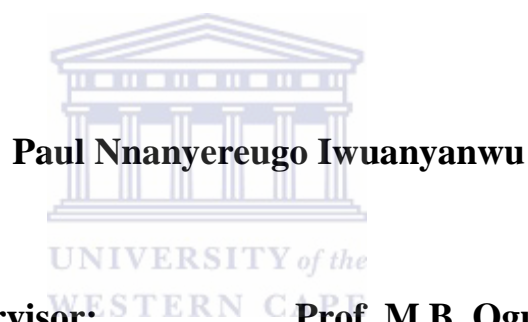


**Full Thesis submitted in fulfilment of the requirement for
Masters in Science Education**

**Pre-service science teachers' conceptual and procedural difficulties
in solving mathematical problems in physical science.**



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DECLARATION

I declare that **“Pre-service science teachers’ conceptual and procedural difficulties in solving mathematical problems in physical science”** is my own work; that it has not been submitted before for any examinations or degree purposes in any other university, and that all sources I have used or quoted have been indicated and acknowledged by complete references.

Paul N. Iwuanyanwu

Signed: Date: **May, 2014**



ACKNOWLEDGEMENTS

And the LORD proceeded to answer me and to say: "Write down the vision, and set it out plainly upon tables, in order that the one reading from it may do so fluently." (Habakkuk 2:2)

There can be no progress or achievement without sacrifice, and a man's world success will be by the measure that he sacrifices to purify and lift up his thoughts, and fixes his mind on the development of his plans, and strengthening of his resolution and self-reliance. The higher he lifts his thoughts, the greater will be his success, the more blessed and enduring will be his achievements. He can only remain weak, abject, and miserable by refusing to lift up his thoughts. (James Allen)

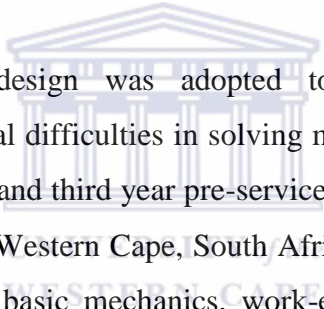
My never-ending gratitude goes to His Highness God Almighty. I wish to express my deep appreciation to the following people who helped me to purify and lift up my thoughts in the best way ever. I am terribly grateful to you all for your evergreen inspiration and encouragement which constantly lightened my task. May God almighty reward you for your valuable guidance and assistance throughout this study. I have unbounded appreciation for two great icons: Prof. M.B. Ogunniyi and Dr. R. Govender, whom it is impossible adequately to thank; the electric Prof. M. Ogunniyi who handled an earlier version of my research proposal and breathed in me his profound and prolific spirit of academic writing. As a man sits down after investing to see his investment growing, I have joined your never-ending investments on mankind. Thanking you for making a mark in my life.

I like to think that throughout the period of writing this thesis I remained my usual relaxed, easy-going, smiling and companionable self. Whatever the truth, the fact that I should even think so is entirely due to the following doctors: (Dr. R. Govender) my co-supervisor, Dr. O. Koopman (my friend and brother in Christ), Dr. Funmi Amosun and Dr. B. Thuynsma. Rest in peace my friend and colleague (Late Dr. Simasiku Siseho), your voice was a gift. Death is not a defeat, but a victory.

My appreciation also goes to Ms. De Mink for her kind reception. And to all of you whom God has used as instruments to uplift and support me in one way or the other, I say thank you to you, Mr. B. Busika, Mr. Michael & Mrs Lottie King, Mrs. Nyamende, Mr. J. Koeberg, Mr. F. Malie, and others in this endless list. A warm thankfulness to my beloved parents Dr. & Mrs F. Iwuanyanwu, thank you a million times for all the parental guardians, unconditional love, imputed moral values that work and your everyday advice – son, "A man would do nothing if he waited when to do it that no one would find fault from what he has done." This is my build up.

ABSTRACT

Students frequently leave first-year physical science classes with a dual set of physical laws in mind- the equations to be applied to qualitative problems and the entrenched set of concepts, many erroneous, to be applied to qualitative, descriptive, or explanatory problems. It is in this sense that the emphasis of this study is on ‘change’ rather than acquisition. Thus, a blend of theoretical framework was considered according to the aim of the study. Of immediate relevance in this regard within the “constructivist paradigm” are: Posner, Strike, Hewson and Gertzog’s (1982) conceptual change theory and the revised Bloom’s Taxonomy. Moreover, the very shift or restructuring of existing knowledge, concepts or schemata is what distinguishes conceptual change from other types of learning, and provides students with a more fruitful conceptual framework to solve problems, explain phenomena, and function in the world (Biemans & Simons, 1999; Davis, 2011).



A quasi-experimental design was adopted to explore pre-service teachers’ conceptual and procedural difficulties in solving mathematical problems in physical science. Sixteen second and third year pre-service teachers in one of the historically black universities in the Western Cape, South Africa, participated in the study. Two inseparable concepts of basic mechanics, work-energy concepts were taught and used for data collection. Data were collected using questionnaires, Physical Science Achievement Test (PSAT), Multiple Reflective Questions (MRQ) and an interview. An explicit problem solving strategy (IDEAL strategy versus maths-in-science instructional model) was taught in the intervention sessions for duration of three weeks to the experimental group (E-group). IDEAL strategy placed emphasis on drill and practice heuristics that helped the pre-service teachers’ (E-group) understanding of problem-solving. Reinforcing heuristics of this IDEAL strategy include breaking a complex problem into sub-problems. Defining and representing problem (e.g. devising a plan-using Free-Body-Diagram) was part of the exploring possible strategies of the IDEAL. More details on IDEAL strategy are discussed in Chapter 3. The same work-energy concepts were taught to the control group (C-group) using lecture-demonstration method. A technique (i.e. revised taxonomy table for knowledge and cognitive process dimension) was used to categorize and

analyse the level of difficulties for each item tested (e.g. D_1 = minor difficulty, D_2 = major difficulty, and D_3 = atypical difficulty).

Data collected were analysed using a mixed (quantitative and qualitative) methods approach. The findings reveal that many the pre-service teachers involved in the study have much difficulty in using physics and mathematical principles side by side to solve problems. In the process of justifying conceptual and procedural steps of problems solved and written explanations provided by the pre-service teachers, the common difficulties noted are similar to earlier findings in the area (e.g. Heller *et al.*, 1992; Kim & Pak, 2002; Larkin *et al.*, 1987; Lawson *et al.*, 1987; Junkins, 2007; McDermott, 1993; Redish, 1999; Reif & Allen, 1992; Selvaratnam, 2011).

The studies cited above that many students (including pre-service teachers) still retain conceptual and procedural difficulties in solving mathematical problems in physics mechanics (work-energy) even after instructional materials have been simplified. Also, by using a taxonomy table, it was observed that a problem solver (pre-service teacher) may have the required conceptual knowledge needed to solve a given problem (i.e. have an idea of “what” to do), but might lack procedural knowledge (i.e. have little or no idea of “how” to implement such idea) or vice versa. Also, no significant difference was found between male and female pre-service teachers with respect to conceptual and procedural difficulties encountered while solving maths-in-science problems. In other words, many pre-service teachers tend to hold invalid work-energy conceptions as a result of the commonsensical way in which these concepts are used in their everyday life.

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ABBREVIATIONS USED IN THE STUDY

| | |
|-------|---|
| BRT | Bloom's Revised Taxonomy |
| CAPD | Conceptual and Procedural Difficulties |
| CAPS | Curriculum and Assessment Policy Statement |
| CAT | Contiguity Argumentation Theory |
| DoE | Department of Education |
| FET | Further Education and Training (Grade 10 -12) |
| GET | General Education and Training (Grade R – 3) |
| IDEAL | (see meaning on pp.54) |
| ISP | Intermediate and Senior Phase (Grade 4-9) |
| MQR | Multiple Reflective Questions |
| NCS | National Curriculum Statement |
| RNCS | Revised National Curriculum Statement |
| WCED | Western Cape Education Department |

WESTERN CAPE

KEY TERMS

Conceptual and procedural difficulties/obstacles

Alternative conceptions/misconceptions

Conceptual and procedural knowledge

Math-in-science instructional model

Conceptual change approach

Constructivism

Cognitive conflict

Physical sciences

Work-energy problem

IDEAL problem-solving strategy



CHAPTER ONE

. . . the nature of science assumes that the physical world is governed by natural laws which operate inexorably and without change, and the universe is a vast mechanism governed by laws which are essentially mathematics in nature (Pratte, 1971, p.92). Mathematics unifies the conceptual structure of physical science and contextualizes its paradigm. This means mathematics forms the epistemological base of science (Junkins, 2007; Redish, 2005).

1.0 Introduction

This study is construed in the context of pre-service teacher education. It is an inquiry that seeks to find an effective way to overcome the conceptual and procedural difficulties that students (pre-service teachers) tend to encounter in solving mathematical problems in physical science. More specifically, the study pivoted on conceptual and procedural discrepancies second and third year pre-service teachers demonstrate in their conceptions while solving math-in- science problems. As a way to ameliorating the problem at hand, and in response to demands of the emerging multicultural society in South Africa, this study has adopted a number of relevant cognitive theories such as: the conceptual change theory (e.g. Posner, Strike, Hewson and Gertzog, 1982; Strike & Posner, 1985, 1992); border crossing (Aikenhead, 1996); collateral learning theory; and the contiguity argumentation theory (CAT) (Ogunniyi, 1996). The study focuses specifically on the extent to which pre-service science teachers' conceptual and procedural difficulties impedes their abilities to solve mathematical problems in physical science.

1.1 Background

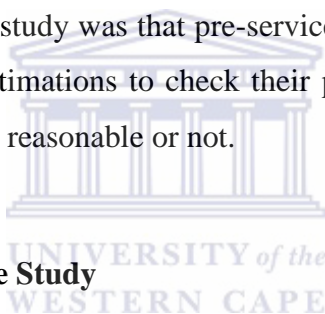
A need for this study arose from my experience in teaching physical science to pre-service teachers in a university in the Western Cape. Drawing from my classroom experiences in teaching the subject I became aware that some students lacked adequate mathematical knowledge to solve physical science problems. For example, some students display:

- poor transfer of conceptual & procedural knowledge when solving physical science problems,

- pedagogic incompetency,
- inabilities to proceed with basic mathematical operations needed in physical science even when concepts are oversimplified (e.g. Mechanics)
- lack of language proficiency
- inability to apply content knowledge at the level taught
- reluctance to provide heuristics as problem solving strategies
- inabilities to make necessary connections between math-in-science concepts

By connections, I mean the pre-service science teachers' abilities to recognize when particular mathematics procedures are applicable to physical science calculations so that they can select from their "mathematics toolboxes" the correct methods needed to solve given problems.

Apart from the learning difficulties faced by the pre-service teachers, one other factor that triggered this study was that pre-service science teachers often have little experience in making estimations to check their physical science calculations and determine if an answer is reasonable or not.



1.2 Motivation for the Study

Copious factors motivated this particular study. Nonetheless, the most important are discussed in the sub-sections that follow:

1.2.1 Institutional Implication

The Education and Social Sciences Faculty of the University in which the study took place has seen a steady decline in pass rates in physical science courses. The average pass rate in the subject for the past three years is less than 50%. This is because more students from disadvantaged communities now constitute the majority in the Faculty of Science. To address this problem, the faculty had to come up with innovative strategies to ameliorate the poor student performance in the subject. Some of these strategies include the introduction of tutorials, direct activity related teaching and curriculum development with the aim to address the current change in student profile. This study therefore, arose in response to an existing challenge facing the institution. It could be considered as an attempt directed at providing

useful information for the institutional decision-making process. In other words, the results from the study could feed directly into institutional teaching and curriculum development processes.

1.2.2 Institutional Remediation

The objective of the Education and Social Sciences faculty in which I teach therefore, has been to provide quality teachers who would make a difference at the secondary and primary school level, with whatever human and material resources that may be available. To achieve this objective, the faculty prepares pre-service teachers for the worst possible scenarios at the school level through its cognate and professional academic courses. In this regard, student teachers are exposed to a holistic mentoring programme which involves a good grounding in the academic courses, micro-teaching, improvisation techniques before the actual teaching practice and constant support, monitoring and feedback protocols during the teaching practice. While at the same time ensuring that the pre-service teachers acquire critical pedagogical content knowledge that would enable them to teach effectively. For the objective of the present study, it is, however, vitally important that science teachers have a clear understanding of the scientific concepts that they are likely to teach after their training at the institution. Their success or failure in doing so will directly or indirectly proliferated in the quality of their teaching and the type of students they produce.

Therefore, it is important that teacher education institutions ensure that graduating teachers are competent in physical science concepts and that the didactics component conveys such concepts as well as possess positive attitudes to achieve desirable goals enunciated in the new curriculum. With this in mind, the South African National Curriculum Statement (NCS 2005) for grade 10 - 12 physical science portrays a teaching pedagogy that promotes development of critical thinking and scientific reasoning and strategic abilities among students. The successful implementation of this curriculum requires teachers who are competent in the intellectual skills and strategies needed for learning science effectively. Also, this mandate is clearly spelt out in the subsequent curriculum policy documents such as Revised National Curriculum Statement (RNCS) and the Curriculum Assessment

Policy Statement (CAPS). Similarly, the further education and training (FET) band for physical science specialization offered by the Faculty of Education where the study was conducted aims at preparing high school grade 10-12 physical science teachers. It can be assumed that before the goal can be achieved there should be some congruence between what the pre-service teachers learn during the lectures and what they will later on be expected to teach at high school level.

1.3 Pre-Service Science Teachers course Background

During the second and third year physical science courses, mechanics as part of physics module with sub-section of work and energy is covered. The sub-section of the mechanics, work and energy is frequently taught by second and third year pre-service physical science teachers to grade 10 – 12 during their teaching practices at secondary schools and is examinable in grade 12 national examinations (known as *matric*).

1.4 Problem statement

There is enough research evidence to show that poor performance at Matric (National Senior Certificate Examination) or other levels is not an accidental event. It is in one way or the other a reflection of poor foundation laid most probably at the primary school level considering that most primary school teachers are not primarily trained to teach science. For example, Selvaratnam (2011) tested 73 matric physical science teachers in about 50 *Dinaledi* schools (that is, Mathematics and Science focus schools) in the North West and KwaZulu-Natal provinces in South Africa on five intellectual strategies: clear representation of problems, identifying and focusing on the goal, identification and use of relevant principles, use of equations for deductions and, proceeding step-by-step with the solution. The findings showed that the teachers' competence was poor in all the five intellectual strategies tested. About 60% of the teachers tested were unable to solve the science problems given to them correctly. The concern that one problem will always lead to another is a reciprocal to the kind of future generations of science students teachers with conceptual and procedural difficulties will produce.

Jones (1995) and Simon (1993) have also expressed concern about the number of pre-service teachers having weak conceptual backgrounds in the subject they are likely to teach. A study by Taplin (1995) identified several topics in which pre-service mathematics teachers performed poorly. These included applying measurement formulae, the relationships between different mathematical operations and the application of geometric principles. The study further suggested that one area mostly in need of remediation is the transfer of procedural knowledge (see-Figure 2.1) to unfamiliar situations. This was evidenced by inadequate problem-solving skills. It is against this background that the present study will be construed. Therefore, the underlying assumption is that the study would contribute to efforts directed at equipping pre-service science teachers in the department with the essential knowledge, skills and values needed for their future teaching career.

1.4.1 *Setbacks for Physical Sciences in South African Basic Education (post 1994)*

In South Africa, since 2008, a National Senior Certificate Examination (*matric*) is written by all grade 12 students which provide students entry into a college or university. Physical science is one of the subjects in which learners are assessed. Physical sciences are divided into two sections namely Physics (Paper 1) and Chemistry (Paper 2). The results from this examination become part of the criteria used for admission into the universities. Since 2009 – 2011, the number of physical science candidates sitting for the matric exam has decreased from 220882 to 180585 (DoE, 2011). Various reasons for this declination have been pivoted around the issues of inadequate training of teachers and lack of content knowledge in the teaching and learning of physical sciences (DoE, 2011, p.117).

The 2011 report of National Senior Certificate Examination titled National Diagnostic Report on Learner Performance in Physical Science in South Africa revealed the overall students achievement rates in physical science from 2008 – 2011. It was reported that a serious lack of mathematical skills such as: (1) Interpretation and drawing of graphs, (2) solving equations and, (3) working with trigonometric ratios contributed to students' poor performances in basic mechanics

questions (e.g. work and energy). Hiebert and Lefevre (1986) explained that when students are unable to connect between conceptual and procedural knowledge appropriately, they may have some understanding of the mathematical concept but not solve the problem, or they may be able to perform some tasks but may not understand what they are doing. Herscovics (1989) described this as “cognitive obstacles.” Prediger (2006) explained that such challenges posed by such cognitive or epistemological obstacles demands the reconstruction of prior knowledge.

Other challenges reported in the diagnostic students’ performance revealed that students have little or no problem solving skills; many students grappled with problems and stopped midway in their answers that involve calculations. The report shifted the blame to inadequate teaching and learning as clear evident was demonstrated in ways that students presented muddled answers to straightforward questions (DoE, 2011, p. 116-126)

1.4.2 Work and Energy Alternative Conceptions

The diagnostic report discussed in (section 1.4) further revealed students’ average performance per question in physical science P1 (i.e. Physics). The mechanics section of paper 1 (physics) contributes at least 50 marks out of the overall 150 marks of paper 1 and comprises of Vertical projectile motion, Momentum and relative velocity, Work and energy, and Doppler Effect. The trend observed in all provinces of South Africa clearly shows that at least 60 percent of exam candidates answered questions on Doppler Effect correctly of which only 20% of the candidates attempted work and energy questions correctly (DoE, 2011, p.124-125). Common errors and misconceptions that led to poor performance on work and energy (e.g. work-energy theorem) as stated in the report include:

- (1) Misconception (e.g. defining *work-energy theorem as work done by the non-conservative force is equal to the change in gravitational potential energy plus the change in kinetic energy*)
- (2) Omission of essential key words in stating the theorem
- (3) Students’ inability to draw a free body diagram
- (4) Inaccurate representation of quantities on the diagram (wrong labelling) viz:

- (a) Drawing the fractional force in the wrong direction.
 - (b) Drawing a force diagram instead of a free body diagram.
 - (c) Representing forces with lines instead of arrows.
 - (d) Drawing forces with their starting points from different positions instead of from the same point.
- (5) Omitting the angle (θ) between the force (F) and displacement (Δx).
- (6) Not realizing that $\Delta K = 0$, because speed was constant.

One of the suggestions for improvement provided in the report to counter the above common errors and misconceptions suggested that teachers should extract from the standardized NCS examination formulae page usually provided in Physical sciences paper 1 (Physics) and paper 2 (Chemistry) and build up a list of subscripts and symbols for different physical quantities and use them in their teaching. For example, if it is decided to use F_g as gravitational force, the teacher should keep using this label in all free body diagrams. This will prevent students from getting confused and not knowing which labels to use.

This study, therefore, focuses on pre-service physical science teachers and situated in a university science education context with emphasis on pre-service teachers' conceptual and procedural difficulties in solving mathematical problems in physics mechanics (e.g. work and energy). The pre-service physical science teachers besides learning the physical science subject are interested in metacognitive aspects such as, how physical science is learned, what students have difficulties with, and how the teacher's knowledge can be implemented in a classroom situation (Arons, 1997; McBride *et al.*, 2010; McDermott *et al.*, 1991).

1.5 Aim of the study

The aim of this study is to investigate pre-service teachers' conceptual and procedural difficulties that impede their abilities to solve mathematical problems in physical science. In pursuance of this aim answers will be sought to the following questions:

1.6 Research questions

1. What conceptual difficulties do pre-service physical science teachers exhibit while solving mathematical problems in physical science?
2. What conceptual and procedural discrepancies in their conceptions of math-in-science are evident in their solving physical science problems?
3. What strategic connections do they make between relevant mathematical and physical science concepts while solving physical science problems?

In view of the above questions the following null hypotheses are posited for testing:

1. The pre-service teachers do not hold inadequate mathematics concepts that prevent them from solving mathematical problems in physical science.
2. The pre-service teachers are not deficient in procedural and conceptual knowledge needed to solve math-in-science problems
3. The pre-service teachers are not able to make any strategic connection between relevant mathematical and physical science concepts while solving physical science problems.

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1.7 Theoretical Framework

A theoretical framework provides the necessary platform or context in which to situate a study. Without some form of theoretical framework the researcher does not know what to do. Even in the so-called grounded theory does not emerge in a vacuum. It arises out of a prepared mind that is fully furnished with considerable knowledge in an area of study (Ogunniyi, 2008, 2011).

A plethora of research findings in science education has shown that many students retain fundamental conceptual difficulties in solving science problems (e.g. mechanics) even after instruction (e.g. Bell & Janvier, 1981; Heller *et al.*, 1991; Jewett, 2008; Jones, 1995; Junkins 2007; Kim and Pak 2002; McBride and Silverman 1991; McDermott, 1993; Simon, 1993; Taplin, 1995). Viewed from this perspective, the following question arises: what are the conceptual difficulties that pre-service teachers face in solving mathematical problems in physical science? In

order to construct the theoretical foundation for examining this question, the conceptual change approach forms the basis of this study is enriched with the notion of epistemological obstacles (Brousseau, 1976; Sierpiska, 1994). Brousseau (1976) asserted that processes of knowledge acquisition and concept construction are not linear due to various obstacles. He has explained the connections between the learning process and the mathematical structure of the learning content.

In opposition to “didactical obstacles” being evoked by the way of teaching, he has created the notion “epistemological obstacles” for those obstacles that are rooted in the structure of mathematical content itself, in its history and the development of its field of application. By “epistemological obstacles” he (Brousseau) meant those obstacles of purely epistemological origin which one cannot and should not escape from because of their constitutive role for the knowledge to be constructed (p.178, translation by Pridiger, 2004b).

In addition the study draws from the critical contextual constructivist theory, which attempts to explain the undercurrents behind pre-service teachers’ conceptual difficulties to solve mathematical problems in physical science. Of immediate relevance in this regard within the “constructivist epistemology,” are: Posner and associates (e.g. Posner, Strike, Hewson and Gertzog (1982), conceptual change theory and revision of Bloom’s Taxonomy. Posner *et al.* (1982) believe that when a student adapts or replaces one idea with another, they are said to undergo conceptual change.

Thus, Posner and associates proposed that the following four conditions are essential in order for conceptual change to occur i.e. for a person to revise their existing conceptions:

- Dissatisfaction with existing conceptions i.e. these must prove to be inadequate
- A new conception must be intelligible i.e. they should be able to grasp it
- A new conception must be initially plausible i.e. it must have some degree of fit and must not be counterintuitive
- A new conception must be fruitful i.e. it must have the potential to be extended and lead to new insights.

Hewson (1992) outlined at least three elements that are necessary for successful conceptual change teaching, which include: 1) availability of techniques to diagnose learners' alternative conceptions, 2) a design to lower the status of the alternative conception and to strengthen the accepted one and 3) learners' outcomes that are based on an explicit consideration of their prior knowledge. In line with the latter, research evidence in education has shown that knowledge exists in various forms. For example, Alexander *et al.* (1991) provided a summary of up to thirty different types of knowledge constructs that have previously been used in research and to this list more can be added.

