional…."

L1 "*Yima, yimass uthi ithini?"* Translated: "Wait. Its mass. What about mass?"

L3: "Yima. Ndifuna ukwezela umzekelo." Translated: "Wait, let me give you an example." (She takes a sheet of paper and writes F =ma). "Iqala ibe directly proportional?"

L1: "*Yintoni* edirectlly proportional" Translated: "Directly proportional?"

L3: "*Yi* net force." Translated: "It's net force"

L1: "It's directly to what?"

L3: "To the mass of the object. *Handiti?*" **Translated:** "Is it not so?"

Tr: You are saying the net force is inversely proportional to what?

L3: To the mass of an object

Tr: Right, then…

L3: And directly proportional to what. *Ndifunukwazi*. It's directly proportional to what. **Translated**: I would like to know…

Tr: (Speaking to the group). OK. Did you hear the question? She is saying according to Newton's 2^{nd} law of the net force is inversely proportional to mass and directly proportional to what?

L1: Oh, it's net force is directly proportional to what?

L3: Umm

L4: To acceleration

Tr: To acceleration, *handiti*. **Translated:** Right.

(Discussion continues, other learners and teacher clarify the relation between acceleration, mass and net force in the relationship, F=ma).

L1: (Reading the question.) "Name the forces that are responsible for the change in velocity. Explain your answer.

Tr: "Now, can you look at the wording properly, *neh*. Forces that are responsible for the (putting emphasis) change in velocity. Which one is being referred to as the change in velocity? That change (given) at the top. I go back to my question. Is that change an increase or a decrease in velocity?

Several Learners: (Chorus answer) – "An increase"

Tr: "It's an increase *handiti*, right. What does, what does, umm, friction do to velocity?

L2: "It opposes."

Tr: "So if it opposes, does it increase velocity? Does is help to increase velocity?"

L3: "No, *iyayi reducer*" **Translated**: "No, it reduces it"

Tr: "What does it do?"

L3: "Ingxaki, handiti I frictional force iba ku opposite (gesturing to the left) direction yale uyi aplayayo. That's why izakuincreaser." **Translated**. "The problem, right, is that frictional force will be in the opposite direction to the applied one."

Tr: So, are you saying frictional force increases velocity?"

L3: "Decreases"

Tr: "It decreases velocity"

L3: (Nodding her head) "Yes"

Tr: "L4, you do not seem to agree."

L4: (Shaking his head). "*Hayi, Hayi Sir. Andivumi ncam, andivumi ncam Sir*". **Translated:** "No, no Sir, I do not quite agree, I do not quite agree Sir."

Tr: "*He, awvumi ncam neh. Tetha sive*, tell us, what are you saying?" **Translated**: "Oh, you do not quite agree, say it out…."

L4: "Ifriction, Meener, iyaincreaser, inancika, ivelocity." **Translated:** "Friction, Sir, increases, velocity."

Tr: "Iyaincreaser ivelocity? Now, let's go back to Newton's 2nd law of motion, neh. You said a net force will increase acceleration in the direction of the force. Does friction work in the direction of displacement?

L4: "No, it opposes"

Tr: "It opposes, neh."

Several Learners: "Yes"

Tr: "So, friction will not increase velocity because it is opposing motion. You see that."

L3: *"Nditshilo mna"* **Translated:** "I said so."

Tr: "So, of the forces that are acting which one is…"

L4 & L5: "Force applied."

Tr: "Force applied neh. Thank you. Its force applied. Yeah." You say force applied, then you explain it. How would you explain it?"

L4: "It depends with the forces, Sir."

Tr: "It all has to do with the direction. So we are saying that the forces that are in the direction of acceleration are the forces that are responsible for acceleration."

L3: "Niyivile?" **Translated:** "Did you get that?"

L5: "*Kubuzwa I effect ezokwenzala xa kuincrese I velocity.* So which means *ivelocity or imovement or ikinetic* energy *yayo izotshintsha*. **Translated**: "It is asking about the effect of increasing velocity. So which means the velocity, or movement or its kinetic energy will change."

Tr: "If you say, *izotshintsha*, that is to change hey. A change can be an increase of a decrease. Which change?"

L5: "Increase"

Tr: "It will increase?"

L5: "Yes."

Tr: "So we can put that down."