Common categorizations of such knowledge are conceptual, procedural, and metacognitive knowledge (J.R. Anderson, 2004; de Jong & Ferguson-Hesseler, 1996; Jonassen, 2009; Krathwohl, 2002). Further, categorizations of such knowledge can be found in the original framework of Bloom's taxonomy namely: (1) factual knowledge, (2) conceptual knowledge, and (3) procedural knowledge. In addition to this, a fourth, and new category is metacognitive knowledge which provides a distinction that was not widely recognized at the time the original scheme was developed (Krathwohl, 2002, p.214). Pintrich *et al.*, (2000), have explained the metacognitive knowledge as knowledge that involves cognition in general as well as awareness of and knowledge about one's own cognition. See the overview structure of the knowledge dimension of the revised taxonomy in Table 1.1 below. In this study, this is how I will also refer to knowledge.

Table1.1 Structure of the Knowledge Dimension of the Revised Bloom's Taxonomy

| Knowledge Dimension | Definition |
|---|---|
| A. Factual Knowledge <i>Aa. Knowledge of terminology</i> <i>Ab. Knowledge of specific details and elements</i> | <i>Refers to the fundamental elements that students must know to be acquainted with a discipline or solve problem in it.</i> |
| B. Conceptual Knowledge <i>Ba. Knowledge of classification and categories.</i> <i>Bb. Knowledge of principles and Generalizations</i> <i>Bc. Knowledge of theories, models, and structures</i> | <i>The interrelationships among the basic elements within a larger structure that enables them to function together</i> |
| C. Procedural Knowledge <i>Ca. Knowledge of subject-specific skills and algorithms.</i> <i>Cb. Knowledge of subject-specific techniques and methods.</i> <i>Cc. Knowledge of theories, models, and strategies</i> | <i>Refers to how to do something; methods of enquiry, and criteria for using skills, algorithms, techniques, and methods.</i> |
| D. Metacognitive Knowledge <i>Da. Strategies knowledge</i> <i>Db. Knowledge about cognitive tasks, including appropriate contextual and conditional knowledge</i> <i>Dc. Self-knowledge</i> | <i>Refers to as knowledge that involves cognition in general as well as awareness of and knowledge about one's own cognition.</i> |

(Krathwohl, 2002 – tabularized for the study)

Furthermore, these knowledge components as depicted in Table 1.1 above can have different properties (Merril, 2000), levels (Grayson, Anderson & Crossley, 2001), distinctions in meaning (L.W. Anderson & Krathwohl, 2001), and how they are used by means of underlying idea of some pattern (Novak, 2010). To understand the meaning of physics concepts and how they are connected to form physics principles, a student need to possess conceptual knowledge as well as procedural knowledge in order to solve a physics problem. This includes strategies, methods, and tools for concept mapping (Slotta, Chi, & Joram, 1995; Hestenes, 1987 cited in Madelen, 2012). More details of this revision and its relevancy to this study are presented in the conceptual framework section in Chapter 2. Also, in Chapter 2, I shall discuss in more detail conceptual change which is largely derived from the science education literature as well as other studies relevant to the present study.

1.8 Significance of the study

The concern expressed in the background section is that pre-service science teachers lack investigatory or innovative problem-solving skills. This is a serious matter since it is important for teachers to be competent problem solvers if they are to be able to teach physical science effectively. Failure to address pre-service physical science teachers' deficiencies could have long-term consequences. To teach physical science effectively, it is necessary for pre-service teachers to be competent in a complex web of knowledge domains: knowledge of and about physical science and about pedagogy of physical science (Borko *et al.*, 1992; Cooney, 1994). It is hoped that by going beyond the normal boundary of conceptual theory as espoused by Posner *et al.* (1982) to the inclusion of other socio-constructivist theories more valuable insights arising from the study would prove useful and informative in programmes aimed at equipping pre-service physical science teachers particularly those who later on would teach grades 10-12.

1.9 Delimitation of the study

According to Ogunniyi (1992) the delimitation of a study is concerned with the scope or the boundary of the study. In the light of the aforementioned, this study focuses mainly on a pre-service teacher training programme offered at one of the universities in the Western Cape, South Africa. In order to set a clear boundary, this study looked specifically on second and third year pre-service science teachers' conceptual and procedural difficulties in solving mathematical problems in physical science. The university at the time of the study had only sixteen second and third years pre-service teachers registered for physical sciences. All the sixteen pre-service teachers took part in the study. As such, the findings are not meant to be generalized to the other universities in the province or South Africa as a whole.

1.10 Operational Definition of terms

- a. **Conceptual Change:** In a general sense, conceptual change enriched by constructivist perspectives on learning is characterized by the building of new ideas in the context of old ones through partial or major restructuring of already existing knowledge, concepts or schemata (Biemans & Simons, 1999; di Sessa, 2006; Duit, 1999).
- b. **Concept mapping** is either a teaching or a learning tool that aids in identifying main concepts and sub-concepts and shows the interrelationships of these knowledge structures. They are intended to represent meaningful relationships between concepts in the form of propositions. Propositions are two or more concept labels linked by words in a semantic unit (Novak & Gowin, 1984).
- c. **Misconceptions:** According to Ben-Ari (2001, p.258), a constructivist would see a misconception as logical construction based on a consistent, though non-standard theory, held by the student and not as a slip or (trivial) mistake.
- d. **Constructivism:** According to Taylor (1997) constructivism is a theory of epistemological inquiry that empowers teachers to draw from life the thread of being and weave it into their emerging pedagogies. It emphasizes learning and not teaching. This study recognizes the fact that pre-service science teachers come to class with prior knowledge. This knowledge has been gained from the previous schooling, home, peers and social environment also known as everyday science.
- e. **Conceptual difficulties:** Learning difficulties that students tend to encounter in solving mathematical problems in physical science. Put another way, individual learning experiences that in some way hinder the understanding of certain concepts (Herscovics, 1989).
- f. **Conceptual knowledge** is knowledge of facts, properties, and relations. It can be thought of as a connected web of knowledge, a network in which the linking relationships are prominent as the discrete pieces of information (Heibert & Lefevre, 1986, p.3).

- g. Procedural knowledge:** Knowledge exercised in the performance of some task. In the classroom, procedural knowledge is part of the prior knowledge of a student, in that it facilitates the application of conceptual knowledge required in solving a problem (Hiebert & Lefevre, 1986).
- h. Physical Science Achievement Test** is a test developed to measure the cognitive achievement of the pre-service science teachers in the experimental and the control groups.

1.11 Overview of the Study

Chapter 1 provides the background and purpose of the study. The focus of the study is to find an effective way to overcome the conceptual and procedural difficulties that second and third year pre-service teachers tend to encounter in solving mathematical problems in physical science. It also attempted to investigate what conceptual and procedural discrepancies second and third year pre-service teachers demonstrate in their conceptions while solving math-in-science problems.

Chapter 2 provides a more detailed review of relevant literature with respect to conceptual and procedural difficulties, conceptual change, misconceptions and related cognitive theories (including the Revised Bloom's Taxonomy) and the teaching of science in multicultural contexts. Chapter 3 presents the research design, the research processes, the methods used for data collection and analysis as well as the development of the instruments e.g. the Physical Science Achievement Test (PSAT) and the Multiple Reflective Questions (MRQ) and the interviews. Chapter 4 presents and discusses the findings in the study. Lastly, Chapter 5 presents the conclusion, implications and recommendations.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

In Chapter one, I provided the background and purpose of the study. This review examines plethora of studies that have been carried out on conceptual and procedural difficulties held by both teachers and students relative to various science concepts. The focus, however, has been largely on students than on teachers. In view of the key role that teachers play in the instructional process, a study of their conceptual and procedural difficulties in solving mathematical problems in physical science is likely to provide useful insights on learners' alternative conceptions as well as their conceptual ecology.

It is apposite to suggest that the notion of conceptual change theory and the role it plays in the instructional discourse (including the criticisms that have been leveled against it) is of critical importance to the study. In order to achieve this, a combination of the knowledge and cognitive process dimensions form a very useful aspect of the Revised Bloom's Taxonomy (Table 1.1). Using the taxonomy to classify objectives, activities, and assessments provides a clear, concise, visual representation of a particular course unit (Krathwohl, 2002, p.218).

This chapter begins with theoretical considerations while actual studies relevant to the present study are presented later. Of immediate relevance in this regard are the many studies that have focused on students' inability to conceptually link equations, diagrams, or graphs used in physical science with the actual situations they are supposed to represent (Bell & Janvier, 1981; Junkins 2007). Other scholars (e.g. Posner *et al.*, 1982; Hewson and Hewson, 1989, 1991) have sought to unravel the mystery of why conceptual change is so difficult. For example, the extent to which humans are able to learn new knowledge, meaningfully, is dependent on how well this new knowledge fits with what they already know. Some of the reasons suggested are: epistemological reasons; cognitive reasons; attitude and motivation and instruction.

Driver *et al.* (1994) reports that “children have ways of construing events and phenomena which are coherent and fit with their domains of experience...” (p. 2). Much has also been said about knowledge acquisition and concept construction discrepancies e.g. the International Mathematics and Science Survey (TIMSS), reports on the low achievement of South African students in the areas of mathematics and science, relative to other countries (Howie, 2001 & 2003). For example, of the 38 and 50 countries that participated in the Trends in Mathematics and Science Study (TIMSS) in 2001 and 2003, respectively, some of which are developing countries, South African learners came last in Mathematics and Science (e.g. see p. 1 – 20).

Selvaratnam, (2011) explained that there are multiple, complex problems that contribute to learners' poor performance such as teachers' poor content and pedagogical knowledge, infrastructure of schools and low teacher qualifications. To ameliorate this state of affairs, some scholars have suggested the need to upgrade the training of science and mathematics teachers throughout the country (Adler and Reed, 2002; Breen, 1999; Pendlebury, 1998; Taylor and Vinjevd, 1999). However, lots of challenges face teacher education in South Africa, particularly in the areas of mathematics and science with more emphasis on (Howie, 2001, 2003, p.1-20; and Reddy, 2004) whose studies revealed that South African learners are performing poorly in science.

Similarly Ogunniyi (1999) revealed students poor understanding of chemical change conceptions and suggested that a lot of remedial work is necessary to forestall or reduce the perpetuation of such learning deficits among learners. To achieve this, equipping pre-service teachers and in-service teachers with adequate content and pedagogical skills would be necessary. This study focuses on second and third year pre-service science teachers' conceptual and procedural difficulties in solving mathematical problems in physical science.

2.1 Teaching and learning Physical Sciences

Within the field of science education, concepts of *work* and *energy* are inseparable in a didactical context. They are critical concepts that are used in analyzing physical phenomena. They are global concepts that appear throughout the physics curriculum

in mechanics, thermodynamics, electromagnetism, and modern physics. While the concepts of work and energy are dominance in physics mechanics, energy is also at the heart of descriptions of processes in Chemistry, Life Sciences (Biology), Astronomy, and Geology. Unfortunately, the concepts of work and energy are filled with possibilities that swing students into various confusions when solving problems related to these concepts. In view of that, it is critically important to address conceptual difficulties that students encounter in their conceptions of work and energy science problems.

I begin by discussing the concept of *work*, a concept that is not easy to explain or define due to its alternative conceptions. It is conceivable to say that apart from A B C D (alphabetical letters) known to mankind; the nearest word commonly used by every mouth that can speak is the word *work*. It is one of the most frequently used global concepts on daily basis, before a child sees the four corners of a classroom; the child would have already used the word *work* (e.g. mom is at work, papa my toy is refusing to work, etc.). Therefore it may be right to say that one of the most useful concepts known to a child before entering a classroom is the concept of work. As the child (now a student) continue to use the concept of work taught to him by those around him at the early stage of his development he may find it difficult in the later stage to accept scientific concept of work which now contradicts his conception of work.

For example, a *mother left home for work in the morning and after work she returned home and felt exhausted due to excessive work she did at her work place. From science perspective, she had done no work.* In that regard, an alternative conception is evident, and this is where conceptual change framework can help to reboot a person's (student) conception by merging various cognitive approaches with a focus on viewing knowledge as being constructed such as with the Piagetian interplay of assimilation and accommodation. However, certain limitations of the constructivist ideas of the 1980s and early 1990s led to their merger with social constructivist and social cultural orientations that more recently resulted in recommendations to employ multi-perspective epistemological frameworks in order to adequately address the complex process of learning (Aikenhead, 1996; Duit & Treagust, 1998; Fakudze & Ogunniyi 2002; Ogunniyi, Jegede, Ogawa, Yandila & Oladele, 1995).

While other frameworks could be an aid to inculcate modification of alternative scientific conceptions, the question now is, does that solve the student's problem(s) surrounding the scientific conception of work? Perhaps, honest answer is no, even after the student alternative conception has been scientifically modified, the student may still retain conceptual difficulties in dealing with or solving science problems surrounding the concepts that have been scientifically modified, as such a framework that is more versatile to guide the student of how, when, what and why is one that every trained educator would possibly know, that is, the revised taxonomy of learning. This will be presented shortly.

2.1.2 Scientific definition of work and energy with possible confusion for Students

One of the most complicated problems in some textbooks and classroom solutions is to define what *work* really is without provoking confusion to its common use in everyday life. While a single definition may be insufficient in providing an explanation of *work* that befits all contexts, this study has adopted a definition of *work* extracted from the international edition physics textbook (Giancoli, 2005, p.137), which defines *work done on an object by a constant force to be the product of the magnitude of the displacement (d) times the component of the force parallel (F_{\parallel}) to the displacement*. In equation form, $W = F_{\parallel} d \cos \theta$, where F_{\parallel} is the component of the constant force \vec{F} parallel to the displacement \vec{d} of the object, θ is the angle between the directions of the force and displacement. This textbook was selected as it is one of the prescribed physics textbooks for the students that are involved in the study. Many physics textbooks may identify displacement of the object as Δd considering the fact that before the object is displaced it must have been at a certain position which can be regarded as d_0 (i.e. initial position of the object) and the object would have d_1 (i.e. final position of the object) after being displaced. As such ($\Delta d = d_1 - d_0$). Identifying the "displacement of the object" as Δd or as simply "displacement" in view of that of Giancoli is inadequate as what is being displaced is not identified. A study done by Jewett (2008) similar to the present study pointed out that such vagueness leads to conceptual difficulties later in the study of mechanics when student encounters friction forces or forces applied to deformable or rotating objects.

On the other hand, energy is one of the most important concepts in science. Traditional way of defining energy is “the ability to do work”. Again, like the definition of work, this energy definition is not very precise, nor valid for all types of energy. It is, however, valid for mechanical energy which is a part of the discussion in the present study. In this study, the crucial aspects of energy are translational kinetic energy ($K = \frac{1}{2}mv^2$) and potential energy ($U = mgh$), where m = mass of the object, g = acceleration due to gravity, height the object displaced, v = speed at which the object displaced (Giancoli, 2005, p. 143). The commonality of students’ misconceptions and conceptual difficulties has raised major concerns in the teaching and learning of work and energy quantities (e.g. Alant, 2004; Kim & Pak, 2002; Lawson *et al.*, 1987, p.811-817; McDermott, 1993; Redish, 2005; Reif and Allen, 1992).

Drawing on the work of Jewett (2008), his arguments suggested various ways of teaching work and energy; steps he regarded would eliminate or reduce the sources of confusion for students in physics mechanics. From his study, the following can be deduced:

- (1) complicated problems can be solved with only *one* definition of work and *one* energy equation, without the necessity for introducing other work-like properties or energy-like equations
- (2) it is entirely *possible* to teach mechanics without specifying a single definition of the displacement as in ($W = F_{\parallel} r \cos \theta$) [here Jewett used r to mean displacement (d)]
- (3) in solving problems relating Net work done (i.e. W_{net}) on a rigid, non-deformable and deformable systems, it is more fruitful to think about *systems* rather than about *objects*.
- (4) for non-deformable system, instead of adding the forces and then calculate the work, rather calculate the individual works and then add them together.
- (5) In a situation where a block slides on a surface, conceptual fruitful approach are: (a) drop the phrase “work done by friction,” (b) do not invoke work-energy theorem, and (c) identify the combination ($-f_k d$) with the change of mechanical energy E_{mech} of the system involving the block and the surface with which it is in contact.

- (6) Regardless of whether other forces besides friction act on the block-decrease in mechanic energy (M_E) corresponds to an increase in internal energy of the system (given that $+f_k d = \Delta E_{int}$)
- (7) While using this approach ($+f_k d = \Delta E_{int}$) results in the mathematical steps in energy problems involving friction as the approach involving ($W = -f_k d$), it removes the conceptual difficulties and inconsistencies for the student.

2.1.3 *Conceptual and procedural difficulties students' exhibit in solving basic mechanics*

Following Jewett arguments, his study investigated possible confusion for students in solving problems of work and energy. While all the listed arguments are of critical important to the present study, the seventh argument has been given more attention in this study. Drawing on the seventh argument, Jewett did not say *how* the seventh approach could remove conceptual difficulties and inconsistencies for the students. In so far as the seventh approach is concerned, there is no empirical evidence recorded in the study that construes or testifies his claim. It may be said that the mere statement is too little to convert into reality context. Also, in his first and third arguments, it is not clear who the problem solver is, he did not specify who (was he alluding to (a novice such as a student or an expert such as himself). If he alluded to students, he did not say *how* his approach can help them implement problem-solving strategies without encountering conceptual and mathematical difficulties that most students often encounter as reported in various studies (e.g. Bell & Janvier, 1981; Jewett, 2008; Junkins, 2007; Jones, 1995; Kim & Pak, 2002; McBride and Silverman 1991; Simon, 1993; Taplin, 1995). In addition, the study did not provide any concession for students who may still retain confusion after being exposed to his proposed approach of solving work and energy problems.

With more emphasis on the work of (Kim & Pak, 2002) titled “students do not overcome conceptual difficulties after solving 1000 traditional problems”. In their study, they investigated whether problem solving eliminates the conceptual difficulties first year students in the Physics Education Department of Seoul National University encounter in their conceptions of basic mechanics found by researchers elsewhere. They investigated the conceptual understanding of the students using qualitative questions about basic mechanics.

The findings suggested the following: (1) students did not have much difficulty in using physics formulae and mathematics, (2) students still retain many of the well-known conceptual difficulties with basic mechanics such as (a) lack of differentiation among force, acceleration and velocity, (b) misunderstanding of Newton's third law, and (c) a gap between the use of algebraic expressions and associated physics concepts; (3) there was little correlation between the number of problems solved and conceptual understanding held by students which suggested that traditional problem solving has a little effect on students' conceptual understanding.

As pointed out earlier, the present study is concerned with the second and third year pre-service teachers' conceptual and procedural difficulties in solving mathematical problems in physical science (e.g. basic mechanics - physics). While all the three major findings in the study of (Kim & Pak, 2002, p.761-763) are very important for the present study, this study draws most attention on the first and second findings. Starting with the second, it was found that students lack conception of differentiation among force, acceleration, and velocity as students were asked to draw arrows to show the direction and the magnitude of velocity and acceleration for a ball rolling up and down an inclined plane.

In terms of representation of knowledge some students were able to draw the arrows for the velocity but failed for the ones of acceleration. Those who managed to draw the acceleration correctly gave wrong explanation of the concept. For example, a student explained that 'acceleration was constant because the sum of the forces was zero.' In the same question another student explained that the direction of the acceleration was opposite to the direction of motion and the magnitude of the acceleration was the same as that of the velocity. Many studies conducted more than three decades ago equally shared the same views with the works of (Jewett, 2008; Madelen, 2012; Heller *et al.*, 1991; Junkins 2007; Jones, 1995; Kim & Pak, 2002; Simon, 1993; Taplin, 1995). For example, it has been reported that for many students, the concepts of velocity, acceleration, and force are vaguely related to something moving and not clearly distinguished (Clement, 1982; Gunstone, 1987; Trowbridge, 1981; Whitaker, 1983; Halloun, 1985; Trumper 1996).

Similarly, in a separate study conducted by McDermott (1993), titled “*how we teach and how students learn, a mismatch*,” though a different physics topic compare to the second finding in the work of Kim and Pak (2002), results emerged from tasks administered to more than 500 university students on electric circuits revealed students failure to differentiate between two related concepts: the resistance of an element and the equivalent resistance of a network containing that element. Lacking a conceptual model on which to base predictions, most students relied on intuition or formulas.

Still on the second finding in the work of (Kim & Pak, 2002, p.763), the (b) part revealed students misunderstanding of Newton’s third law. A problem statement was given to the students, which says a block was placed on a frictionless incline and a person pushed the block horizontally to keep it from moving. The students were asked two questions: (1) to draw a free body diagram of the block showing all the forces acting on the block, (2) explain which forces would change in magnitude if the person stopped pushing. It was found that among twelve students (44%) who had the correct free-body diagram, only two students recognized that the normal force would decrease as the force exerted by the person disappeared and fourteen (52%) wrote that the normal force did not change because it is $(mg\cos \theta)$ and the gravitational force and the angle of the incline did not change.

For the most part, the (c) part blended with the first finding revealed students’ gap between the physics concepts and the algebraic expressions. Student understanding of work-energy theorem was investigated. One of the items tested on the students was a straightforward application of the work-energy and impulse-momentum theorems. The problem statement says two carts initially at rest on a frictionless and horizontal table, the carts glided freely. The masses of the carts differ. A constant force F of the same magnitude exerted on each of them as each cart travels between the two marks on the table. Students were asked to compare the momentum and kinetic energy of the two carts after the carts passed the second mark. A common mistake made by six students was to assume that the two carts travelled between two marks in the same time. Only five students were able to start the problem from work-energy and impulse-momentum theorems, although all students learned the concepts in their high school years. Reif and Allen, (1992), asserted that students’ difficulties are not due to erratic performances or lack of available knowledge, but

due to their deficiencies in interpreting the knowledge they have. Similar results, regarding the work-energy and the impulse-momentum theorems, were reported by Lawson *et al.* (1987, p.811-817), that students reasoning was based solely on mathematical definition without understanding the way physical quantities are related.

In the study of McDermott (1993) as alluded earlier, 28 honours students of two classes: calculus-based physics section and a regular section of algebra-based physics were asked questions on impulse-momentum and work-energy theorem to see if they understand the relationship between impulse and momentum and the relationship between work and energy. Among the many errors was the failure of most students to recognize the cause-and-effect relationships inherent in the theorems. The following recommendations were reported: (1) Many students need explicit instruction on problem-solving procedures to develop the requisite skills, (2) postponing use of algebraic formalism until after a qualitative understanding has been developed has proved to be an effective approach (examination results indicate that students who learned in this way often do better than others on quantitative problems and much better on quantitative questions) , (3) persistent conceptual difficulties must be explicitly addressed by multiple challenges in different contexts as certain conceptual difficulties are not overcome by traditional instruction, (4) Deep-seated conceptual difficulties cannot be overcome through assertion by an instructor – active learning is essential for a significant conceptual change to occur (e.g. effective instructional strategy for obtaining the necessary intellectual commitment from students is to generate a conceptual conflict and require them to resolve it. p.4).

With this in mind, the second recommendation by McDermott, (1993) has been given the most attention in the present study as review of similar studies have placed more emphasis on the same issue. To understand what is being, McDermott argues that the use of algebraic formalism should be postponed until after a qualitative understanding of the concept in question has been developed (e.g. work and energy). This approach was considered to be mostly effective as examination results indicate that students who learned in this way often do better than others on quantitative problems and much better on quantitative questions. Other studies that shared

similar view in the same topics include (Jewett, 2008; Lawson *et al.* 1987, p.811-817; Kim & Pak, 2002; Reif and Allen, 1992).

Results so far show that in general there are no short cuts, but there do exist better or worse ways of learning physics concepts such as mechanics (Redish, 1999). However, plethora research evidence has shown that there can be alternative progress to reducing conceptual and mathematical difficulties in solving basic mechanics. An active engagement in learning, rather than passive reception, has long been promoted to stimulate the cognitive development according to constructivist views on learning as well as motivational aspects (Heuvelen, 1991; McDermott, 2001; Prince, 2004). To actively engage in the physics studies, e.g., discuss problem solving strategies in groups and then as individual usually promote a more coherent view of physics problem solving. Drawing on the works of (Heller *et al.*1992; Madelen, 2012; Onwu & Ogunniyi, 2006, p.131; Ogunniyi, 2009) are some of the examples that show that teaching problem-solving through cooperative grouping (i.e. group versus individual problem-solving approach) can facilitate conceptual understanding and possibly reduce students' conceptual difficulties.