Appendix J: Interview Schedule for diagnostic test

Interviewee(s)	Test Item Reference	Questions
Jennifer Zizipho	1	Classify the following as either vector or scalar: Temperature; pressure; speed; displacement; time
Siphosethu		
Mfanukona Mvuzo Sandisile Themba	2.1, 2,2	Explain this statement " Energy is power"
Lilo Gcobisa	2.1	Explain this statement 'Force is power
Ongezwa	2.3 ; 2.6	Is displacement a type of force? Is velocity the same as volume? Is there a relationship between these terms? Explain.
Simthandile Siphosethu Bongeka	2.6	Explain the concept of acceleration
Lilo Sive Nqayi	3.1	Explain the trigonometric ratios of Sine. Cosine, Tangent using a right angled triangle
Yolanda Nolufefe Zanozuko Ongezwa	3.2.1	Why did you use 'm.g'? What does 'm.g' represent?

Appendix K: Interview schedule for summative test

Interviewees	Test Item	Questions
Pikini	**2.2 – 2.3**	Please explain your answer in more detail or in IsiXhosa?
Sive Nqayi	**2.2-2.3**	Elaborate on your statement that says "normal force is just there to be shown on a diagram"
Tania, Nolufefe, Nkosinathi, Mvuzo, Gcobisa, Zanozuko, Sive Nqayi	**2.4**	What is the difference between 'Work done' and 'Net work' done as applied to this question.
Chumani, Yanga, Ongezwa	**2.4**	What is the direction of frictional force relative to displacement? How do you show it when doing calculations?
Bongeka, Siphenathi X, Athenkosi, Ayanda	**2.4**	How did you get the angles for the forces you used in your calculations?

Appendix L: Transcription Tr3 – Interview D1

Interviewer (Int): Given, my question is a very short one…

Given (Gvn): Yes sir

Int: …based on the diagnostic test that is in front of you. Now, in question 2.2 you were supposed to define or explain what is energy and give an example. Now, you wrote that "energy it's a power done by a person". Now, can you explain why you are saying energy is power.

Gvn: Because energy, energy is a, it's something that you do with power.

Int; Something that you do with power?

Gvn: Yes Sir

Int: But scientifically energy and power are two different concepts. OK, maybe let's go to vernacular, to Xhosa, neh

Gvn: Yes Sir

Int: What is energy in Xhosa?

Gvn: Energy, *amandla* Sir

Int: And what is power?

Gvn: Power, (he hesitates) *amandla nawo*

Int: *Amandla nawo?*

Gvn: Yes Sir

Int: So don't you think that makes people believe that energy and power are the same thing?

Gvn: Yes Sir, it's the same thing but it's different

Int: It's different in what sense?

Gvn: Energy is what you are doing to use power

Int: Energy is what you are doing to use power

Gvn: Yes Sir

Int: That's your understanding of it?

Gvn: Yes Sir

Int: So, I want to get clarity. In Xhosa you are saying energy is *amandla*, and power?

Gvn: And power it's the same, *amandla*

(Interviewer explains to Given the difference between energy and power)

Appendix M: Transcription Tr3- Interview with Zimbini

Int: The question I am going to ask you is based on the diagnostic test. I'm going to ask you about what you wrote in question 2. In question 2 you were supposed to define several terms, right. Ah, in 2.1, you wrote that "*force is power. Force is the power that you use to moving something*". Why did you say that force is power because force and power are two different things?

Zim: (looks at interviewer and kept silent)

Int: Maybe we can put it in Xhosa

Zim: Yes, Sir. *Kalok tishala neh., iforce, xa sithetha ngeforce,* when you push something..

Int: Ehe…

Zim: …*uyipusha…Andiyazi tishala ukba ndiwathi, ndizawyibeka njani iforce nge* English but *xa upusha iobject uyipusher ngala* force. *So ndiye ndayithatha as ukba iforce* yipower. Ndiye ndohluleka uku differentiata iforce ne power.

Int: Maybe *masithi iXhosa iforce yinton*? What is the name of a force?

Zim: *Yhoo tishala* force (Long pause) *ngesiXhosa tishala. Hayi andiyazi iforce ngesiXhosa*.

Int: Then ipower?

Zim: *Ipower tishala ngamandla*

Int: Ngamandla?

Zim: Yes

Int: How about *iforce*

Zim: *Yhoo hayi tishala*

Int: OK, ok. That's fine.

(Interviewer explains to Zimbini the difference between energy and power)