For example, in Heller *et al.* (1992) study, they investigated the effects of cooperative group learning on the problem solving performance of college students in a large introductory physics course. They implemented an approach that combines the explicit teaching of a problem-solving strategy with supportive environment to help students implement that strategy. Supportive environment as referred in their study implies an environment where students practiced using strategy to solve problems in mixed-ability cooperative groups. It was observed that during this joint construction of a solution, individual group members can request explanations and justifications from one another, in well-functioning groups; students share their conceptual and procedural knowledge as they solve a problem together. Results from the study further suggested that better problem solutions emerged through collaboration than achieved by individuals working alone.

2.2 Conceptual Change Theory

One of the best known conceptual change models in education, based on students' epistemologies is that proposed by Posner and associates (e.g. Posner, Strike, Hewson and Gertzog (1982). The question of what conceptual change is, is deemed necessary to ask. The later authors initially used the idea of conceptual change in education as a way of thinking about the learning of disciplinary content such as physics and biology (Carey, 1985). Since then, its use has expanded in two ways. First, to understand what conceptual change is and how it is related to the current study, it is necessary, in my view, to consider its links to constructivism (as a view of how people learn, in particular how it might influence science teaching and learning). Second, its links to students' conceptions (that is, ideas different from those generally accepted and held by students of all ages in all countries, often regarded as alternative conception or misconceptions, Hewson, 1992). Hewson and Hewson (1983) employed conceptual change model in students regarding three concepts namely: density, mass and volume. Conceptual change model was applied to classroom instruction by Hennessey (1993). Various findings revealed that conceptual change model enhances better understanding of concepts, helps students negotiate the meaning of scientific concepts (Beeth & Hewson, 1999).

2.2.1 Conceptual Ecology

A person's conceptual ecology is what that person uses to determine whether certain conditions are met; whether a new conception is intelligible or makes sense, plausible or can be believed to be true and fruitful or useful (Hewson, 1992). If the new conception satisfies all three parameters, learning proceeds without difficulty. For example, a conception of *impulse* defined as the change in momentum of an object is enhanced with the inclusion of Law of Conservation of Linear Momentum and Newton's second law of motion respectively. However, if the new concept conflicts with existing concepts, then it cannot become plausible or fruitful until the learner becomes *dissatisfied* with the old concepts. Thus, learning requires that existing conceptions be restructured or even exchanged for the new concept. Such claim supported one of the findings in Prediger's (2006) study that says learning

often demands the reconstruction of prior knowledge when confronted with new experiences and challenges.

2.2.2 Deficiencies of Conceptual Change Theory

In the last decade, several authors (Chiu, Chou and Liu, 2002) have argued that “although Posner’s theory is widely accepted by science educators and easy to comprehend and apply to learning activities . . . it does not delineate what the nature of a scientific concept is, which causes difficulty in learning the concept” (p. 689). A major criticism of the original conceptual change theory is that it presents an overly rational approach to student learning- an approach that emphasizes and assumes logical and rational thinking (Pintrich, Marx, & Boyle, 1993). Pintrich *et al.* refer to this approach as "cold conceptual change," because it ignores the affective (e.g., motivation, values, interests) and social components of learning. In particular, the notion of conceptual ecology was criticized because it focuses solely on the learner's cognition and not on the learner as a whole. Furthermore, it does not consider other participants (i.e., the teacher and other students) in the learning environment and how these participants influence the learner's conceptual ecology, thus influencing conceptual change. Strike and Posner (1992) also recognized similar deficiencies in their original conceptual change theory and suggested that affective and social issues affect conceptual change.

Despite this pessimistic view, this study argues that social constructivist and cognitive apprenticeship perspectives have also influenced conceptual change theory (Hewson, Beeth, & Thorley, 1998). Thus, conceptual change is no longer viewed as being influenced solely by cognitive factors, but also encourages discussion among students and instructor as a means of promoting conceptual change. Nonetheless, affective, social, and contextual factors also contribute to conceptual change (Duit, 1999). As a way to dealing with the deficiencies of conceptual change theory, it may be of important to draw a glance to concept learning challenges that participants in this study may have encountered in one learning phase or the other as they made their ways (from primary and secondary education) to the university.

One of the studies apposite to the remark above is the one carried out by Ogunniyi (1999) that focused on determining what knowledge, attitudes or views about

science and technology were held by grades seven to nine students in the Western Cape. One of the instruments attempted to determine grade seven students' conceptions of chemical change of substances. One of the conclusions reached in that study was that the students had a poor understanding of the concept. The students who held a valid understanding of the concept did so at a relatively low cognitive level (Ogunniyi, 1999). He further advises that for the students to be able to cope with the challenges posed by the syllabus on this topic, a lot of remedial work would be necessary. One way to forestall or reduce the reoccurrence or perpetuation of these deficits among learners is to equip pre-service teachers and in-service teachers with adequate content and pedagogical skills.

2.3 Learning Theories

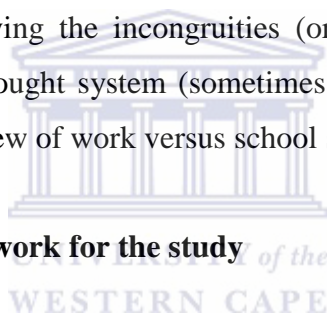
There is also a plethora of studies which have shown how students negotiate the movement from everyday science to classroom science (e.g. Aikenhead, 1996; Fakudze & Ogunniyi 2002; Ogunniyi, Jegede, Ogawa, Yandila & Oladele, 1995; Phelan, Davidson & Cao, 1991). Ogunniyi (1988) proposed the harmonious dualism hypothesis, in which he suggested that conflicting world views can co-exist without the learner necessarily experiencing cognitive conflict. This is possible because the learner construes such worldviews are considered as playing different roles depending on the context in vogue. This hypothesis was modified later and replaced with what he termed "Contiguity Learning Hypothesis" (Ogunniyi, 1996) which in turn was modified to the Contiguity Argumentation Theory-CAT (Ogunniyi, 1997, 2004, 2007a & b). For most students, especially in Africa, everyday experiences and the scientific worlds are different thus requiring adjustment and reorientation as they move between their home contexts into the school. CAT attempts to explain how "two or more coexisting or successive mental states dynamically not only recall, relate or collaborate, but also compete, supplant or dominate one another in the learning process depending on the context" (1996: 44).

View from CAT, **Dominant ideas** is those that are most favourable between rival ideas. These are dependent on the context or socio-cultural background of the learner who is exposed to the new idea. Dominance is usually dictated by overwhelming evidence in support of the new ideas or claims. In a different context

the same dominant ideas can be a **Suppressed idea**, for example, the commonsensical meaning of work and school scientific meaning of work in basic mechanics. **Assimilated ideas** are those ideas in the current cognitive structure which are influenced or modified by new ideas to create a more stable mental state. **Emergent ideas** are those ideas that are new and have no rival or opposing ideas (e.g. new concepts in school science) in the learner's existing cognitive structure.

Equipollent ideas are those competing ideas which exert comparably equal intellectual and emotional forces on the learners' cognitive structure (Ogunniyi, 2007a).

Further, CAT suggests that when two or more distinct world views come together in the mind, they either attract or repel each other depending on the context (Ogunniyi and Hewson, 2008). Interestingly, CAT explains a dialogical framework as depicted in Figure 3.5 for resolving the incongruities (or anomalies) that normally arises when two competing thought system (sometimes multiple) are placed side-by-side (e.g. commonsensical view of work versus school scientific view of work).



2.4 Conceptual framework for the study

A conceptual framework is what the researcher considers as the frame of reference for his study. It guides the overall direction of the study (Ogunniyi, 1992, 2008). Although a conceptual framework is inextricably linked to the theoretical framework, it may embrace a combination of theoretical frameworks or elements of such frameworks (Ogunniyi, 2008).

As pointed out earlier in Chapter 1 (section 1.4-problem statement of the study), Physical sciences in South African context is a combination of Physics and Chemistry. In this study, I will focus on the Physics aspects of the Physical science, with emphasis on work and energy problems, which can be solved by using identification of key-concepts in a given problem statement, interpretation of data (known and unknown quantities), mathematics, and concept mapping. If the problem is simple, identification of key-concepts in the problem statement & interpretation of data can be enough to find an answer. If the problem is complex, we might need

numerical methods to simulate the problem and provide a strategic concept mapping to find solution(s) to the problem.

2.4.1 Identification of Key-concepts in the problem statement

In various aspects of life, before a problem can be solved there need to be some sort of data collection. Before data is collected we need to know something about the context of the problem, there need to be identification of what to be collected. By key-concepts I mean those concepts that generate meaning to the problem statement and help problem solvers to unfold known and unknown quantities. Processes in identifying key-concepts in a problem statement may involve recognizing pattern, recalling, understanding, knowledge of terminology, knowledge of specific details and elements. In short, it involves factual and conceptual knowledge blended with the first two cognitive process dimensions. When a physics problem statement about basic mechanics is being read, a problem solver underlines key-concepts which sometimes include words like (stationary/rest, constant/steady/uniform, frictionless, known and unknown quantities, etc.).

For example, the type of key-concepts needed to be identified in a mechanics (e.g. work-energy) problem statement that asks students to calculate how much work is done if a person pulls a crate against a frictionless surface 7cm long with a force of 200N at an angle of 30° to the horizontal are (frictionless, displacement (Δx), force applied (F_A), horizontal force (F_x), angle (θ), work (W)). Failure to identify these key-concepts can lead to various obstacles invoking procedural knowledge, metacognitive knowledge that is necessary to apply, analyze, evaluate and create problem solution. If identification of key-concepts in the problem statement is a success, then the student needs to interpret identified key-concepts in terms of explicit and implicit known and unknown quantities.

2.4.2 Interpretation of data (known and unknown quantities)

Interpretation of data may require a student to clarify, paraphrase, represent, or translate identified key-concepts. It is evident when a student is able to convert information from one form of representation to another. Like in the case of the example I gave on calculating work done, the student may clarify what frictionless

surface means in the problem context as well as the force applied (F_A) and horizontal force (F_x) implicating the angle between the (F_A) and the horizontal surface. Representing identified key-concepts has a link with what Mayer (1992) called problem representation, in which a student builds mental representation of the problem and illustrate it on a free-body-diagram. Also, the student needs to translate or convert the displacement quantity (Δx) from centimeter (cm) to meter (m) which is the system international unit of displacement measurement. If the different forms of knowledge and cognitive processes required to identifying key-concepts and to interpret data in a physics complex problem are exhibited, then the use of an appropriate math-in-science instructional model can be galvanized to achieve the desired goal. An example of the specified steps of such model is illustrated in Figure 2.1.

2.4.3 A model for the use of mathematics in physics

The models in physics are mathematical models, which is to say that physical properties are represented by quantitative variables in the models (Hestenes, 1987). Many studies in science education have shown that most students need some mathematics experience prior to studying physics since mathematics is the language we use to understand and communicate physics as well as other sciences (Bing & Redish, 2009; Martinez-Torregrosa *et al.*, 2006; Redish, 2005). Several studies among tertiary physics students have been reported to have trouble, even after one semester of calculus, expressing physics relationships algebraically (Clement, Lochhead, & Monk, 1981). Sabella & Redish (2007) believe that because physics problems are typically quantitative, focusing on finding appropriate formulas and manipulating the equations to solve for a numerical value is indeed one aspect of being proficient in physics problem solving.

In 2009, Bing and Redish studied different ways of how students frame the use of mathematics in physics. They found that even though students had knowledge and skills of how to apply certain mathematics in order to solve a problem, they often got stuck in a frame that would not lead them to the correct answer. If, for example, students failed to solve a problem due to the wrong mathematical approach, they were unable to map the physics concepts to the appropriate math without assistance.

Knowing how to use mathematics in physics is therefore an important issue in order to be proficient in physics problem solving.

While Bing and Redish’s finding speaks about “how to use mathematics in physics,” McDermott, (1993) second recommendation was concerned about “when to use mathematics in physics.” Neither study complemented the *how* and *when* to use mathematics in solving physics problems, which the present study from an approach perspective has considered critically important in terms of connecting conceptual and procedural knowledge (see Table 1.1 – Knowledge dimension and Figure 2.1- the use of math-in-science instructional model).

A study done by (Hiebert & Lefevre, 1986) on mathematical concepts also showed that conceptual knowledge linked to procedural skills brought about a better understanding of concepts. Besides the use of conceptual change theory as reviewed in the literature, modelling mathematics through applicability of conceptual and procedural knowledge can also be used to address students’ conceptual difficulties (Redish, 2005). In addition, Baddeley (1976) and Aderson (1983) explained that when procedural and conceptual knowledge are connected to each other, retrieval is enhanced because the knowledge structure or network, of which the procedure is a part, comes equipped with numerous links (Figure 2.1).

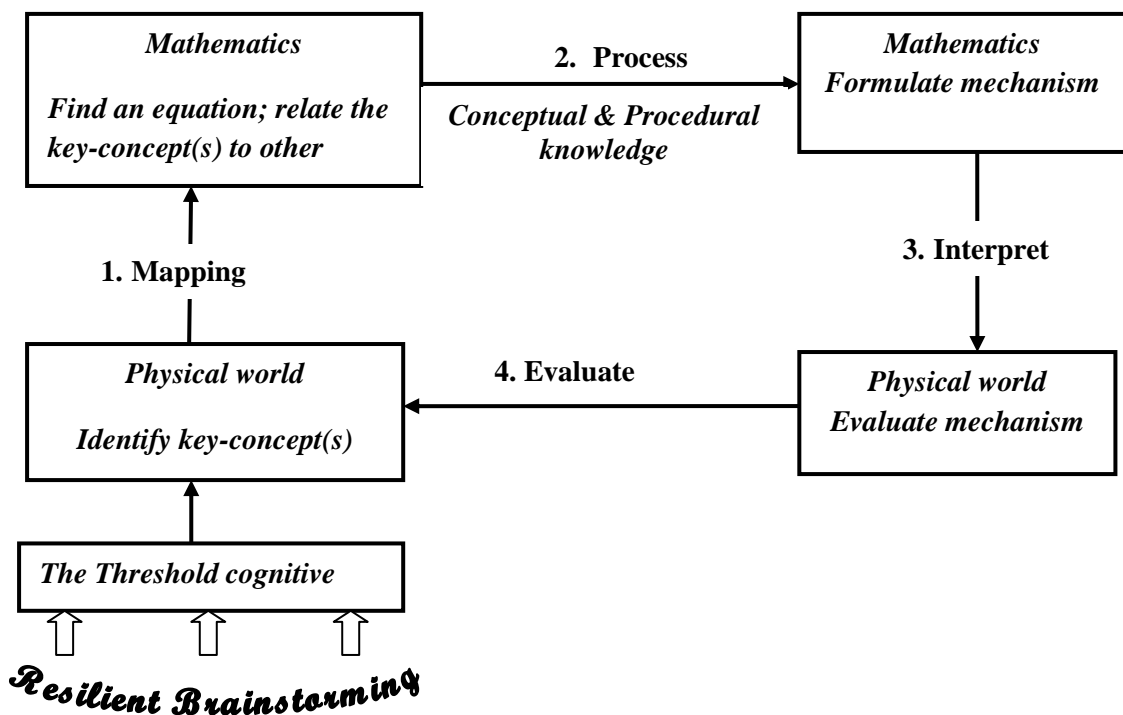


Figure 2.1. A modified mathematical model (after Redish, 2005, p.6).

Figure 2.1 illustrates resilient brainstorming phase as a point of departure where a component problem that needs to be dealt with is selected. In the course of brainstorming phase, a decision has to be made as to what characteristic of the system needs attention and what needs to be ignored. For example, at threshold phase a student may look at a complex physical component (problem) and decide what critical elements must be kept and what marginal effects can be ignored at first, to be corrected later.

Step 1: Map

Once the student has decided what needs to be considered in solving a physical science problem, the next procedural step is to map the strategy to solve that problem. In other words, he/she first of all identifies and maps the physics structures into mathematical ones. The student will then proceed to create a mathematical model by applying conceptual knowledge critical to the solution of the problem. Redish (2005) has stated that in order for the student to do so, he/she has to understand what mathematical structures are available and what aspects are relevant to the physical characteristics he is trying to model. Understanding what mathematical structures are available has a link with what Junkins (2007) had in mind when he stated that in science classes students must learn how to recognize what particular mathematics procedures are applicable so that they can select from their "mathematics toolboxes" the correct methods needed to solve new problems.

Step 2: Process

When the student has mastered the mathematical structures he/she can then apply the acquired knowledge and skills to simplify and transform the cognitive threshold to leverage his/her capacity in solving the physics problem in question.

Step 3: Interpret

The student still has to interpret and see what his/her results imply about the system in physical terms and then proceeds to step 4 which deals with evaluation. Apart from procedural and conceptual difficulties students encounter, they often lack the necessary experience in making estimations to check their physics calculations and determine if an answer is reasonable or not. To test the validity or otherwise of

his/her answer the student needs to evaluate the appropriateness of the concepts and procedures he/she has mobilized to solve the problem in vogue.

Step 4: Evaluate

At this level, the student will now have to evaluate results to see whether or not the model he/she has used adequately yields the valid result. Otherwise he/she has to modify his/her model.

As explained in step 1, the use of maths-in-science includes a concept map preceded by the second step titled “process”. In this study, the concept map involves mapping mathematical-science concepts and strategies to solve given problems. According to Ogunniyi (1986) concepts are the meaning attached to scientific facts. The learning of science for most students is a big challenge.

Studies have shown that more often than not students have a tendency to isolate elements of knowledge and do not possess a well-founded basic framework in which newly acquired concepts can be connected (Brandt, Elen, Hellemans, Heerman, Couwenberg, Volckaert & Morisse, 2001). This lack of connection can be due to the students’ difficulties concerning concept formation and application of acquired knowledge in exercises (Pendley, Bretz & Novak, 1994), curricular tendency to partitionise concepts, teachers’ inability to connect these concepts whilst teaching and misconceptions acquired from common sense experiences.

The ability of teachers and students to connect concepts is what Ausubel (1963) calls meaningful learning. A concept map is used as either a teaching and/or learning tool that aids in identifying the main concepts and the sub-concepts and to show the interrelationship of these knowledge structures. Concept mapping was initially defined by Novak & Gowin (1984) as a visual lens to promote new knowledge production and understanding. Concepts or ideas are organised in a logical, hierarchical pattern. It is created by an individual in the way he/she perceives reality by transforming the knowledge to be mapped from its current, linear form to a context-dependent hierarchical form. During this transformation of knowledge the student is presented with an opportunity for creativity and may serve:

1. to challenge his/her assumptions,

2. to recognize new patterns,
3. to make new connections and
4. to visualise the unknown (Wandersee, 1990, p. 927).

Many science concepts such as mechanics (e.g. work & energy) have been found by teachers and researchers to be particularly difficult for students and may well be one of the sources of the alternative conceptions they hold (e.g. Boo, 1998; Hesse & Anderson, 1992). Hesse & Anderson (1992) attributed the difficulty that students encounter in learning science concepts and their misconceptions to the students' learning methods as well as to the teachers' teaching methods. They found that traditional teaching methods are ineffective in helping students learn these concepts. To overcome students' difficulty in the area, several instructional methods have been used. One of the most frequently used instructional methods in this regard is concept mapping.

According to Novak (1990) concept mapping may help teachers to move their own learning approaches towards more meaningful practices. Thus, they will emphasise the meaning of key concepts and principles in ways students can form a conceptual understanding of the subject. Concept mapping enables the students and the teachers to visualise concepts and arrange them in a systematic way. It presents a clear picture of what students are thinking.

What the Redish's (2005) model (Figure 2.1) suggests is that to solve a physical science problem the underlying mathematical concepts and procedures involved must first be well mastered before they can be applied to solve the problem. I believe that connecting procedures with their conceptual underpinnings is the key to processing the web of knowledge required to solve the problem. Heibert and Lefevre (1986) have indicated that a good grasp of the conceptual eases the mental effort required in solving a given problem. In their view procedural knowledge has two main parts namely, symbols and a set of rules, formulas or algorithms that are used to solve mathematical problems. They stated further that if procedures are linked with conceptual knowledge, they become stored as part of a network of information, glued together in the cognitive structure and are less likely to deteriorate than an isolated piece of information. To them, memory is especially good for relationships that are meaningful and highly organized.

2.4.4 Meaningful Learning

The ability of teachers and students to connect concepts is what Ausubel (1963) calls meaningful learning. Meaningful learning is recognized as an important educational goal. It requires that instruction go beyond simple presentation of Factual Knowledge and that assessment tasks require more of students than simply recalling or recognizing (Bransford *et al.*, 1999; Lambert & McCombs, 1998). Meaningful learning occurs when students build the knowledge and cognitive processes needed for successful problem solving (Mayer, 2002).

According to Mayer, (1992) problem-solving involves devising a way of achieving a goal that one has never achieved. It involves figuring out how to change a situation from its given state into a goal state. He pointed out two major components in problem solving viz: (1) problem representation (which requires a student to build a mental representation of the problem), and (2) problem solution (which requires a student to devise and carry out a plan for solving the problem).

2.5 Alternative conceptions

The extant literature has revealed that learners hold a wide range of misconceptions or alternative conceptions about one phenomenon or the other which might hinder them from doing well in science. It is a common saying that good teachers produce good students. While it is important that the teacher has vast knowledge and understanding of the theories and principles around the subject before he/she is able to teach it. The views and attitude of the teacher towards a subject matter will determine to a large extent how he/she teaches that subject matter or how his/her students would value what he/she teaches. This will also enable the teacher to easily identify students' misconceptions and be able to choose the appropriate teaching-learning methods to address and try and correct those misconceptions. Alternative conceptions of numerous natural phenomena have been well-documented in a plethora of studies (e.g. Gilbert and Watts, 1983) and books (Driver *et al.*, 1985).

Throughout this study, the term “misconception” will be used to refer pre-service science teachers' conceptions that are different from valid scientific conceptions. Characteristics of misconceptions can be summarized as, misconceptions that are

resistance to change, persistent, well embedded in an individual's cognitive ecology, and difficult to extinguish even with instruction designed to address them (Driver & Easley, 1978). Misconceptions make it difficult to see what Sungur (2001) calls the "big picture," to realise the links among science concepts and principles, and thereby, apply these principles meaningfully to daily life. Scientific misconceptions reported in different studies, particularly, from work done by Viennot (1979) and Driver (1973), revealed more detailed understanding of some of these misconceptions and more importantly why they are so "highly robust" and typically outlive teaching which contradicts them (Viennot, 1979, p.205).

Most of these studies have employed a constructivist perspective where conceptions are seen as stable entities within cognitive structures or frameworks (Driver, 1981; Mayer, 1996). The "misconception literature" includes studies on light (e.g. Stead and Osborne, 1980); electricity (e.g. Osborne, 1981; Shipstone, 1984); force and motion (e.g. Watts, 1983); the gaseous state (e.g. Engel Clough and Driver, 1985); the particulate nature of matter (e.g. Novick and Nussbaum, 1981) and gravity (e.g. Gunstone and White, 1981).

Various studies have suggested that although alternative conceptions act as a critical barrier to learning (Gilbert *et al.*, 1982; Driver *et al.*, 1985; Ogunniyi, 1987, 1988, 1995), they are comfortably held and even vigorously defended (Schmidt, 1997). In that regard, (Schoon and Boone, 1998, p.565) recommended that science teacher training programs must not only prepare pre-service teachers to help their students overcome alternative conceptions, but they must also address the alternative conceptions held by their own teacher candidates. This will not only help to break the cycle of alternative conceptions being perpetuated but will also help to improve the self-efficacy of the teachers themselves

While every theoretical framework has its own limitations or deficient gaps, it is essential for this study to continue engaging frameworks that remedies the shortcomings. As a way to dealing with the deficiencies of alternative conception, this study now considers another constructivist view of learning, in particular cognitive conflict strategies, derived from a Piagetian constructivist view of learning. The commonly employed strategy has been to create cognitive conflict

situations as a means of getting the subjects to question the credibility of their viewpoints, and then to make them more open to accepting the scientific notion.

2.6 Cognitive conflict theory

A cognitive conflict can be produced by various situations such as experiencing a cognitive gap, as if the person involved were vaguely aware that something within his knowledge structure was missing (Hewson & Hewson 1984; Mayer, 1996, 2001, & 2002). Also, it can be produced by experience of puzzlement, a feeling of uneasiness, a more or less conscious conflict, or a simple intellectual curiosity (Haskell, 2001; Herscovics, 1989). Disequilibria—that is, questions or felt lacunae that arise when the subject attempts to apply his schemas to a given situation is also regarded as cognitive conflict (Lambert, & McCombs, 1998; Mayer, 1992).

The surprise produced by a result which contradicts a subject's expectations, resulting in the generation of perturbations (von Glasersfeld, 1989) is also one of the cognitive conflicts. These cognitive conflicts are effective tools in teaching for conceptual change (Duit, 1999). Science lessons are then built on these prior/common sense notions or alternative frameworks. Where the scientific notions and the common sense notions were close, it was assumed that it would be relatively easy to convince the learner about the credibility of the scientific view (Aikenhead and Jegede, 1999). However, when the two notions are in direct conflict with each other, it would be problematic. Many studies indicate that children are able to hold both notions simultaneously. They use whichever notion is deemed best for a given context (Jegede, 1995; Ogunniyi, 1996).

2.7 Language perspective in learning

While the medium of instruction (for Physical science I – IV) at the institution where this study was conducted is in English, another aspect this study endeavored to look at is the issues of language. In this case, the role language plays in the didactic situations. Many studies (e.g. Ogunniyi, 1996; Nkopodi and Rutherford, 1993; Rollnick and Rutherford, 1996) have examined the effect of language on the learning of science. Results indicate that the language of instruction is definitely a

barrier in the learning of science – more so for those who have English as their second or third language and receive science instruction in English. The participants in this study are English second language speakers who receive Physical Science instruction in English.

It is apposite to state that there are many related concepts in science which are given different names in English. However, in some of the African languages spoken in South Africa, the same word is used for different concepts (Moji and Grayson, 1996). Moji and Grayson (1996) investigated the effect of a single term in mother tongue, for several related but different physics terms in English, on African students' learning of physics. They suggest that this limited nomenclature of physics concepts leads to misconceptions and poor conceptual translation which could explain the generally poor performance of African students in physics.

An aspect of the contiguity argumentation theory of learning alluded to earlier, as will be shown in Figure 3.5 later, is that it allows the researcher to monitor conceptual development among students in the context of a classroom discourse. It also reveals the nature of cognitive shifts that might be taking place e.g. in terms of how students interrogate scientific concepts with the knowledge or alternative concepts they hold. It is here that their mathematical and scientific conceptual deficits are made manifest. Contiguity argumentation learning can serve as a useful method for acquiring procedural skills for ameliorating cognitive conflicts or more positively for attaining cognitive harmonization through the process of accommodation, integrative reconciliation, restructuring and adaptation (Ogunniyi, 2007a & b).

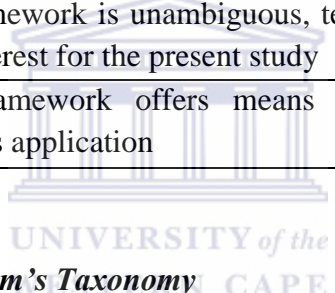
2.8 Bloom's Taxonomy of Learning

An active engagement in learning, rather than passive reception, has for long been promoted to stimulate the cognitive development as well as motivational aspects according to revised Bloom's taxonomy situated under constructivist views on learning (Anderson, Krathwohl, *et al.*, 2001; McDermott, 2001; Prince, 2004). The original Bloom's taxonomy published in 1956 is a framework that was designed to classify curricular objectives and test items in order to show the breadth, or lack of breadth, of the objectives and items across the spectrum of the six major categories

in the cognitive domain. The categories were Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation. This study is therefore interested in the revised version of Bloom's Taxonomy by Anderson, Krathwohl *et al.*, (2001). In contending the use of revised taxonomy by Krathwohl and other scholars, in this study, I have made explicit the criteria that I followed before recruiting the framework:

Table 2.1 Criteria for choosing revised taxonomy of learning

| | | Yes | No |
|---|--|-----|----|
| 1 | that theoretical framework is relevant to the present study | √ | |
| 2 | that the present study fits in with what has already been done around the theoretical framework (i.e. provide a detailed context for the study to solve its problem) | √ | |
| 3 | that with the theoretical framework the present study will lead to new knowledge | √ | |
| 4 | that theoretical framework is unambiguous, testable by methods, offers area(s) of interest for the present study | √ | |
| 5 | that theoretical framework offers means of analyzing data collected through its application | √ | |



2.8.1 The Revised Bloom's Taxonomy

According to Mayer (2001), the revised Taxonomy is based on a broader version of learning that includes not only acquiring knowledge but also being able to use knowledge in a variety of new situations. Like the original taxonomy, the revised taxonomy presents its cognitive process in categories. With the exception of rearranging, renaming of categories from noun phrases to verb phrases. The revised taxonomy reflects a more active form of thinking and is perhaps more accurate. Again, the categories were ordered from simple to complex and from concrete to abstract (Krathwohl, 2002). See diagram as depicted in Figure 2.1.

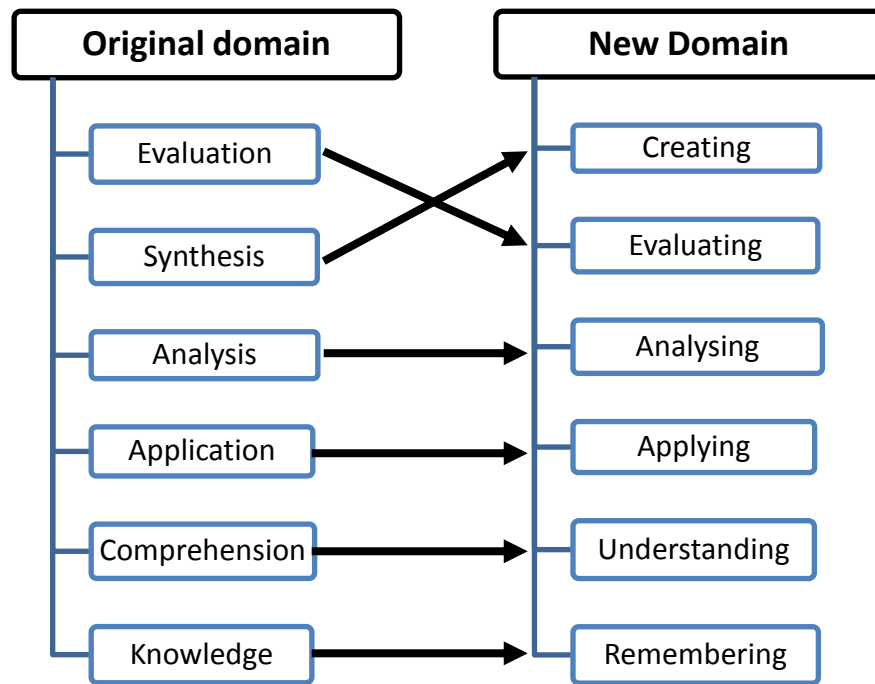


Figure 2.1b. The Original versus New Cognitive Process Domain. (Adapted from: Anderson *et al.*, 2001, p.213).

2.8.2 *Connecting conceptual and procedural knowledge*

Hiebert and Lefevre (1986) describe two types of mathematical knowledge in terms of conceptual knowledge and procedural knowledge. These have distinguishing characteristics of the richness in connections and linkages between ideas or pieces of information. Heibert and Lefevre (1986) defined conceptual knowledge as a connected web of knowledge, a network in which the linking relationships are prominent as the discrete pieces of information (p.3). Development of conceptual knowledge is achieved by the construction of relationships between pieces of information. The linking process can occur between two pieces of information that already have been stored in memory or between an existing piece of knowledge and one that is newly learned.

Procedural knowledge is defined in two parts, as knowledge consisting of the form and symbolic language of mathematics, and as knowledge consisting of rules, alogarithms or procedures used to complete a mathematical task (Hiebert and Lefevre, 1986, p.6). Hence procedural knowledge can exist as isolated pieces of information, and development of procedural knowledge requires some form of input, therefore, connections between conceptual and procedural knowledge increases the

chances for the retrieval of what has been learned when needed, because they serve as an alternate access route for recall.

Hiebert and Lefevre argued that if conceptual knowledge is linked to procedures it can enhance problem representations and simplify the demands of procedural skill display, thereby promote transfer and reduction of the number of procedures required. Connections between procedural ability and conceptual knowledge are mutually beneficial for procedural skills and conceptual knowledge in solving mathematical problems in physics.

McBride and Silverman (1991) have stated that the connections between conceptual knowledge and procedural knowledge are important for four reasons: (1) Science and Mathematics are closely related systems of thought and are naturally correlated in the physics world. (2) Mathematics can provide students with concrete examples of abstract mathematical ideas that can improve learning of science concepts. (3) Mathematics can enable students to achieve deeper understanding of science concepts by providing ways to quantify and explain science relationships. (4) Mathematics activities illustrating science concepts can provide relevancy and motivation for learning science. (p. 286-287). Some benefits for conceptual knowledge arise from the highly routinized procedures that can reduce the mental effort required in solving a problem and thereby make possible the solution of complex tasks.

2.8.3 The Cognitive Process dimension

The cognitive domain in the original Bloom's taxonomy involved knowledge and the development of intellectual skills. This includes the recall or recognition of specific facts, procedural patterns, and concepts that serve in the development of intellectual abilities and skills (Krathwohl, 2002, p.214-215, see Figure 2.2).

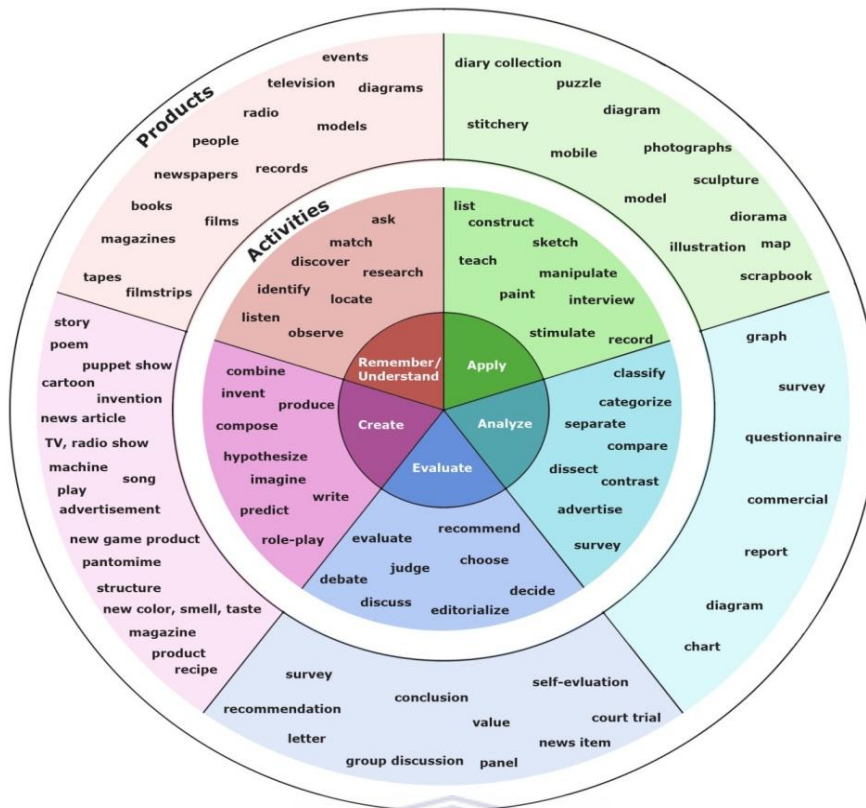


Figure 2.2. The Cognitive Process dimension: (Adapted from Aderson *et al.*, 2001)

2.8.4 The Revised Taxonomy table

In the revised taxonomy table, the Knowledge dimension forms the vertical axis of the table while the Cognitive Process dimension forms the horizontal axis. Thus, the intersections of the knowledge and cognitive process categories form the cells. Accordingly any objective could be classified in the Taxonomy table in one or more cells that correspond with the intersection of the column(s).

Table 2.2 The Revised Boom's Taxonomy Table

| The Knowledge Dimension | The Cognitive Process Dimension | | | | | |
|-------------------------|---------------------------------|------------------|-------------|---------------|----------------|--------------|
| | 1. Remember | 2. Understand | 3. Apply | 4. Analyze | 5. Evaluate | 6. Create |
| Factual Knowledge | | | | | | |
| Conceptual Knowledge | | | | | | |
| Procedural knowledge | | | | | | |
| Metacognitive Knowledge | | | | | | |

Source: (Krathwohl, 2002. p.216)

2.8.5 *Cognitive Processes for Retention and Transfer*

Two of the most important educational goals are to promote *retention* and to promote *transfer* which, when it occurs, indicates meaningful learning. To Mayer & Wittrock (1996) retention is the ability to remember material at some later time in much the same way it was presented during instruction while transfer is the ability to use what was learned to solve new problems, answer new questions, or facilitate learning new subject matter. To put simply, retention requires that students remember what they have learned, whereas transfer requires students not only to remember but also to make sense of and be able to use what they have learned (Bransford *et al.*, 1999; Detterman & Stenberg, 1993; Haskell, 2001; Mayer, 1995; McKeough *et al.*, 1995 cited in Mayer, 2002). Put another way, retention focuses on the past and is closely related to “Remember”, whereas transfer emphasizes the future and is increasingly related to the other five cognitive process categories (Understand, Apply, Analyze, Evaluate, and Create).

2.9 **Studies relevant to the present study**

Drawing on the theoretical effectiveness of studies on students’ conceptual and procedural difficulties in solving mathematical problems in physical science in the developing countries such as South Africa is rather few. In thinking about this, among the few studies done in South Africa which are relevant to the present study are (DoE, 2011; Ogunniyi, 1999; Selvaratnam, 2011).

Despite the relevance of the reviewed empirical studies to the present study (e.g. Bing & Redish, 2009; Heller *et al.*, 1992; Jewett, 2008; Jones, 1995; Junkins 2007; Kim & Pak, 2002; Madelen, 2012; McDermott, 1993; McBride and Silverman 1991; Reif & Allen, 1992; Simon, 1993; Taplin, 1995), their findings emerged from teaching and learning environments different from South African context where the present study is undertaken. For example, Kim and Pak’s (2002) study accounted for students in the Republic of Korea (Asia) while Jewett (2008) and Junkins (2007) accounted for students in the Western countries, nonetheless, results from these studies alluded to conceptual and procedural difficulties students encounter in solving basic mechanics, but they do not inform the present study the effect their findings will have on students in different contexts similar to the present study.

In addition to the latter, the approach used in solving work-energy problem proposed by Jewett (2008) offers the present study little information in terms of efficacy as no concession is given to those students who may still retain confusion and conceptual difficulties after being exposed to his seventh approach as reviewed in the literature. If it was anything like the ounce of experience I had while teaching the 2nd and 3rd pre-service teachers, a more likely explanation that may suffice such discrepancy is that of McDermott's (1993) assertion. To understand what is being said here we need to look at McDermott's study once again. How different is McDermott's suggestion to remedy such discrepancy in the present study. Drawing on the work of McDermott hence considering the theoretical frameworks underpinning this study, what McDermott did differently that may help the present study to address its problem was that he pursued both the cause and effect in his study.

In pursuance of the cause of students' conceptual and procedural discrepancies in their conceptions of math-in-science, he provided guidelines or suggestions that could foster students' conceptual and procedural efficacy in terms of problem solving, e.g., postpone the use of algebraic formalism until after a qualitative understanding has been developed. This recommendation is believed to have endorsed students' performances in terms of problem solving and has proved to be an effective approach (he stated that examination results indicate that students who learned in this way often do better than others on quantitative problems and much better on quantitative questions). For deep-seated conceptual difficulties he explained that it cannot be overcome through assertion by an instructor, but active learning is essential for a significant conceptual change to occur (e.g. effective instructional strategy for obtaining the necessary intellectual commitment from students is to generate a conceptual conflict and require them to resolve it).

With the latter in mind, a blend of recommendations from the works of (Bing & Redish, 2009; Junkins, 2007; Kim & Pak, 2002; Ogunniyi, 1999) are essential, and for implementation of instructional strategy and its effectiveness (Heller *et al.*, 1991; Ogunniyi, 2009; Redish, 2005, see Figures 3.5 and 2.1 respectively), integration of math-in-science to enrich students' conceptual and procedural knowledge (Hiebert and Lefevre 1986; Junkins, 2007; Krathwohl, 2002; Taplin, 1995), with proper monitoring of retention and transfer of such knowledge (Mayer, 1995; Meyer & Wittrock ;1996 cited in Mayer, 2002), and implication thereof (Simon, 1993).

Some scholars (e.g. Bing & Redish, 2009; Junkins, 2007; McDermott, 1993) have contended that through proper implementation and monitoring of the use of math-in-science instructional model students often discover “oh, so this is why we learned that in algebra...” In many cases students discover that it is one or more mathematics skills that initially block their ability to understand and internalize new science concepts. According to Junkins (2007), students in science classes must learn how to recognize when particular mathematics procedures are applicable so that they can select from their "mathematics toolboxes" the correct methods needed to solve new problems. Thus, a lack of mathematical skills can have a negative impact on students' abilities to solve complex problems in physics and can greatly hinder a deeper understanding of many important concepts; especially those in physical science (see Junkins, 2007).

2.10 Summary

A review of relevant literature indicates that the learning theory of constructivism can be effectively used to explain the existence of pre-service science teachers' conceptual difficulties of a range of natural phenomenon within and across age and contextual settings. Many studies situated in a constructivist setting have shown various aspects of students' learning discrepancies such as their inability to grasp concepts even when concepts are made explicit, epistemological obstacles, conceptual difficulties, inability to link math-in-science concepts, pedagogic incompetency and inability to apply content knowledge at the level taught (Alant, 2004; Bell & Janvier, 1981; Brousseau, 1976; Junkins 2007; McBride *et al.*, 2010; McDermott, 1991; Reif and Allen, 1992; Sierpinska, 1994).

The implication of the above studies is that constructivist teaching can lead to effective learning of scientifically valid ideas without necessarily getting students to abandon their own ideas. Many of the studies that were done involve using cognitive conflict situations, within a constructivist setting, to effect lasting conceptual change. Jenkins (2001) and Matthews (1994) have disputed the many claims made for constructivism including regarding it as “a powerful model to promote conceptual change” (Keogh & Naylor, 1997, p.12). These arguments will be carefully considered and the cautions heeded when making recommendations and

discussing the implications of this study. This is critical to us as teachers and teacher educators since it implies that if students are given proper guidance as to which notions are valid and useful in a given context, then perhaps they would not be experiencing cognitive conflicts which might lead to them rejecting the scientific ideas.

Also, in this review, some attention has been given to the issue of conceptual obstacles/difficulties held by pre-service and practising teachers. For example, Hiebert & Lefevre (1986) explained some of the reasons why students are unable to connect between procedural and conceptual knowledge appropriately needed to solve science problems. They highlighted the followings: (1) students may have some understanding of the mathematical concept but not able to solve science problems given to them, (2) students may be able to perform some calculations/tasks but may not understand what they are doing. It is on this context that Herscovics (1989) described such learning discrepancies as “cognitive obstacles”. Cognitive obstacles as explained by Herscovics is individual learning experiences that in some way hinder the understanding of certain concepts. To overcome such students’ learning discrepancies, Prediger (2006) explained that such challenges posed by such cognitive or epistemological obstacles demands the reconstruction of prior knowledge. Other concerns reported in the literature include the work of Simon (1993) and Jones (1995), major concern expressed was the number of pre-service teachers having weak conceptual backgrounds in the subject they are likely to teach.

In pursuance of the present study which focuses on pre-service teachers conceptual difficulties in solving mathematical problems in physical sciences. Taplin (1995) identified several topics in which pre-service mathematics teachers performed poorly. These included applying measurement formulae, the relationships between different mathematical operations and their principle applications. The study further suggested one mostly area for remediation, that is, transfer of procedural knowledge which was evidenced by inadequate problem-solving skills. This study therefore, is situated in the context of studies that have shown that conceptual math-in science obstacles are not limited to learners but are also prevalent among pre-service and practising teachers (e.g. Jones, 1995; Simon, 1993; Taplin, 1995).

Finally, this review of the relevant literature clearly shows that, despite the studies that have been carried out on conceptual obstacles/difficulties, there is still a lot to know about how pre-service teachers acquire or overcome conceptual difficulties in solving mathematical problems in physical science. This literature review has been used as a backdrop to this study and some of the issues that have emerged might not be directly addressed in the study but will be considered in the later discussions. Chapter 3 describes the methodology employed in the attempt to find answers to the research questions raised in the first chapter.



CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter describes the overall research method and design employed in the present study. It describes the process adopted in the step-by-step procedure used in the development of the instruments namely: work and energy for the Physical Science Achievement Test (PSAT) with Questionnaire (MRQ) and the interviews. Further, the chapter provides a detailed account of the implementation of the instruments including the process of establishing their validity and reliability, the selection of the sample and the selection of the participants for the interviews. Also included in the chapter are the process of data gathering, analysis and reporting of related studies and their respective methods for data gathering.

According to Creswell (2005), a research method describes specific procedures of a particular research study. To him, a research method expresses both the structure of the research problem and the plan of the investigation used to obtain empirical evidence for a given study. It includes an outline of what the investigations will do from writing the hypotheses and their operational implications to the final analysis of data. In that regard, each method has a unique purpose and its application entails a unique set of procedures and concerns. This gives the reader the opportunity to judge whether or not the inferences or conclusions drawn from such data are valid and reliable. Put simply, the purpose of a research method is to enhance control of the same learning variable and draw conclusions about the effect of one type of variable of exposure upon achievement or problem solving (Kerlinger, 1973).

3.2 Sample

This study selected a purposive sample also called ‘deliberate sample’ (Cook and Campbell, 1979) because it is based on an institution in which I work and in which I have encountered the problem which forms the motivation for this study. The study was conducted at a historically black university in Cape Town, South Africa using both second and third year pre-service science teachers. The participants come from

a multicultural background. The institution produces a large number of qualified teachers yearly and hence is considered to provide the appropriate context for the study. Two groups were selected in the study viz: (1) pre-service teachers who do both physical science and mathematics were treated as the control group (C-group), and (2) pre-service teachers who do physical science and mathematical literacy were treated as the Experimental group (E-group). The C- group are those pre-service teachers who have done Mathematics up to grade 12 at high school and also have chosen mathematics as their elective major with physical science specialisation while the E-group are those pre-service teachers who may have done either Mathematics/Mathematical Literacy at high school and have chosen Mathematical Literacy with Physical sciences as their area of specialisation at the university.

The differences in terms of Mathematics and Mathematical Literacy course modules in the FET faculty of the university are that Mathematical Literacy modules as the name suggests does not include the kind of Mathematical topics needed to perform basic operations of Physical science problems (e.g. work and energy). Mathematical concepts such as trigonometry, Pythagoras theorem, making subject of formula/equations, quadratic expression, geometry, etc are not part of the Mathematical Literacy modules. It is against the background of the concerns listed in Chapter 1 (section 1.1, background to study) that those pre-service teachers with Mathematical Literacy and Physical science were classified as the E-group with the hope that exposing them to the use of maths-in-science model may help them to address their conceptual and procedural difficulties they tend to encounter in solving Physical science problems.

The research group comprised sixteen second and third year pre-service science teachers. They had enrolled at the university in 2011 & 2012 academic year to follow the science teacher training program (B.ED) FET specialization. Seven of the pre-service teachers were third year undergraduate students and nine were second year undergraduate students. All were registered fulltime students in the aforesaid faculty.

3.2.1 Faculty Course Guidelines For FET Physical Science Pre-service Teachers

The Education and Social Sciences Faculty comprises of General Education and Training (GET), which focuses on the Foundation phase (FP- Grade R – 3), Intermediate and Senior Phases (ISP – Grades 4 -9) and Further Education and Training (FET – Grade 10 – 12). To be a Physical science grade 10 -12 teacher, a student needs to take the FET courses with a science emphasis. Therefore, the physical science pre-service teachers in this study had taken the FET courses appropriate for Natural Science or Technology for which they will be awarded *Baccalaureus Educationis* (B.ED) with natural science or technology specialization.

At the first year FET level, pre-service science teachers are expected to do seven compulsory subjects and a minimum of 2 or maximum of 3 elective subjects known as majors.¹ The elective subjects include wide range of FET band subjects (that is, grade 10-12 high school subjects). The university first year elective subjects include Mathematics 1, Physical science 1, Life science 1, and so on. This means that at first year level a pre-service teacher who wants to major in three high school subjects can take Mathematics 1, Physical science 1 and Life science 1 (Biology 1) or other combinations.

At the second year level a pre-service teacher is allowed to drop any one of the three elective subjects whether he or she passes it or not. As such must continue with the other two elective subjects as majors (or specialization) up to the end of the four year degree program. Again, nothing forbids a pre-service teacher to specialize in three elective subjects as long as the subjects are passed at all levels with a minimum of 50%. As pre-service science teachers are not restricted to choose a subject combination, many of them choose to avoid mathematics completely. Some choices of subject combination include physical science and a local language (Afrikaans or isiXhosa). Some students choose a business subject with physical science, etc. The problem with these combinations become multiple as the literature reported in Chapter 2 of this study revealed and envisaged challenges pre-service science

¹ Elective subjects as applied in the FET course guidelines at the university in respect to mathematics means that mathematics is optional to the pre-service physical science teachers throughout their studies as they are entitle to choose any subject combination they want.

teachers might face to do the basic mathematics needed in physical science calculations.

Table 3.1 Distribution of pre-service teachers by ethnic group, age, gender and home language

| Group | C group (N = 9) | E group (N = 7) | Total (N = 16) |
|----------------------|-----------------|-----------------|----------------|
| Ethnic group | | | |
| Black Africans | 5 | 5 | 10 |
| Coloured | 4 | 2 | 6 |
| Gender | | | |
| Female | 2 | 0 | 2 |
| Male | 7 | 7 | 14 |
| Age | | | |
| 16-20 | 1 | 0 | 1 |
| 21-25 | 5 | 2 | 7 |
| 26-30 | 2 | 1 | 3 |
| 31-35 | 1 | 3 | 4 |
| 36-40 | 0 | 1 | 1 |
| Home Language | | | |
| Afrikaans | 3 | 0 | 3 |
| English | 1 | 2 | 3 |
| IsiXhosa | 4 | 3 | 7 |
| IsiZulu | 1 | 2 | 3 |

3.2.2 Gender profile of Sample

Only 12% of the participants were female (see Figure 3.1 and Table 3.1), thus, examining the effects of gender on pre-service teachers' ideas became a doubtful exercise from which to draw any valid conclusions.

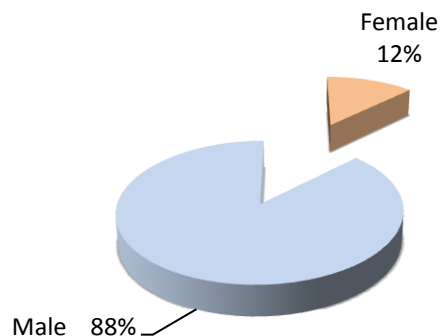


Figure 3.1 Gender profile of sample

3.2.3 Age profile of Sample

As shown in Table 3.1, the age frequency of the sample shows a wide spread of ages within the group. The ages ranged from a minimum of 16 to a maximum of 40 years with a standard deviation of 5.2 years for the group of $N = 16$ students. The frequency modal is between the age categories of 21 - 25, with most participants in their earlier 20s. The median was found to be 26 years.

3.2.4 Language profile of Sample

The biographical information in Table 3.1 showed that close to 44% of the participants were Xhosa speakers (See Figure 3.2 below). The other languages, English, Afrikaans and IsiZulu were equally represented in the sample group about 19% respectively.

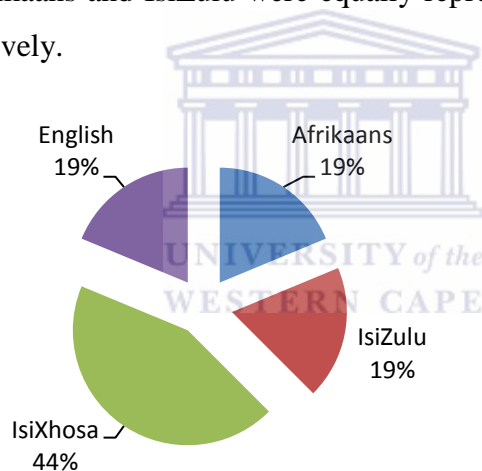


Figure 3.2 Home language profile of sample

3.3 Methodology

As pointed out in Chapter 1, the main objective of this study is to provide a plausible way to addressing conceptual difficulties pre-service science teachers face in solving mathematical problems in Physical Science. A teaching strategy as part of intervention (that is, prior to post-test) is based on the following considerations: mathematical modelling in physics and cognitive conflicts which are based on problem-solving strategies that students find relatively convincing (Mayer, 1992 & 1995). The teaching strategy that is apposite for the pre-test and post-test in this

study was based on an interactive approach within an intact classroom (see Figure 3.5) to provide the researcher with an opportunity to facilitate conceptual change as part of normal class activities.

For the topic of the study I have used basic mechanics (e.g. work and energy), which is part of the physics module covered in the second and third year level (see section 1.3 of Chapter 1). It would be extremely difficult to design a strategy that may provide a conflicting situation for all students in a classroom. However, in teaching work and energy, the key concepts, their definitions, formula derivatives as well as worked examples were written on the whiteboard. Mathematical modelling depicted in (Figure 2.1) as an approach to ameliorating pre-service teachers' conceptual difficulties in solving problems in work and energy was introduced and incorporated in the teaching of the E-group. In what follows, each cohort of students followed a particular schedule of lecture sessions, which do not overlap. It was limited with respect to time by the teaching schedule for the first semester, so the teaching intervention spread out in 4 lecture periods of 55minutes. This was however in line with the time normally allocated to that topic, to avoid the Hawthorne Effect i.e. if they are exposed for a much longer period they would have learnt more. If it had spanned a longer period then this would thus not be a true reflection of what learning would have taken place within the time normally allocated to the concepts in question.

3.3.1 Teaching problem solving to E-group

First, no research method is independent of the context in which it is done. The E-group was taught general concepts of work and energy, problem-solving strategy that is based on a variety of some of the methods and findings reported in the reviewed literatures. The concerted methods and findings describe the nature of conceptual difficulties and didactical obstacles of work-energy problem solving (e.g. Heller *et al.*, 1992; Jewett, 2008; Kim and Pak, 2002; Lawson *et al.*, 1987, p.811-817; McDermott, 1993; Redish, 1999; Reif and Allen, 1992). While it is impracticable to use all the methods found interesting in the later studies, three methods that stood out for the present study are that of Kim and Pak (p.761-763), McDermott, and Heller *et al.* in respect of problem researched area, not only that the

three studies shared similar views and concerns with that of the present study, but presented findings, clarity and testability of methods used quicken the present study.

Second, Heller *et al.*, in their method approach to problem solving-strategy of work-energy have explained one of the reasons why when students arrive at their numerical answer, they are usually satisfied, they rarely check to see if the answer they got make sense or not. Similarly, the later concern is one of the major concerns of the present study mentioned in Chapter 1. Further, the reason they gave was that too often students neither use their conceptual knowledge of physics to qualitatively analyze the problem situation, nor do they systematically plan a solution before they begin. They begin to solve a problem by plugging into the algebraic and numerical solution – they search for and manipulate equations, plugging numbers into the equations until they find a combination that yields an answer. It is on this standpoint that McDermott's second recommendation pointed out in Chapter 2 of the present study argues that the use of algebraic formalism should be postponed until after a qualitative understanding of the concept in question has been developed (e.g. work and energy).

In order to account for this in the present study, in particular, in the intervening teaching and learning sessions of the E-group, a set of context-rich practice and test problems were constructed that reinforce the usefulness of the problem solving heuristics (known as IDEAL), which I shall discuss in the next section. Thus, the E-group was also taught how to apply content knowledge at the level taught (one of the concerns raised in the work of Kim and Pak and how to make estimations to decipher their physical science calculations and determine if an answer is reasonable or not, (listed concerns mentioned in chapter 1).

Third, during the intervening teaching and learning sessions of the E-group, the group was encouraged to practice using the integration of both the problem solving heuristics (known as IDEAL) and the mathematical model (see Figure 2.1) to solve context-rich math-in-science problems which requires them to make a systematic series of translations of the problem into different representations, each in more abstract and mathematical detail. For the sake of brevity, more emphasis was placed on how the E-group can learn general qualitative and quantitative problems solving

skills that they can apply to new situations to overcome conceptual and procedural difficulties.

3.3.2 *Problem solving instructional approach for the E-group*

Drawing on theoretical framework underpinning the present study, various findings in the reviewed literature as well as listed concerns that triggered this study to be conducted (see chapter 1). As per section of the mechanics, the intervening teaching and learning for the E-group prior to the post-test focused on pre-service teachers' conceptual and procedural difficulties that impedes their abilities to solve mathematical problems in physical science in particular: (1) relationship between work and energy (2) common principle/theory (e.g. work-energy theory); (3) applications of work and energy in everyday life; (4) discriminating examples from non-examples (5) mathematical application in physical science problems, and, of course, (6) problem-solving strategies (e.g. specific strategies- breaking a complex problem into sub-problems).

Following the later concerns, every effort was made in each session to ensure students overall structural knowledge about the complexity of work and energy problems. Emphasis on drill and practice and reinforcement on step-by-step method as required of pre-service teachers was prompted in each session. As a form of concession to help pre-service teachers' understanding of problem-solving, a heuristic known as *IDEAL* was recommended during problem solving such as:

- Identify the problem (understand the problem)
 - Define and represent the problem
 - Explore possible strategies
 - Act on the strategies
 - Look back and evaluate the effects of your activities
- } Devise a plan- Use Free Body Diagram

Reinforcing approach include: raising questions such as (1) what information is important? (2) What information is missing? (3) Which formulae are necessary? (4) What is the first thing to do?

In an effort to inculcate the later areas mentioned, lesson plans for a THREE week period were designed to run 4 lecture periods of 55 minutes each as pointed out earlier. Since I see the physical science pre-service teachers (E-group) once a week

according to the workload schedule of the science education faculty and students timetable, it was decided that the three lesson plans be split into three different days of the three weeks (week 1, 2 and 3) and taught according to the students' timetable. That way inconveniences for both the participants of the study and the researcher was avoided. In week 1, one lecture session was taken within which the instructor taught both C and E-groups qualitative conception of work-energy as outlined in the lesson plans of the learning journal. In the second week, two lecture sessions were taken, the E-group was taught algebraic formalism (that is, problem-solving strategies) using maths-in-science model while the C-group was taught algebraic formalism (as in Figure 3.8) without the use of maths-in-science model (Figure 2.1). In week 3, both groups were taught complex aspects of work-energy problems using various solving strategies such as IDEAL. For more details on the three weeks lesson plans as part of intervention (see appendix E).

There was also the need to facilitate the three weeks intervention teaching and learning for the E-group in a supportive environment that fosters open discussion of given problems, arguments (exchange of ideas to resolve problems that result conflict), and joint construction of a problem solution. Of the recommended pedagogical schema for implementing a supportive teaching and learning environment apposite for the intervention is that of (Ogunniyi, 2009, see Figure 3.5). From the approach depicted in (Figure 3.3) below, the E-group had to solve work and energy problems provided in the Learning Journal (Appendixes A, B and C), a format that requires them to exhibit both conceptual and procedural knowledge.

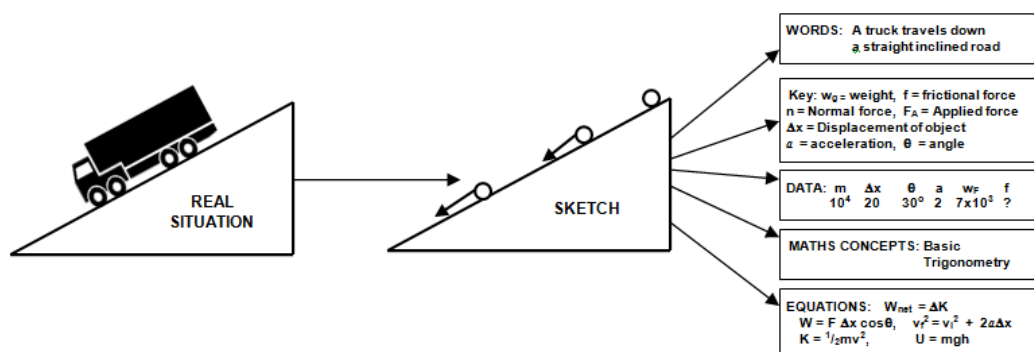


Figure 3.3 Qualitative and quantitative representation of problem-solving strategy.

From figure 3.3, the pre-service teachers were asked why would the construction of a physical representation of science problem (i.e. free-body-diagram) be helpful or even necessary in solving complex problem. As in figure 3.3, the physical representation of the problem provides a basis for generating physics equations. Also, the physical representation provides a situation that can be used to check one's errors (Larkin, 1983; Larkin & Simon, 1987, p. 65-99).

Again, the pre-service teachers were incited with questions that could help them facilitate problem-solution. The second question prompted was what information is important or missing? And the third, why would formula (a) [$v_f = v_i + at$] may not be used to calculate the velocity of the moving truck, but formula (b) [$v_f^2 = v_i^2 + 2a\Delta x$]? There is also reason to think that what occurs during qualitative analysis of a physics problem is more than the construction of a physical representation, because the often complex intuition driven from what happens in a cognitive conflict would correspond to the Piagetian concept of assimilation, whereas conflict resolution would correspond to accommodation (Niaz, 1995).

3.4 The Research Design

In research, the two mostly used methods are quantitative and qualitative methods. Quantitative research involves the use of numerical values to analyze data while qualitative research focuses on the web of meanings on how people make sense of their worlds. Recognizing that all methods have limitations, researchers felt that biases inherent in any single method could neutralize or cancel the biases of other methods. For example, the results from one method can help develop or inform the other method (Wilson, Foster, Finnegan, Thomas, Swift, Sapsford, Abbott, 1993, p. 30).

Alternatively, one method can be nested within another method to provide insight into different levels or units of analysis (Tashakkori and Teddlie, 1998). Or the methods can serve a larger, transformative purpose to change and advocate for marginalized groups, such as women, ethnic/racial minorities, people with disabilities, and those who are poor. These reasons provide justifiable grounds for using a mixed method in the study. Tashakkori and Creswell (2007) refer to mixed

methods as research in which the investigator collects and analyzes data. Data integrates the finding, and draws inferences using either qualitative and quantitative approaches or methods in a single study or a program of inquiry.

The choice of the research design for the study is based on the nature of the research questions and the nature of the phenomenon under study. In addition to the research questions stated earlier, another key question that aims at revitalizing the instrument design of the study is:

What conceptual difficulties do pre-service science teachers overcome in solving mathematical problems in physical science?

The stated question as well as the main research questions is empirical in nature. Empirical questions are questions that require data to be collected from the real world (Lecompte & Preissle, 1992). In order to respond to the questions pre-service science teachers are the primary source of data. They have to be asked questions from which their responses will reflect how they overcome conceptual difficulties in solving mathematical problems in physical science. They also have to be asked questions which will require their responses to reflect how they map concepts and proceed with mathematical operations needed to solve physical science problems. To this end, the study involved the use of both quantitative and qualitative designs. The quantitative aspect is quasi-experimental pretest-posttest control-group design. This is because it is not feasible to randomize the participants (Fraenkel & Wallen, 2000; Ogunniyi, 1992). Specifically, the design entails two groups: one experimental group (E) and one control group (C).

Design diagram

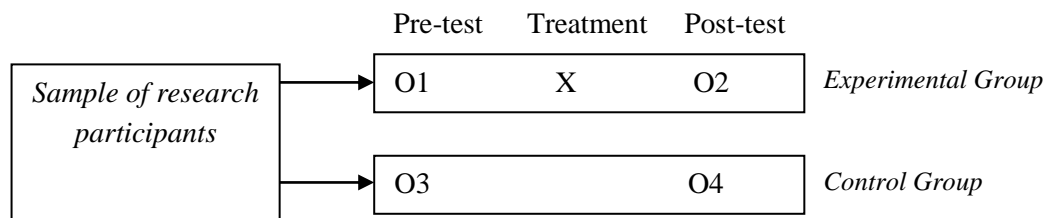


Figure 3.4 A quasi-experimental control-group design

Where O_1 and O_3 are the pre-tests administered three weeks before the commencement of the intervention while O_2 and O_4 are the post-tests with X stands for the treatment administered simultaneously upon the completion of the intervention. More about the intervention implemented in the study shall be discuss shortly. Furthermore, Ogunniyi (1992) is of the opinion that a quasi-experimental control-group design is tight enough to eliminate possible sources of extraneous variables, e.g. history, mortality of participants, statistical regression, etc., which might affect the validity of the instrument and or the quality of the data obtained.

In a meaningful way to accentuate optimal implementation of the instrument design, the participants E-group were introduced to mathematical modelling while their counterpart C-group was only exposed to traditional lecture approach. Such approach informed the study about the efficacy of the intervention in addressing pre-service teachers' conceptual and procedural difficulties in solving mathematical problems in physical science. It follows that both groups were exposed to equal teaching hours, consisting of 4 lecture sessions of 55 minutes each on selected math-in-science concepts (e.g. work and energy).

In line with socio-constructivism which construes learning as a social activity, the treatment was also supplemented with an instructional protocol that involves the use of classroom arguments and discussions. This is because a plethora of studies have shown the effectiveness of arguments and discussions in facilitating conceptual understanding (e.g. Erduran *et al.*, 2004; Ogunniyi, 2007a & b; Osborne, *et al.*, 2004; Simon *et al.*, 2006). Figure 3.5 below shows an argumentation framework used in the class to engender dialogues among the pre-service teachers. It provides learners with the opportunity to express their views freely as well as clear their doubts. Viewed from this perspective, dialogical argumentation enables learners, in their attempt to construct knowledge, to actively participate in class by making claims and using evidence to justify such claims, while other learners make counter-claims or rebuttals.

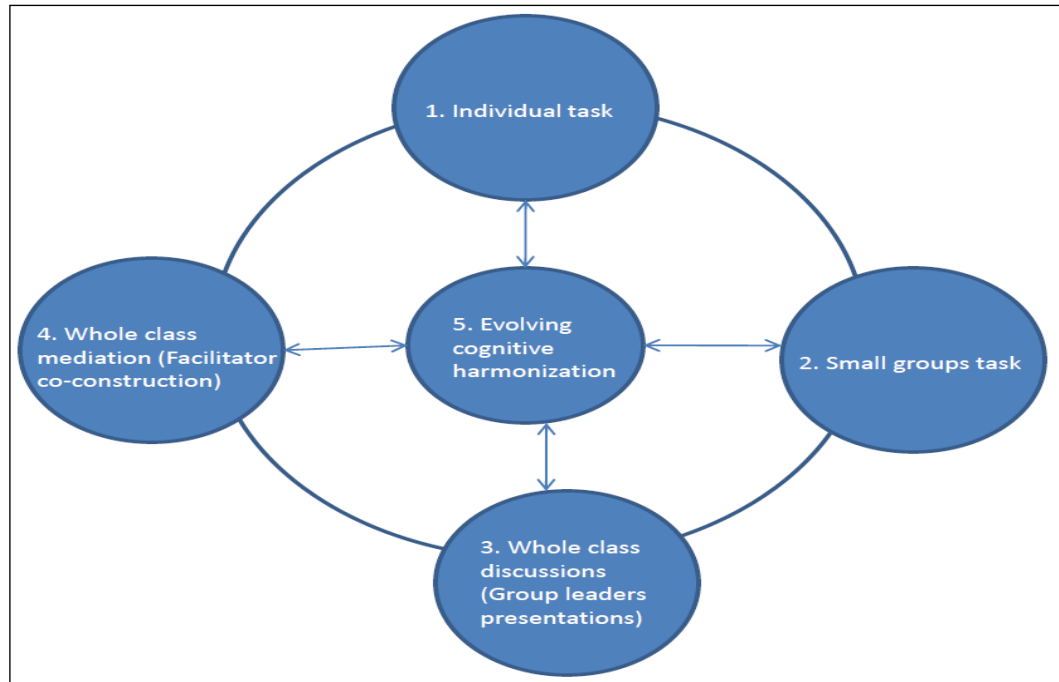


Figure 3.5 A Pedagogical schema for implementing dialogical argumentation-based classroom discourses-modified after Ogunniyi (2009).

3.5 Instrumentation

3.5.1 *The quantitative and qualitative data*

The qualitative component of the study involved semi-structured questionnaires and semi-structured interviews on how the pre-service teachers acquire or overcome conceptual and procedural difficulties in solving mathematical problems in Physics (e.g. work and energy). In each questionnaire sufficient space was provided for the participants to write any extra comments. All these comments were then used in the qualitative analysis of the study to collaborate the quantitative data. Due to the different approaches used in conducting the study, a number of instruments were used to collect data. Different types of instruments used are:

1. The Physical Science Achievement Test (PSAT) which generated the pre- and post-test instrument for determining conceptual difficulties pre-service science teachers demonstrated in solving mathematical problems in physical science. The data collected through the PSAT was analysed in terms of quantitative and qualitative descriptions.

2. Questionnaires explored focused on:
 - (i) the pre-service science teachers' procedural and conceptual discrepancies in their conceptions of math-in- physical science they exhibit while solving physical science problems.
 - (ii) the pre-service science teachers' perception about making strategic connections between relevant mathematical and physical science concepts while solving physical science problems.
 - (iii) the E-group's perceptions of the use of math-in-science model.
3. The interviews explored how the pre-service teachers acquire or overcome conceptual and procedural difficulties in solving mathematical problems in Physics (e.g. work and energy). Included in the interview questionnaires are questions that sought to know how and when the pre-service teachers used different problem-solving strategies at the level taught.

3.5.2 *Physical Science Achievement Test (PSAT)*

The PSAT (see appendixes B and C) was developed to measure the cognitive achievement of the pre-service science teachers in the experimental and the control groups. The exemplary learning journal used in the study helped the pre-service science teachers negotiate meanings within their conceptual ecology and constructs their own knowledge as they interact with the learning material. The PSAT, which consists of a Multiple-Reflective Question (MRQ), concentrated on pre-service science teachers' conceptual discrepancies and content-based questions extracted from one of their prescribed physics textbooks (i.e. Giancoli Sixth Edition). The PSAT comprised of two sections, A and B. I decided that the problem context in section A be based on conflict, and that the format of response be in form of argument and discussion. That way, conceptions and misconceptions of work and energy held by pre-service teachers can be made explicit (see appendix B).

For both instruments (section A and B of the PSAT), most items required students to provide a reason or explanation for their answers or choice of a particular method leading to possible solution. The instruments could therefore be even more

efficiently used as a diagnostic tool in the science classroom as it allows for large scale use and is much easier to mark and analyze. There was also the need to know how the pre-service science teachers (E-group) make conceptual and procedural links while modelling math-in-science.

As a way to elicit information about the above approach, a step-by-step solution method was highly recommended for the pre-service science teachers to follow in order to answer the content-based questions (see appendix C attached). This approach was subsequently used in all the items in (3.1 – 3.5) of section B which is useful for diagnostic purposes for testing “real” understanding as it provides sufficient information that can decipher whether a learner has arrived at his or her answer through surface learning or deep learning. Such approach provides opportunity for following up responses while reducing ambit of guessing since conceptual knowledge is knowledge of facts, properties, and relations and procedural knowledge is knowledge of the skills needed to carry out mathematical problems.

3.5.3 Consideration in developing work and energy instrument

In basic mechanics, work and energy are inseparable. It is sometimes regarded or treated as a topic and not topics; this is not because it is a simplest topic to easily learn and understand. It is a broad topic that can easily breed possible confusion or misconceptions during teaching and learning process as pointed out earlier in Chapter 1. To avoid possible confusion that often arises in didactic discourse, for the present study, it was necessary to incorporate both concepts and treat them as a single topic. Even at that, there has not been any approach that can possibly eliminate confusions or misconceptions that students exhibit in learning the concepts of work and energy.

In Chapter 1 and 2, I presented empirical findings from science education studies on work and energy, no report has guaranteed students’ conceptions without difficulties. A blend of such reports have shown that many students retain fundamental conceptual difficulties in solving science problems such as mechanics even after instruction (e.g. Bell & Janvier, 1981; Kim and Pak, 2002; Heller *et al.*,

1991; Jewett, 2008; Junkins, 2007; Jones, 1995; Simon, 1993; Taplin, 1995; McBride and Silverman 1991; McDermott, 1993).

Some of the lessons learned in critical reviewing of related literature have informed the present study that problem could arise if development of instrument for intervention does not envisage “didactical obstacles” sometimes known as “epistemological obstacles”. That is, those obstacles that are often evoked by the way of teaching, of which in the case of the present study, refer to those obstacles that are rooted in the structure of mathematical content itself, in its history and the development of its field of application in science. With this in mind, I had to select the aspects of work and energy problems that could possibly generate conflict of mathematical content in science. Also, I considered the pre-service teacher physics syllabus and the school physical science syllabi and identified the concepts that were considered essential to effectively teach the concepts and to engage with the material to be covered in the course. More on that was discussed in Chapter 1 of this study.

In addition to the latter, I considered work and energy problems that have been previously identified as commonly occurring confusions for students and teachers in South Africa (see DoE, 2011, p.124-125; Selvaratnam, 2011). A thorough review of the literature, which focused on appropriate data gathering methods and tools, followed (See Chapter 2). The advantages and disadvantages of each method were carefully considered. In deciding the format of the instrument to use, time for taking the pre-tests and post-tests, context and the participants were taken into consideration.

3.5.4 Pilot of the study

The study was piloted to check the suitability of research instruments. The pilot study attempted to implement an instructional module that could facilitate conceptual change and possibly ameliorate pre-service teachers’ conceptual and procedural discrepancies they exhibit in their conceptions of math-in-science while solving physical science problems. A possible corollary is that the students be provided with basic mechanics key concepts, their definitions, formula derivatives as well as worked out examples through mathematical modelling that could also help them make strategic connection between relevant mathematical and physical science concepts.

To do this there was a need to examine the concepts of work and energy that were held by the pre-service teachers (Appendix B – items 1-1.21, 2.1-2.2, section A of the PSAT) and their learning strategies before the intervention (Appendix C – items 3.1- 3.5, section B of the PSAT). The primary focus was not on the entire mechanics module for the second and third year physics education, but on the two generic concepts cutting across the curriculum of the Faculty i.e. work and energy. These two concepts constituted the central concern of the study. The underlying assumption is that the envisaged module would impact on the way that other modules are taught. Some lessons learned from the pilot study phase led to effecting some changes in the study phase. The discussions that follow focus on the changes made in methods of data collection, theoretical framework, reliability and validity issues, and data analysis.

3.5.5 Validity and Reliability procedure

A valid instrument is one that measures what it is supposed to measure (Ogunniyi, 1992). Fraenkel and Warren (2000, p.169) assert that validity refers to the appropriateness, meaningfulness and usefulness of the specific inferences researchers made based on the data collected using an instrument. The validation of an instrument therefore ensures that the data collected using the instruments can be used to draw valid interpretations and inferences about the participants' characteristics under study.

The instruments used in this study went through various processes of validation e.g. instruments were submitted to four science and mathematics university lecturers to review the items in terms of linguistic clarity, question construction, scientific accuracy of the items; the time allocated; the readability, comprehensiveness i.e. that the aspects of work and energy content was adequately covered and the suitability of the test for the particular level of study. Meetings to meet with the reviewers of the instrument (lecturers) were scheduled. Several postponements to meet deadline (finalization) of the instrument were experienced, at times reviewers gave excuses why they needed more time to critique the instrument.

All of these excuses led to several postponements which were handled professionally by the researcher and regarded as part of learning experience. The question of how long is necessary was asked by the researcher, all the responses

received amounted to “ifs”. To immune and subjugate delays for the data to be collected, on the one hand, participants of the study were kept posted about the development, on the other hand copious phone calls were constantly made to persuade the instrument reviewers (lecturers) to speed up reviewing processes.

After all, a discussion about all the aspects ensued, gaps were filled and discrepancies, inconsistencies and ambiguities detected by the reviewers of the instruments were removed. Suggestions made by the reviewers (lecturers) required that the instruments be reduced in terms of quantities. The final revised instruments reflected both the input from persons with considerable knowledge in the specific content area, and as well as student (users of the instrument) input, and as such, the instruments were assumed to have face, content and construct validity. There was also the need to re-structure some of the instruments of the PSAT, after this was done to the satisfaction of the reviewers, the instruments were again submitted to peer-group comprising of both masters and PhD students for review and rating.

3.5.6 Reliability procedure

Reliability constitutes the ability of a measuring instrument to produce the same answer or result on successive occasions when no change has occurred in the thing being measured (Gay *et al.*, 2006). Reliability sometimes known as dependability or trustworthiness is expressed numerically, usually as a reliability coefficient. There are at least five different methods to establish reliability of an instrument in social science education research.

For the sake of brevity, the present study deemed it necessary to consider three out of five known methods to establish its instrumentation reliability. Thus, the stability method (also called test-retest method), internal consistency method, scorer or rater reliability method. To test instrumentation reliability of the study, it follows that the ratings obtained from the aforesaid groups above were then subjected to appropriate formulae (e.g. the Spearman-Brown formula). Consequently, inter-rater agreement of 0.85 was obtained which indicated a degree of validity in terms of content items.

Further, there was the need to establish the extent to which items in the pre-test – post-test are consistent among themselves and with the test scores as a whole. Internal consistency reliability was sought; a 0.66 was obtained when subjecting

PSAT items to the split-half method of item analysis. The split was made by separating all the odd numbered items from the even ones. A reliability coefficient of such value indicates that the PSAT items to some great extent are likely to yield consistency.

The index of reliability, that is, correlation coefficient (r) was sought, to check whether the said instrument is capable of delivering the same or similar results consistently when administered to the same participants of the study. In order to achieve this, the stability (test-retest) method was recruited. Both the E-group and C-group completed the PSAT pre-test and then three weeks later they were tested again (i.e. post-test). Two tests (pre-test-post-test) of scores obtained from both groups were correlated using Pearson Product Moment. A 0.77 correlation coefficient was obtained which indicated the extent of the instrument's consistency of the test scores for the two groups.

It worth note taking that, though one may obtain a high reliability coefficient of say 0.92 (which is definitely good), it does not necessarily mean that scores obtained perfectly reflected the participants' status with respect to the variable being tested, hence no test is perfectly reliable (Gay *et al.*, 2006). So many factors can be responsible for low or high reliability coefficient such as Hawthorne effect. Nevertheless, Fraenkel and Wallen (2008) suggest a reliability coefficient of 0.70 for an instrument to be considered reliable. Thus the instruments were deemed valid and reliable for use in data collection.

3.5.7 Trustworthiness

So far, I have explained various methods used in the study to validate the instrument used for collecting data as well as ensuring its reliability in terms of stability, inter-rater agreement, and internal consistency. For the quantitative parameter of the study, what is yet to be considered is its validity. Thus, in qualitative research, validity is the degree to which the qualitative data collected accurately gauge what is trying to measure (Gay *et al.*, 2006, 370:403).

Qualitative researchers can establish the trustworthiness of their research by addressing the credibility, transferability, dependability, and conformability of their studies and findings. For the present study, utmost care was taken to ensure that all

the complexities that are present in the study are addressed such as problems or patterns that are not easily explained. To achieve this, triangulation which is the use of different strategies and instruments in gathering and analyzing both qualitative and quantitative data (Cohen, *et al.*, 2007) was employed.

3.5.8 Purpose of the Learning Journal

As shown in Figure 3.6, the participants of this study comprised 16 second and third year pre-service science teachers in one of the historically black universities in the Western Cape Province (Cape Town), South Africa. The researcher compiled a learning journal (*a diary comprising of a learner's self report and reflections of his/her learning processes*). The learning journal was completed individually as instructed.

The purpose of the learning journal for the study was in twofold namely: (1) to help participants to analyse, assess and reflect upon their own learning process and thus enhance their own learning of the concepts of *work* and *energy* (2) to help the researcher to follow and evaluate participants' learning processes, conceptual difficulties they overcome in solving mathematical problems in physical science. Further, the participants were encouraged to make notes separately as they study given sections in the journal and once they are satisfied with their solution, then they write it down according to the instruction. Also, writing legibly and presenting their work neatly in the learning journal were included in the instructional section of the journal. At the end of each teaching session throughout the study participants handed in the learning journal to the researcher and collected it at the start of teaching session.

A thorough review of relevant research literature led to a selection of the instrument format in the learning journal and research methods used in the study. The PSAT (Physical Science Achievement Test) and MRQ (Multiple Reflective Questions) pre-test was administered to sixteen participants after modifications were made. The post-test was administered to the same sixteen participants comprising of second and third year pre-service science teachers upon the completion of the intervention. The data from the instrument was analysed and semi-structured interviews were then conducted with five participants who volunteered in order to triangulate the data

obtained from them. All the data was again analysed using quantitative and qualitative methods. The research design employed in the study is summarized in Figure 3.6 below:

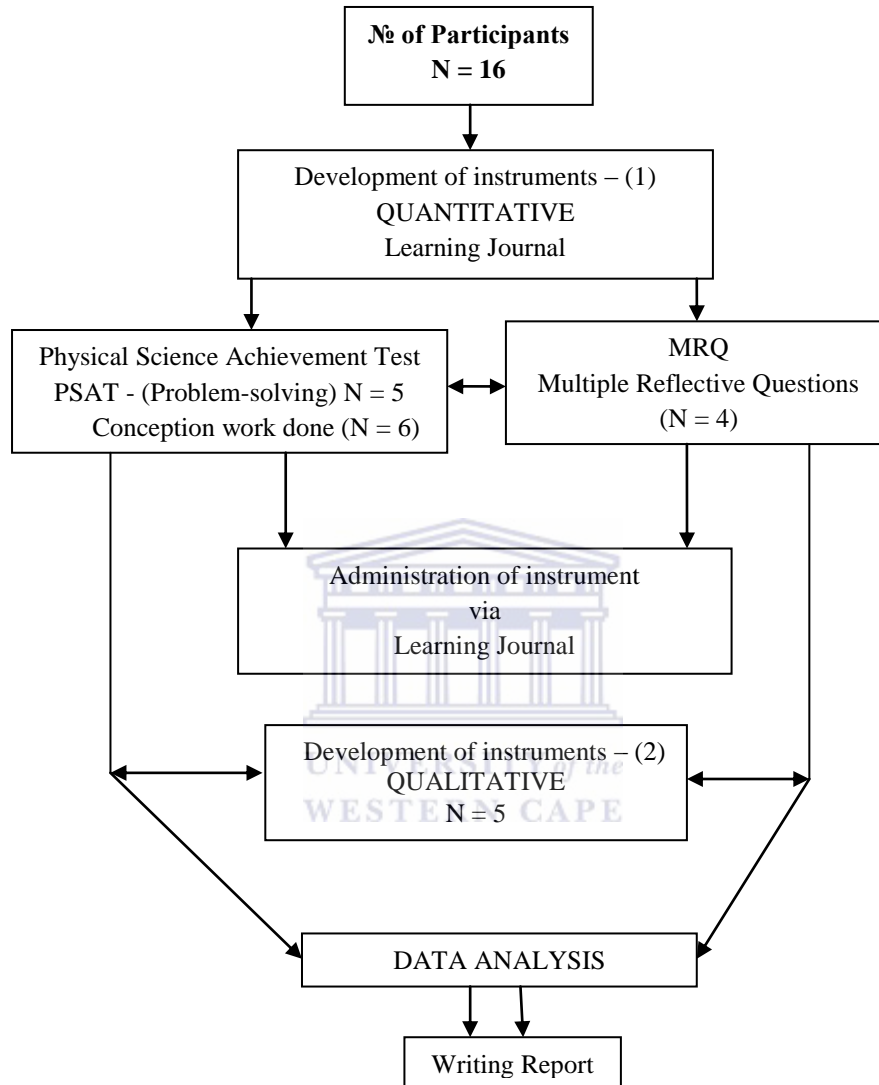


Figure 3.6 A pictorial representation of the methodological process

3.6 Data collection

The primary focus of data collection in this study was to engender instruments that could examine pre-service teachers' conceptual difficulties in solving mathematical problems in basic mechanics, of which sub-concepts such as work and energy are chosen as generic topic of interest in the study.

3.6.1 Administration of the PSAT

First, the purpose of the PSAT and the overall research plan was explained to the pre-service teachers to decrease the anxiety normally associated with such “tests” and to emphasize the need to take the PSAT seriously. The final PSAT was administered, as a test, to the both groups (control group and experimental group). Because the two groups at the time of the study were receiving their lecture classes on two separate campuses of the same institution.

Different days and times were scheduled to administer the instrument. With the (E-group) stationed at the main campus far away from the (C-group). This, however, posed inconveniences as well as additional costs on the researcher to administer the instruments. Full lecture period of about 55 minutes was allocated to complete the test. A colleague (science education lecturer) sat in to check whether these instructions were clearly conveyed and to assist with any questions of clarity that might come up during the session. No extra time was allowed as full lecture period of about 55 minutes was good enough to complete the PSAT test, except for two participants who arrived late due to transport delay.

3.6.2 Probing content knowledge of the E-group at the level taught

For section B of the PSAT, particular effort was made to ensure that the context was such that the pre-service teachers, as far as possible, were able to relate to work and energy diagram, and situations and identify key concepts, known and unknown quantities (data) needed for solving a particular problem, especially those questions that are deep rooted in mathematical structures or content. To illustrate this, I have included one of the questions that pre-service teachers struggled with to grasp the nature of mathematical concepts in it during the intervening teaching session (i.e. prior to the post-test).

As can be seen in Figure 3.7, the problem statement of the question presented a context in which a 3kg block slides at a constant velocity of 7m/s along a horizontal surface. It then strikes a rough surface, causing it to experience a constant frictional force of 30N. The block slides 2m under the influence of this frictional force before it moves up a frictionless ramp inclined at an angle of 20° to the horizontal. It follows that the question required a free-body diagram to be drawn to show all the

forces acting on the block as it moves a distance Δx up the ramp, before it comes to rest. In response to the question, free-body diagrams drawn by the pre-service teachers fall short with what Mayer (1992) called problem representation, in which a student builds mental representation of the problem and illustrate it on a free-body-diagram. Thus, many pre-service teachers could not sketch correct free-body diagram that represents the problem. Only four out of the sixteen participants sketched the free-body diagram correctly, which exhibited the notion they held.

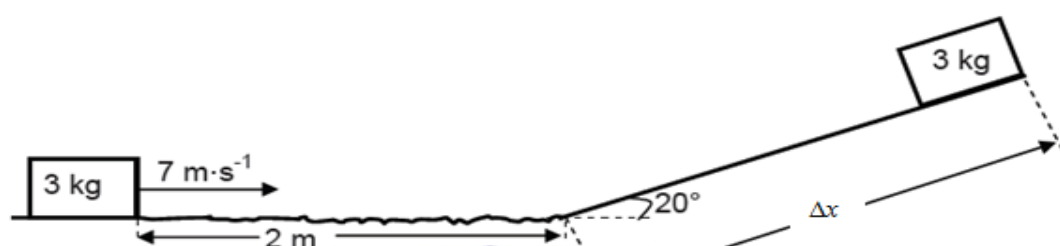


Figure 3.7: Diagram of work-energy

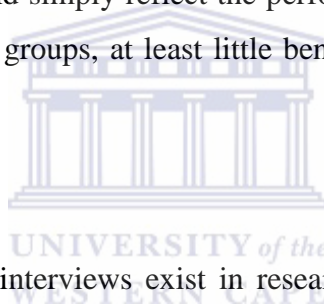
The next question that followed was problem-solving, which says by means of apposite calculation show that the speed of the block at the bottom of the ramp is $3 \text{ m}\cdot\text{s}^{-1}$. Many pre-service teachers could not differentiate between two related concepts (e.g. net force F_{net} and acceleration), others lack conceptual model on which to base their interpretations and calculations in respect to the distance of 2 m covered along the rough surface. Others were stuck in the ambit of what transpired between the rough surface and smooth surface (i.e. friction surface and frictionless surface).

Those who managed to state the correct formulae could not proceed due to misinterpretation or lack of procedural knowledge. Next, in the same problem, the third question required that the distance (Δx), the block slides up the ramp be calculated. Again, majority of the pre-service teachers failed to solve the problem, few attempts made came from those who managed to draw the free body diagram correctly, and even so they did not arrive at the correct answer. In order to address

such challenges, the wheel of the intervening teaching and learning was adjusted, for example, cooperative-group problem solving was adopted for four reasons:

- to enable pre-service teachers share their conceptual and procedural knowledge as they solve problems together,
- to enable the pre-service teachers to observe each other perform the IDEAL thinking and solving strategies discussed earlier,
- mutual critique would clarify all the members' thinking about the concepts in question, and how those concepts and principles should be applied to a particular problem, and
- members can request explanations and justifications from one another

If on the other hand, the desired conceptual change did not occur in the groups, then the group solutions would simply reflect the performance of the highest ability pre-service teacher(s) in the groups, at least little benefit would accrue to anyone from the exercise.



3.6.3 Interview

There are two types of interviews exist in research, namely, structured and semi-structured interviews. According to Schuman and Presser (1981) a structured interview consists of pre-specified questions and the response of the respondent is greatly restricted. While a semi-structured interview in turn allows the respondent to freely express his/her view on a certain issue. Thus, the type of interview used in this study was unstructured interview.

An unstructured interview was adopted to make up for the participants in the study who are English second language speakers; hence unstructured interview allows them to express themselves verbally. Also, this method was used to determine their version of reality, that is to say, their opinions in those PSAT questionnaire items that required personal expression and justification. The interview also provided me with a means to triangulate the various data sources and in this way robustly validate the probes used. I performed the interview myself following interview guides that were prepared prior to the interview. The interview was audio recorded and

transcribed verbatim by me. Next, I will discuss the process of setting up and conducting the interviews and provide detailed accounts on how I attempted to address various issues, especially those relating to validity and reliability of the interview.

3.6.4 Designing the interview instrument

The interview items instrument was constructed in such a way that it yields data combinations that answer the research questions. Also the interview items were constructed to mitigate or broaden the parameter of the PSAT instrument used to collect data quantitatively (see Appendixes B of section A and Appendix C of section B). It consisted of 5 item questions. It was drawn up by selecting a format and ideas that could minimize the discrepancies reported in the aforesaid relevant studies (Kim and Pak, 2002; Heller *et al.*, 1992; McDermott, 1993). All the 5 items were directly linked to the basic mechanics concepts of work and energy used to answer the four research questions.

After setting up the interview instruments, I sought for instrument validation. The previous PSAT instrument reviewers (four science and mathematics university lecturers) were consulted for further assistance to scrutinize the interview instrument. Since they know already the purpose of the study, they employed usual critique process, leaving nothing untouched. After the vigorous processes in reviewing the interview instrument by the panel, recommendations with minor changes were accrued.

3.6.5 Conducting the Interviews

In order to counter threats to internal validity, the study ensured appropriate procedures which prevent bias or personal preference. As pointed out earlier, the participants in the study comprised of two categories based on their combination of subject majors, that is, mathematics pre-service science teachers (C-group) and mathematical literacy pre-service science teachers (E- group). For conveniences, I sought for 5 volunteers from the two groups. Those were willing indicated their interest so they were selected. It follows that three out of the five volunteers came from the E-group and the two came from the C-group. In what followed, both groups

were interviewed with the same set of instrument. Time was allocated for the overall interview, 50 minutes was considered appropriate, however, additional time had to be given for the interviewees whose first language is not English, to enable them to think through the question and formulate a response (Sanders and Mokuku, 1994). There was the need to assign maximum time allowed for each interview item, such was necessary for the following reasons: (1) to ensure that each participant has equal time to respond (i.e. fair chances for all participants), (2) to avoid unnecessary time wasting on issues that are beyond the scope of the study, (3) participants may add to their learning how to manage time effectively when responding to questions (e.g. exams or test).

On the one hand, (Gunstone and White, 1992) were of the opinion that if the questions are asked too quickly then the interviewees might become flustered or unresponsive since it might seem as if their ideas are not being properly acknowledged (p. 86). However, time allocated for each interview item was not fixed throughout the interview, where and when necessary, time was adjusted fairly specially in some cases (when a novel idea came up) I had to probe deeper, this took more time. On the other hand, I had to consciously decide when to move on to the next question. Those who responded out of context were asked to reconcile any discrepancy between the two concepts of work and energy they held. Thus, both the researcher and participants in the study benefited.

3.7 Limitations of the study

The study was limited to one university as pointed out in Chapter 1. In view that the participants of the study are my students, under normal circumstances this could pose a problem of contamination of treatment between the two groups (E-group and C-group), but the chances of contamination of data are rare, which I shall discuss in the next section.

3.7.1 *The situation with the E-group and C-group*

One may argue that since both E-group and C-group participants in the study are my students and coming from the same faculty, they might communicate with each other and share knowledge gained through the intervention sessions (including the

use of mathematical modelling and other exemplary materials) the validity and reliability of the study will be greatly compromised. However, with the situation in the Further Education and Training (FET) faculty, this problem is not likely to occur. First, the education faculty at the time of the study was offering FET programs on two separate campuses situated far from each other. The third year (Experimental group) stationed at the main campus of the university far away from where their counterpart (second year – control group) is situated. Neither of the two groups was told they have counterpart elsewhere, thus each group was treated as if they were sole data contributor of the study.

3.8 Ethical issues

Permission to conduct the study obtained from head of the Faculty (Appendix E), Faculty Ethics Committee (Appendix G) and the participants of the study (Appendix F). Also the requirements for conducting the study laid down by the University of the Western Cape were adhered to and the Ethical Code of Conduct Form was filled and submitted to the Dean of Research through the Education Research Committee. The purpose of the study was explained in writing to the mentioned parties and participants of the study were volunteers.

Confidentiality was assured throughout the study. Likewise participants were assured that in cases where their contributions may be used for future references or publication, their identities and interests will be protected such that their confidentiality is guaranteed. To demonstrate this, the techniques and methods for the data collection did not seek for the participants personal details such as names; student number, rather alphabetical letters were used throughout the study and this was made coherent to the readers. Participants were oriented; during this section they were encouraged to be honest in providing all the necessary paper work such as answering the PSAT and interview instruments.

3.9 Time framework and work plan of the study

The study was conducted during the first semester in which the pre-service teachers were doing physics modules. The targeted time of when the PSAT instrument content should be administered was carefully included in the planning and designing of the instruments so as to obtain tangible result (see the time and work plan designed for the study below):

Table 3.2 Time frames for research activities

| ACTIVITIES | Feb 2012 | Mar Apr 2012 | May 2012 | June 2012 | July 2012 | Aug 2012 | Sep 2012 | Oct 2012 | 2012 2013 2014 |
|--|----------|--------------|----------|-----------|-----------|----------|----------|----------|----------------|
| Introduction: Research Proposal | ① | | | | | | | | |
| Writing Proposal | | ② | | | | | | | |
| Final Submit: Research Proposal | | | ③ | | | | | | |
| Building and Discussing instrument | | | | | ⑤ | ⑥ | ⑦ | ⑧ | |
| Ethical Consideration | | | | ④ | | | | | |
| Permission to do research at the institution | | | | | | | | | |
| Data Collection (pre- & post-test) | | | | | | | | ⑨ | |
| Data Analysis | | | | | | | | ⑩ | |
| Writing Report | | | | | | | | ⑪ | |
| Submit 1 st draft: Research | | | | | | | | ⑫ | |
| Submit Final Draft | | | | | | | | ⑬ | |

3.10 Data Analysis

Quantitative and qualitative methods were used to analyse the data obtained from the PSAT. The PSAT was marked according to a memorandum (see Appendix D) and rubrics (see Table 3.3) that had been jointly agreed on with three other science education lecturers who have commendable knowledge in the content examined. Further, descriptive statistics used included mean, standard deviation and percentages. A Microsoft office EXCEL programme – Analysis ToolPak-VBA was used to perform a descriptive statistics for t-test to test for significant differences. Qualitative analysis of the free response items and MRQ explanations were interpreted as provided by the pre-service teachers. Attempt of coding or categorizing of interview responses was later considered to be unnecessary as no emerging responses were noted. However, alternative approach used to make up such shortcoming was to compliment the quantitative and qualitative responses

comparably. A constant probe of both qualitative and quantitative responses was applied throughout the data analysis.

3.10.1 Assessment (marking & recording) of PSAT pre-post-tests

Positive marking regarding problem-solving in the PSAT instrument was followed. Guidelines as well as rubrics shown below were implemented:

- When a final answer to a calculation is correct, full marks were not automatically awarded until I check that the correct/appropriate formula has been used and that workings, including substitutions, are correct.
- If for example, wrong answer is obtained due to any common error (e.g. calculator), but correct substitution was made, then appropriate mark is allocated for the correct substitution and not for the final answer.
- If one answer or calculation is required, but two are given by the pre-service teacher, only the first one will be marked, irrespective of which one is correct. If two answers are required, only the first two will be marked, etc.

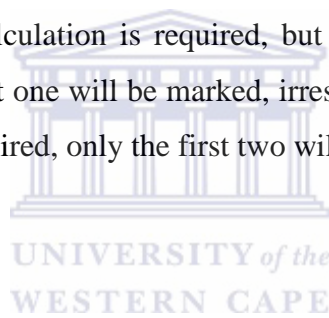


Table 3.3 Rubrics for making pre-test - post-test PSAT items

| Qs No. | Suggested Answer(s) | Mark |
|--------|---|-----------------------|
| 1. | Force F and displacement (Δx) are stated in the definition | 2 |
| 1.1 | $W = F \times \Delta x \cos \Theta$ | 1 |
| 1.2.1 | Agree Reason: Explains that because her displacement is zero | 1 2 |
| 2.1 | Work done Reason: Explanation mentioned product of F and Δx | 1 1 |
| 2.2 | No work done Mentioned that there is no horizontal displacement & $\Theta = 90^\circ$ | 1 1 |
| 3.1.1 | Correct sketch of forces Correct listing of forces Correct representation of forces | 1 1 1 |
| 3.2 | Correct formulae (TWO formulae required for solution) Acceptable explanation Identify known & unknown quantities (data from given problem) Show step-by-step solution (conceptual & procedural accuracy) Arrival at the answer (explanation of how) | 2 1 1 2 1 |
| 3.3 | Correct formulae (ONE formula required for solution) Acceptable explanation Identify known & unknown quantities (data from given problem) Show step-by-step solution (conceptual & procedural accuracy) Arrival at the answer (explanation of how) | 1 1 1 3 1 |
| 3.4 | Correct formulae (ONE formula required for solution) Acceptable explanation Identify known & unknown quantities (data from given problem) Show step-by-step solution (conceptual & procedural accuracy) Arrival at the answer (explanation of how) | 1 1 1 3 1 |
| 3.5 | Correct formulae (ONE formula required for solution) Acceptable explanation Identify known & unknown quantities (data from given problem) Show step-by-step solution (conceptual & procedural accuracy) Arrival at the answer (explanation of how) | 1 1 1 2 1 |
| | | 40 |

3.10.2 Data analysis for conceptual and procedural knowledge (PSAT)

The Bloom's Revised Taxonomy (BRT) table has been recruited (Table 3.4) to categorize and analyse data collected in respect of the main research questions that underlies conceptual and procedure knowledge (reveals how given problems are solved) . The BRT is used in three folds viz:

- (1) To make explicit pre-service teachers' conceptual and procedural discrepancies with respect to knowledge and strategic connections while solving mathematical problems in physical sciences
- (2) To show the breadth, or lack of, or kind of knowledge within the knowledge domain that pre-service teachers exhibit while solving given problems
- (3) To show pre-service teachers' mathematical knowledge retention, transferability and application across the spectrum of cognitive domain

With BRT the research questions that focused on the pre-service teachers' conceptual and procedural difficulties that impedes their abilities to solve mathematical problems in physical science can be tackled, in particular the conceptual and procedural knowledge domain addresses pre-service teachers' conceptions with respect to identifying key concepts in the problem statement, understanding problem terminology, principle(s) underpinning given problem, modelling mathematical concepts in science, interpretation of both known and unknown quantities, unifying math-in-science specific skills and algorithms and specially determining when to use appropriate procedures. Further, the metacognitive knowledge galvanizes how the pre-service teachers make strategic connections between relevant mathematical and physical science concepts while solving science problems. Accordingly any objective could be classified in the Taxonomy table in one or more cells that correspond with the intersection of the column(s).

Table 3.4 Revised Taxonomy table for knowledge and cognitive process dimension

| The Knowledge Dimension | The Cognitive Process Dimension | | | | | |
|-------------------------|---------------------------------|------------------|-------------|---------------|----------------|--------------|
| | 1. Remember | 2. Understand | 3. Apply | 4. Analyze | 5. Evaluate | 6. Create |
| Factual Knowledge | | | | | | |
| Conceptual Knowledge | | | | | | |
| Procedural knowledge | | | | | | |
| Metacognitive Knowledge | | | | | | |

Source: (Krathwohl, 2002, p.216)

3.10.3 *Quantitative descriptions of PSAT pre-test & post-test analysis*

The sixteen pre-service teachers (PT) were identified alphabetically (A – P) in the first column of Table 3.5, where (A – I) represents the C-group and (J – P) represents the E-group. The second column represents E-group and C-group sample. With the gender (G), the number of problems solved (n), and the number of correct responses for the maths-in-physical science problems of the mechanics (work and energy) are listed for each pre-service teacher. The problems were then labeled D_1 , D_2 and D_3 in terms of the level of: (1) mathematical content knowledge needed to solve them, and (2) conceptual and procedural difficulties likely to occur. The letter D has been used to label level of difficulties, where (D_1 = minor difficulty, D_2 = major difficulty, and D_3 = atypical difficulty). With $n = D_2 + D_3$, (see Table 3.5). Thus, these levels of difficulties (D_1 , D_2 and D_3) are therefore linked to the four knowledge domains and six cognitive processes in Table 3.4, where a pre-service teacher who is able to deal with problems level of D_1 (e.g. items 1.0 – 2.2 and 3.1) can be said to have factual knowledge, that is, fundamental elements that students must know to be acquainted with a discipline or solve problem in it.

A pre-service teacher who is able to deal with problems level of D_2 (e.g. item 3.5) can be said to have both conceptual and procedural knowledge, that is to say, he/she above factual knowledge has knowledge to identify key concepts of the problem, categorize and connect principle/theory, model math-in-science structure, has knowledge of subject specific skills and algorithms, and most importantly knows how to use method or strategies to solve the problem. While a pre-service teacher who is able to deal with problems level of D_3 (e.g. items 3.2 – 3.4) can be said to have metacognitive knowledge, that is to say, he/she does not only have factual, conceptual and procedural knowledge, but has strategies knowledge and has acquired individual problem solving skills, which can be traced in the problem-solution produced by any group he/she involved with during the intervening teaching and learning sessions (see last paragraph of section 3.6.2).

The rest of Table 3.5 shows the pre-service teachers' responses and conceptual difficulties, which will be discuss and interpreted in Chapter 4. The absence of a pre-service teacher on the day of a particular test (i.e. pre-test and post-test) is indicated with a minus sign. The total number of the PSAT items was 11, comprised of section A and section B. The section A consisted of 6 items, (items 1 – 1.2.1) and (items 2.1 – 2.2) involved testing of conception of work and energy pre-service teachers held, with no problem solving. Section B involved problem solving of work and energy concepts, consisted of items (3.1 – 3.5). These items were used to test pre-service teachers' conceptual and procedural difficulties with levels of difficulties labelled (D_1 , D_2 and D_3). For the PSAT pre-test analysis, (see Table 3.6, Appendix H).

Table 3.5 Descriptions of PSAT post-test analysis²

| <i>PT</i> | <i>C & E Group</i> | <i>G</i> | <i>n</i> (4) | <i>Minor</i> D_1 | <i>Major</i> D_2 | <i>Atypical</i> D_3 | <i>Total marks</i> | <i>N</i> |
|-----------|------------------------|----------|-----------------|-----------------------|-----------------------|--------------------------|--------------------|----------|
| A | C ₁ | m | 3 | 4s, 3u | 1s | 3s | 28 | 8 |
| B | C ₂ | m | 1 | 4s, 3u | 1u | 1s, 2u | 17 | 5 |
| C | C ₃ | f | 1 | 5s, 2u | 1z | 1s, 2z | 18 | 6 |
| D | C ₄ | m | 2 | 5s, 2u | 1z | 2s, 1u | 22 | 7 |
| E | C ₅ | f | 2 | 7s | 1u | 2s, 1u | 24 | 9 |
| F | C ₆ | m | 1 | 4s, 3u | 1u | 1s, 2u | 14 | 5 |
| G | C ₇ | m | 3 | 6s, 1u | 1s | 2s, 1u | 27 | 9 |
| H | C ₈ | m | 4 | 6s, 1u | 1s | 3s | 27 | 10 |
| I | C ₉ | m | 1 | 7s | 1u | 1s, 2u | 18 | 8 |
| J | E ₁ | m | 2 | 4s, 3u | 1s | 1s, 2u | 18 | 6 |
| K | E ₂ | m | 3 | 6s, 1u | 1s | 2s, 1u | 25 | 9 |
| L | E ₃ | m | 1 | 3s, 4u | 1z | 1s, 2u | 9 | 4 |
| M | E ₄ | m | 0 | 1s, 6u | 1z | 3u | 5 | 1 |
| N | E ₅ | m | 0 | 4s, 3u | 1u | 3u | 9 | 4 |
| O | E ₆ | m | 2 | 5s, 2u | 1u | 2s, 1u | 24 | 7 |
| P | E ₇ | m | 3 | 7s | 1s | 2s, 1u | 30 | 10 |

Key: *PT*= Pre-service teacher, *C & E-group* = Control & Experimental group, *G* = Gender, *n* = Number of problems solved, *N* = number of correct responses

² For the three levels of difficulties D_1 , D_2 and D_3 , there are three code labels, *S*, *U* and *Z*. A satisfactory response is marked by *S*. A frequent but unsatisfactory response that is not correct is marked by *U*. While no responses is marked *Z*. **For example, 2u means 2unsatisfactory responses to the question level of difficulty.** The total number of correct responses is *N*.

3.10.4 Description of Problem-Solving Strategy

The instructional literature underpinning the present study recommends several strategies to help students integrate the conceptual and procedural aspects of problem solving in mechanics (e.g. work and energy). Of immediate relevance to the basic form of the problem-solving strategy for the pre-service teachers in this study was strongly influenced by the work of (Kim and Pak, 2002 and McDermott, 1993), but it has many elements in common with (Heller *et al.*, 1992 and Reif and Allen, 1992) and that of (Redish, 2005) model for the use of maths-in-science problem solving. McDermott's study (1993) which recommends the use of algebraic formalism should be postponed until after qualitative understanding of the concepts in question is developed. Hence, I inculcated such emphasis during the intervening teaching and learning and have made the inception of Figure 3.8 – constructing meanings as benchmark to ensure that qualitative understanding of key-concepts (work –energy concepts) was developed before algebraic formalism. As such, the third level (laws and rules) typify algebraic formalism and physics concepts (i.e. connecting physics and mathematical concepts).

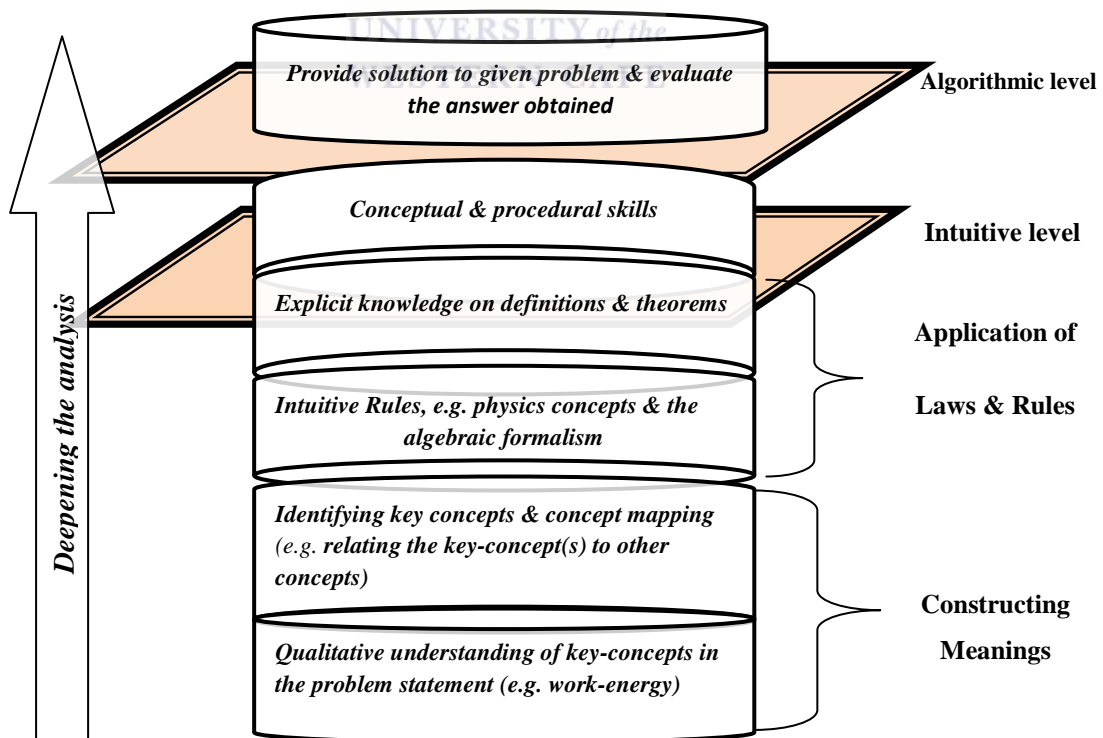


Figure 3.8 Conceptual and Procedural Obstacles can lie deeper

As pointed out earlier in Chapter 3 (section 3.3.2), a form of concession that knit all the recommended solving strategies to help pre-service teachers' understanding of problem-solving has been given a heuristic name known as *IDEAL*. For example, a translation of *IDEAL* into problem situation of PSAT (item 3.3) would expect the pre-service teachers to use their qualitative and quantitative understanding of work and energy in respect to Physics and Mathematical principles to read and understand problem statement (identify the problem – i.e. visualize the problem), define and represent the problem (e.g. Devise a plan- use Free Body Diagram), explore possible strategies (plan a solution), act on the strategies (execute the plan), and look back and evaluate the reasonableness of their answer.

In PSAT Item 3.3 (see appendix C) of all the tested items, many students found item 3.3 very challenging which is a problem of D3 (atypical difficulty), as a result struggled to solve the problem. More details on how various groups (E and C groups) responded to the item will be discussed in depth shortly. To illustrate item 3.3 using *IDEAL* strategy, one main problem statement containing five items (3.1 - 3.5), of which item 3.3 is a part was given, the main problem statement reads - the transportation of goods by trucks adds to the traffic problems on our roads. *A 10 000kg truck, starting from rest, travels down a straight inclined road of length 20m which forms an angle of 30° with the horizontal. The truck undergoes a constant acceleration of magnitude 2m/s² while travelling down the inclined road. The total work done by the engine of the truck to get to the bottom of the inclined road is 7000 J. A constant frictional force opposes the truck's movement.* It follows that the question required a free-body diagram to be drawn (item 3.1) to show all the forces acting on the truck as it moves down to the bottom of the road while item 3.2 required the pre-service teachers to calculate the kinetic energy of the truck, using the equations of motion. Of the most challenging part, item 3.3 required that the work done on the truck by the frictional force be calculated using work-energy theorem. Below is a translation of *IDEAL* into problem situation of PSAT (item 3.3):

- **Identify the problem – i.e. visualize the problem:**

Using work-energy theorem

Since the problem statement restricted to work-energy theorem equation to be used: $W_{net} = \Delta K$

Thus, work net is equal to the sum of all the individual work done by all the forces acting on the truck as it moves down to the bottom.

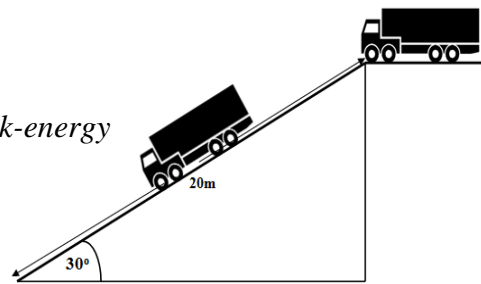


Figure 3.9: Physical representation of moving truck

- **Representation of the problem using a Free-Body-Diagram**

Physics description:

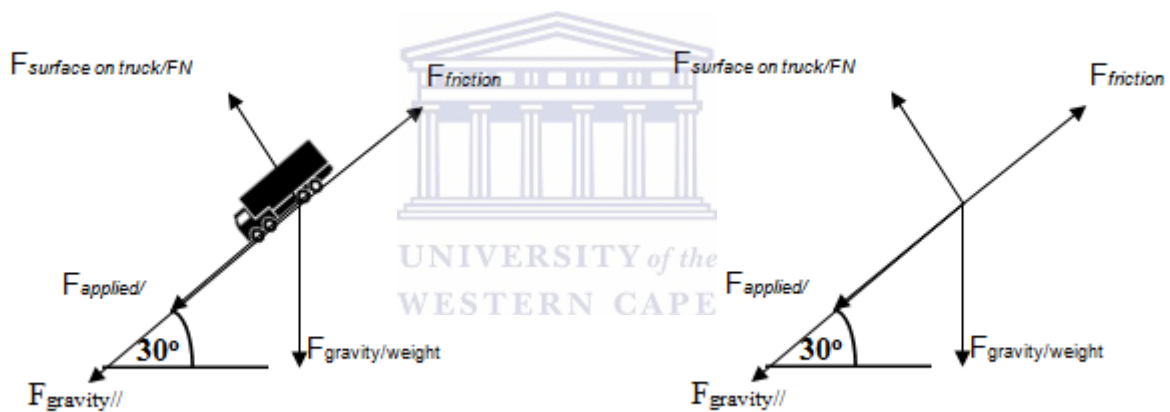


Figure 3.10: Force diagram of forces acting on the truck

Figure 3.11: Free-body- diagram of forces acting on the truck

- **Explore possible strategies:**

From the Free-Body-Diagram, there are three individual forces that have done work on the truck in the same and opposite direction while the truck moves down to the bottom of the road. The three individual forces are: (1) the applied force (the same direction with the displacement Δx), (2) Force of gravity parallel to the incline (the same direction with the displacement Δx), and frictional force (opposite direction with the displacement Δx). With work-net ($W_{net} = \Delta K = \Sigma W = F_{net} \cdot \Delta x \cdot \cos\theta$). Then, $W_{net} = \Sigma W = W_{F_A} + W_{g_{\parallel}} + W_{F_f}$.

Key concepts: what information is important? And what information is missing?

ΔK = change in kinetic ($K_{final} - K_{initial}$)

W_{F_A} = work done by applied force/engine of the truck (7000J)

$W_{g_{\parallel}}$ = work done on the truck by gravity parallel to the incline ($W_g / W_{g_{\parallel}} = ?$)

W_{F_f} = work done on the truck by the frictional force ($W_{F_f} = ?$)

m = mass of the truck (10 000kg)

g = acceleration due to gravity (9.8m/s^2)

a = constant acceleration of the truck (2m/s^2)

θ_1 = angle of incline (30°)

θ_2 = angle representing direction of motion

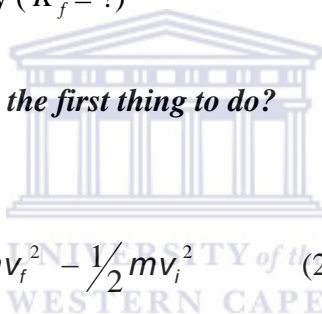
Δx = change in displacement ($x_f - x_i$) (20m)

v_i = initial speed of the truck (0 m/s)

v_f = final speed of the truck ($v_f = ?$)

K_i = initial kinetic energy (0J), hence $v_i = 0$ m/s

K_f = final kinetic energy ($K_f = ?$)



Plan a solution: What is the first thing to do?

First find ΔK and $W_{g_{\parallel}}$

$$(1) W_{net} = \Delta K = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 \quad (2) W_{g_{\parallel}} = mg \sin \theta_1 \cdot \Delta x \cos \theta_2$$

Need to find v_f :

$$(3) v_f^2 = v_i^2 + 2a\Delta x$$

$$(4) K_f = \frac{1}{2}mv_f^2$$

$$(5) W_{F_f} = W_{F_A} + W_{g_{\parallel}} - \Delta K$$

▪ **Act on the strategies (execute the plan)**

***use equation 3 to find v_f ***

$$v_f^2 = v_i^2 + 2a\Delta x \Rightarrow v_f^2 = 0^2 + 2 \times 2 \times 20 = \mathbf{80}$$

*** use equation 5 to find W_{F_f} ***

$$W_{F_f} = W_{F_A} + W_{g_{\parallel}} - \Delta K$$

$$W_{F_f} = W_{F_A} + mg \sin \theta_1 \cdot \Delta x \cos \theta_2 - \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$W_{F_f} = 7000 + (10000 \times 9.8 \times \sin 30^\circ \times 20 \times \cos 0^\circ)$$

$$- \frac{1}{2} \times (10000)(80) + \frac{1}{2} \times (10000)(0)^2$$

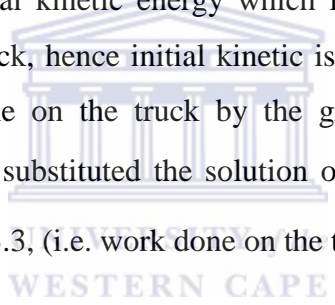
$$W_{F_f} = 7000 + 980000 - 400000$$

$$W_{F_f} = -587000J$$

$$\therefore W_{F_f} = \mathbf{587000J}$$
 (F_f has done work in opp. direction to the movement of the truck)

▪ **Look back (check) and evaluate the reasonableness of the answer.**

- We have 5 equations and 4 unknowns ($K_f, v_f, W_{g_{\parallel}}$ and W_{F_f})!
- We solved (3) to obtain v_f and substituted it into (4) to find the solution for the item 3.2 (final kinetic energy which is equal to the change in kinetic energy of the truck, hence initial kinetic is equal to zero). We solved (2) to obtain work done on the truck by the gravitational force parallel to the incline $W_{g_{\parallel}}$. We substituted the solution of (4) and (2) into (5) to find the solution of item 3.3, (i.e. work done on the truck by the frictional force W_{F_f}).

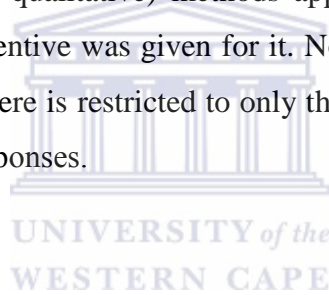


3.11 Summary

A quasi-experimental design was recruited to investigate pre-service teachers' conceptual and procedural difficulties they tend to encounter when solving mathematical problems in physical sciences. The pre-service teachers were categorized into two separate groups namely: control group (C-group) and experimental group (E-group) according to their choices of subject(s) combination with physical sciences. Reasons for the group categorization were discussed earlier in this Chapter. Further, the concepts of work-energy were taught to the pre-service teachers and tested on them at the level taught. An explicit problem-solving strategy known as (IDEAL strategy) complemented with math-in-science instructional model was taught in the intervention sessions (for duration of three weeks lessons) to the pre-service teachers (E-group). For the control group (C-group) they were taught the same work-energy concepts using lecture-demonstration method. Also, the C-group was exposed to the IDEAL solving strategy without the model (i.e. math-in-science

instructional model). With the nature of some of the PSAT items, there was also the need for the study to be carried out in a support cooperative learning environment. In that regard, a pedagogical schema for implementing dialogical argumentation-based classroom discourses- modified after Ogunniyi (2009) as depicted in (figure 4.5) was deemed necessary.

Data was collected using questionnaires, a Physical Science Achievement Test (PSAT), Multiple Reflective Questions (MRQ) and direct interview. A technique (i.e. the revised taxonomy table for knowledge and cognitive process dimension) was recruited to categorise and analyse the level of difficulties for each item tested. The levels of difficulties as already discussed in this Chapter are minor difficulty (D1), major difficulty (D2) and atypical difficulty (D3). The data collected were comparably analyzed to see if a correlation existed between variables based on mixed (quantitative and qualitative) methods approach. Participation in the study was optional and no incentive was given for it. Not all participants chose to answer all questions. Analysis here is restricted to only those questions that pertained to the pre-service teachers' responses.



CHAPTER 4

RESULTS AND DISCUSSION

4.0 Introduction

This chapter describes the results obtained from a small group of second and third year pre-service physical science teachers with the goal of addressing their conceptual and procedural difficulties they tend to encounter in solving mathematical problems in physics. In this chapter, I will present a rich description of the study and the results obtained according to the research questions. In Chapters 1, 2 and 3, I included as much information as possible that had to do with the context, the literatures, the data collection, and the analysis.

The results are grouped under headings derived from the three research questions posed in Chapter 1. As no study is independent of the context in which it is done, relevant literature and theoretical framework underpinning the study are deemed necessary to gauge the findings. The findings will be discussed in two sections. First, findings of the quantitative instrument used for testing the pre-service teachers' conceptual and procedural difficulties in solving mathematical problems in Physical sciences. In the second part is a discussion of the findings on the qualitative instrument.

4.1 Overview

Much work has been done in analysing students' conceptual difficulties in physics mechanics (Kim and Pak, 2002; Redish, 2005), confusion for students (Jewett, 2008), students' deficiencies in interpreting the numerical answer they obtained in a given problem and the knowledge they have (Reif and Allen, 1992), and students' inabilities to connect maths-in-science knowledge (Junkins, 2007). McDermott (1993) have attempted to provide useful suggestions on how to overcome students' persistent conceptual and procedural difficulties by probing the cause-and-effect (see Chapter 2, section 2.13).

Other researchers (e.g. Larkin *et al.*, 1979; and Lawson *et al.*, 1987, p.811-817) have been concerned with the genesis of students' conceptual and procedural difficulties in basic mechanics. Still others (Hestenes, 1987; Hiebert & Lefevre, 1986; Mayer 1992) are specifically trying to understand the cognitive processes involved in learning physics. Some research (Bing & Redish, 2009; Martinez-Torregrosa *et al.*, 2006; Redish, 2005; Selvaratnam, 2011) has focused on students' and teachers' inability to conceptually link the equations, diagrams, or graphs used in physics with the situations they represent. This reflects a basic lack of understanding hidden beneath the ability to do maths-in-science equations (Clement, Lochhead, & Monk, 1981; Sabella & Redish, 2007).

4.2 Pre-service teachers' prior conception of basic mechanics (i.e. work and energy) at the level taught (Section A: Items: 1.0 – 1.2.1 & 2.1 – 2.2)

Six items were used to examine the concept of work that was held by the pre-service teachers as point of reference for their conceptual understanding of work done. The objective of these six items was to ensure that qualitative understanding of the concept of work is developed before the application of algebraic formalism (problem-solving). The underlying assumption is that while item (1.0) focused on scientific definition of work done, then the subsequent item (1.1) would mitigate the components of mathematical definition of work done. These items then expect the pre-service teachers to search for meaning of concept, evaluate their prior concepts held and link mathematical semiotics of work done with respect to their scientific components.

4.2.1 Pre-service teachers' (C and E-group) conceptual ecology on PSAT items (1.0 – 2.2)

As pointed out earlier in Chapter 2 (sections 2.2 & 2.2.1), various scholars (Posner *et al.*, 1982; Hewson and Hewson, 1989, 1991) have sought to unravel the mystery of why conceptual change is so difficult. They have explained that in order for conceptual change to occur, that is, for a learner to revise his/her existing conceptions, such a learner would experience dissatisfaction with existing conceptions, sees a new conception to be intelligent, sees the new conception to be

initially plausible and fruitful. In helping with how the latter can be achieved in teaching and learning situation, the work of (Hewson, 1992) provided at least three ways on how successful conceptual change can take place (see Chapter 1, section 1.8). Having included such guidelines in facilitating the designing and administrating of PSAT instrument to the second and third year pre-service teachers, many pre-service teachers still faced with misconceptions acquired from common sense experiences and difficulties in making concept formation at the level taught. Here are some of the conceptions and alternative conceptions held by both groups (E-group and C-group).

For example, in PSAT item (1.0), here are some of the excerpts provided by the pre-service teachers at the pre-test level:

Item 1.0: Please describe in a few sentences, what you understand by the term “work”.

Pre-service teacher C2: *Work is the product of force and energy used.*

Pre-service teacher C7: *Work is force acting on an object by push or pull.*

Pre-service teachers E1: *Work is the energy used to move stationary object from one point to another.*

Pre-service teacher E6: *Work is energy used up or transformation of energy*

Pre-service teacher C4: *Work is change in energy.*

Pre-service teacher C8: *Work is when a force acts on a person.*

According to Posner *et al* (1982), learning is the result of the interaction or rational activity between what the student is taught and his current ideas or concepts. Of these misconceptions held by the pre-service teachers is by no means a result of acquisition of set of correct responses. Interest in conceptual change has, to a considerable degree, been focused on the problem of students who hold one view in contrast to the canonical view. Like C4 and E6 who were of the opinion at the pre-test level that work is energy used up or change in energy. And yet their persistent to hold incorrect definition of work at post-test level falls short of developing a reasonable view of how a student’s current ideas interact with new. Here the pre-service teachers (C4 and E6) are faced with a challenge to their basic assumptions. Learning, like inquiry, is best viewed as a process of conceptual change (Kuhn, 1970). Kuhn explains that if inquiry is to proceed, the pre-service teachers in

question must acquire new concepts and a new way of seeing the world. As this did not occur (assimilation) in the inquiry minds of the pre-service teachers E6 and C4, he, further explain that their current concepts (alternative conception of work) are inadequate to allow them to grasp some new phenomenon successfully. Thus, more radical form of conceptual change (accommodation), in which the pre-service teachers must replace or recognise their central concepts is necessary.

On the other hand, pre-service teachers (C2, C7 and C8) at pre-test level mentioned one component of correct scientific definition of work, that is, F component. As such, C2 misconstrue displacement (Δx) for energy. If work is defined according to the notion of C2, then work which is a scalar quantity is now a vector quantity, given that force (F , which is a vector) multiply by energy (E , which is a scalar) leaves work as a vector quantity. Even at post-test level, pre-service teachers (C7 and C8) still could not give correct scientific definition of work as the product of force (F) and displacement (Δx) in the direction of the force. In that regard, (Hewson, 1992), argues that there is no sense in which one view can be disappeared to be replaced by the other; students will remember both views and simply say: "I changed my mind" or "it made more sense." It is change of this kind that (Hewson, 1981) called "conceptual exchange."

These misconceptions held by various groups exemplified major concerns pointed out by various scholars (e.g. Kim and Pak, 2002; Lawson *et al.*, 1987, p.811-817; McDermott 1993; Redish, 2005; Reif and Allen, 1992) that commonality of students' misconceptions and conceptual difficulties in the teaching and learning of work and energy quantities have always been a challenge. Only 4 pre-service teachers out of 16 (25%) at pre-test and 6 (37.5%) at post-test held correct scientific conception of work as expected. The little increase at the post-test is evident of pre-service teachers' conceptual ecology.

Item 1.1 expected the pre-service teachers to write down the Mathematical expression (equation) of work done. This item aimed to find out to what extent connection between qualitative and quantitative understanding of work exists in the prior conception of pre-service teachers' maths-in-science. Majority of the pre-service teachers were able to write down correct Mathematical expression of work as

expected ($W = F \times \Delta x \cos \theta$), as such, 10 pre-service teachers (62.5%) with 6 from the C-group (2, 4, 5, 6, 8 and 9) and 4 from the E-group (2, 3, 5 and 6).

Four pre-service teachers (marked by C1, E1, E4, and E7) had incorrect mathematical expression of work done. For example:

Item 1.1: Write down your own definition of work mathematically (i.e. in equation form)

Pre-service teacher C1: wrote ($W = \text{energy/distance}$ or $W = J/\Delta x$)

Pre-service teacher E1: stated that ($W = \text{Power} \times \text{displacement}$ or $W = J/\Delta x$).

Pre-service teacher E4: wrote ($W = \text{charge} \times \text{time}$ or $W = Q \times t$)

Pre-service teacher E7: *The work is the distance travelled by an object pulled times net force used to pull in Newton's per second.*

In item 1.0, definition of work was asked; pre-service teacher C1 was able to give correct scientific definition of work. However, the next item 1.1 asked the same pre-service teacher to write down mathematical equation according to the definition of work in item 1.0. The pre-service teacher C1 was not able to do so. The question here is, what type of conception does C1 have in terms of cognitive processes for retention and transfer? In view of Mayer & Wittrock (1996) explanation of retention and transfer discussed in Chapter 2, such pre-service teacher (C1) might have lacked the ability to remember concept much the same way it was presented in item 1.0 and equally lacked the ability to use what was learned (known) to proceed to new situation (i.e. item 1.1). One of the important conditions that must be fulfilled before accommodation takes place is that *a new conception must be intelligible*. Thus, C1 was not able to grasp or explore the possibilities inherent in his conception of item 1.0 and see how the two items (1.0 and 1.1) can be reconciled or related.

According to the theoretical framework underpinning the present study (conceptual change theory), there are several important conditions which must be fulfilled before an accommodation is likely to occur. (1) *There must be dissatisfaction with existing conceptions*. And (2) *A new conception must appear initially plausible*. Plausibility is also a result of consistency of the concepts with other knowledge. It is, however, conceivable that the pre-service teachers E1 and E4's failures to answer correctly

items 1.0 and 1.1 that are conceptually related are evident of unfulfilled conditions of accommodations (Posner *et al.*, 1982. p.214).

On the one hand, the pre-service teacher E7 had a wrong interpretation of the item 1.1. In item 1.0, he was able to give correct definition of work. What in his conception created such misinterpretation of item 1.1? Since item 1.1 require mathematical equation (or symbolic representation) of work, it is assume that the pre-service teacher E7 might have lacked intelligibility at the superficial level which requires an understanding of the component terms and symbols used and the syntax of the mode of expression (Posner *et al.*, 1982). Two other pre-service teachers C-group (C3 and C7) gave no response (leave page blank). Although these pre-service teachers did not provide any explanation on this item (1.1), one possible reason for leaving the page blank has so much to do with their responses to item 1.0, coincidently both C3 and C7 held similar wrong notion about definition of work.

Item 1.2.1 expected the pre-service teachers to apply their initial conceptions of items 1.0 & 1.1 respectively in order to answer item 1.2.1, that is, by integrating both qualitative and quantitative understanding of work done. The problem statement comprised of an everyday life scientific scenario that says that: “A mother left home for work in the morning and after work she returned home and felt exhausted due to excessive work she did at her work place.” From scientific perspective, the mother had done no work. The responses needed for this item is in twofold. The first aspect is posed as do you agree or disagree? While the second aspect required the pre-service teachers to explain their reasons for agreeing or disagreeing using apposite physics principle.

The item 1.2.1, however, was a bit argumentative, the pre-service teachers prior to the post-test were inducted on how to respond to questions with argumentative elements. For example, the pre-service teachers in responding to item 1.2.1 first interrogate it before reaching a conclusion. Although the dialogical argumentation instructional model (DAIM) was not fully implemented in the present study due to the nature of the PSAT instrument and research questions, however, a blend of some of its features was used to guide how the pre-service teachers respond to item 1.2.1. First, each pre-service teacher was allowed to choose “agree” or “disagree” to the

problem statement. Second, they make claims (in form of reasons) on the given item in a written format. Next, the pre-service teachers present their views in small groups as in (Figure 3.5) while others scrutinize and question some of the claims (Kwofie, 2009; Ogunniyi, 2011). Here are some of the excerpts provided by the pre-service teachers:

Pre-service teacher C1: *Agree. Because the mother's displacement is zero, so I think no work is done.*

Pre-service teacher C2: *Disagree. The mother has done work at her work place moving from home to her work place then work.*

Pre-service teacher E2: *Disagree. She did work otherwise her boss won't pay her.*

Pre-service teacher E7: *Agree. Reasons do not conform to the content-based of the posed question.*

To take an example of two pre-service teachers (C2 and E2) who shared similar views. First, they both disagreed to the scientific view that the mother had done no work. To them work has been done. The pre-service teacher C2 made a statement that the mother has done work at her work place because she moved from home to her work place and then work. Such commonsensical statement sounds very correct in everyday reasoning. From CAT's perspective as explained in Chapter, it is clear that C2 and E2 commonsensical meaning of work (i.e. meaning of work in everyday life) is overwhelmingly dominant over canonical meaning of work. The validity of this statement can therefore only be determined by applying physics and mathematics principles. In that regard, the correct response to item 1.2.1 is "agree". With the mother's point of departure in positive direction (+) as reference, her position at that point is zero ($0m$). After completing her tasks at her work place she returned home, say (in negative direction (-)) to her point of departure. Regardless of how much force (F) she applied. The work done by her at the point of departure is equal to zero, hence ($\Delta x = 0m$).

As pointed out earlier, pre-service teacher C1 who gave correct scientific definition of work for item 1.0, but could not write down the mathematical expression for what his definition stands for was able to answer item 1.2.1 fully correct. It can be said

that pre-service teacher C1 was able to create images for the conception he held in item 1.0, which match his sense of existing conceptual ecology (Hewson, 1992).

Another set of four (4) pre-service teachers at post-test and five (5) at pre-test gave reasons that do not conform to the content-based of the item, reasons that showed lack of basic understanding of the concept in question. One pre-service teacher (E4) gave no response to the item at post-test level. It is worth noting that only 7 (43.8%) of pre-service teachers at post-test and 4 (25%) at pre-test gave correct responses as expected, although all pre-service teachers learned the concept of work in their high school years as well as in their on-going Physics modules at the university.

In item 2.1, pre-service teachers were asked to say with reason(s) whether work is done or not by a horse pulling a plough through the fields. Six pre-service teachers at post-test and four at pre-test were able to give the correct explanation and reasons. Among the 10 pre-service teachers at post-test, four (C3, C7, E1 and E6) and five pre-service teachers at pre-test on the same item said that work was done by the horse (by ticking off the correct answer), but failed to substantiate their answers, as the reasons they gave omitted the F component of work done. Here are some of the excerpts:

Pre-service teacher C3: *Work is done. There is change in energy and position.*

Pre-service teacher E1: *Work is done. The horse put in energy and covered some distance.*

Pre-service teacher C5: *Work is done. Because work is force acting on an object by push or pull.*

Pre-service teacher E7: *Work is done. The horse pulled the stuff across the field and covered some distance.*

Pre-service teacher E6: *Work is done. The horse used energy to pull the object.*

Before responding to the excerpts provided by the pre-service teachers, there is one question that has to be asked. Why are most of the pre-service teachers' conceptions of work pivot around the concept of energy and not force (F) and displacement (Δx)? Other scholars (Posner *et al.*, 1982 and Hewson, 1992) have sought to unravel the

mystery of why conceptual change is so difficult. They have explained that learners use their existing knowledge (i.e. their conceptual ecology), to determine whether different conditions are met, that is whether a new conception is intelligible (knowing what it means), plausible (believing it to be true), and fruitful (finding it useful). Contrary to this view, they believe that a learner might encounter difficulty in learning new concept.

Drawing from this argument, it is therefore conceivable that the one reason why the pre-service teachers drawn their conceptions of work from the concept of energy could be due to the inherent definition of energy. One common definition of *energy is the ability to do “work”*. It is then assume that many pre-service teachers found their existing conceptions (i.e. *energy is the ability to do “work”*) to be more *intelligible, plausible, and fruitful* than the actual meaning of the new concept (work). From CAT’s perspective, this also means that the concept of work held by the pre-service teachers is suppressed by the concept of energy. Hence the extent to which the conception meets the three conditions in italic form is termed the status of a person’s conception. In that regard, the definition of energy must have influenced their conceptual ecology as the new concept (work) conflicts with their existing conceptions. In that event, it cannot become plausible or fruitful until the pre-service teachers become dissatisfied with the old conceptions.

Five pre-service teachers marked (C5, C9, E3, E4 and E7) at post-test and six at pre-test believed that work was done by the horse with reasons that assume work done to be force acting on an object by push or pull. One pre-service teacher C1 at post-test and four pre-service teachers at pre-test believe that work was done since the horse displaced the plough and used energy to do so.

Item 2.2 asked the pre-service teachers to explain with reasons whether work is being done or not by a waiter who carries a tray full of meals above his head by one arm across the room (Figure 4.2). Although a similar question to item 2.2 (Figure 4.1) was discussed during lecture sessions as part of exemplary problems for the data collection.

Pre-service teacher C8: *Work is done. Reason do not conform to the content-based of the posed question .*

Pre-service teacher E4: *Work is done. Force (F) is applied and (Δx) is covered.*

Pre-service teacher C3: *No work is done. (F) does not cause the horizontal (Δx).*

Pre-service teacher E6: *Work is done. There is force applied and distance.*

Pre-service teacher C9: *Work is done. There is force applied in carrying the meal.*

From the excerpts, it is clear that many pre-service teachers held alternative conception between distance and displacement. For example, pre-service teachers (E4 and E6) used *distance* in place of *displacement* without a blink of concern, even though their reasons were incorrect. This is a common misconception. There is, of course, a possible reason why they think and use distance instead of displacement. First, the similarity of the two concepts, distance and displacement are both measured in meters (m). They have the same symbol (Δx). Second, they might have seen no difference between distance and displacement, but is there a difference between the two concepts? Yes, there is. Distance is a scalar quantity (i.e. it has only magnitude) while displacement is a vector quantity (i.e. it has both magnitude and direction).

Following the earlier discussion on items (1.0 and 1.1) above, work is a scalar quantity, (i.e. a product of two vectors (force and displacement) which is measured in Joules (J or Nm)). If distance is used in place of displacement as suppose the case with the pre-service teachers in question, then work is a vector quantity. That is, work is a product of a (vector quantity) force F and (scalar quantity) distance Δx . In terms of commonsensical use of the two concepts, distance is used in everyday life more than displacement. So the concept of displacement conflicts with the pre-service teachers' existing conceptions (distance) which has strong dominance in their conceptual ecology. In that regard, the canonical concept (displacement) is not intelligible, plausible or fruitful.

Also, many pre-service teachers failed to realize that when a force causes motion at right angles to itself, it does not do any work, hence F is perpendicular to the displacement (Δx). Put another way, a force can be exerted on an object and yet do no work. For example, the person shown in (Figure 4.1) does exert an upward force F on the bag equal to its weight. But this upward force is perpendicular to the

horizontal displacement of the bag and therefore has nothing to do with that motion. Hence, the upward force is doing no work. This conclusion comes from the definition of work as discussed in Chapter 2 (section 2.1.2), so $W = 0$, since both a force and a displacement are needed to do work. With force F perpendicular to the displacement d or Δx . This also means $\theta = 90^\circ$ and ($\cos 90^\circ = 0$).



Figure 4.1 Concept of work

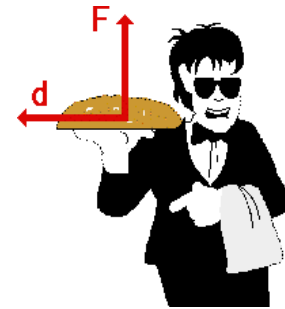


Figure 4.2 Concept of work

Only 6 (37.5%) of pre-service teachers at post-test and 3 (18.75%) at the pre-test were able to explain with reasons that no work is done as there is an upward force, and there is a horizontal displacement but the force does not cause the displacement. Four pre-service teachers marked by E-group (1, 4, 5 and 6) at post-test and (E3, E4, E5, and E6) at pre-test believed that work is being done by the waiter hence F is applied and distance (Δx) is covered as the waiter walks across the room. Such responses are due to their deficiencies in interpreting common experiences of everyday life and sciences, without realizing the contradiction between the scientific conception of work done and common knowledge about work.

Three C-groups members marked by (C1, C2 and C6) at post-test and (C1, C4 and C7) gave reasons that do not conform to the content-based of the item. Two C-groups (C8 and C9) at the post-test and one E-group (E3) explained that work is being done by the waiter with reasons that omitted one component force F and others who omitted displacement Δx in their explanation mentioned force as the only component needed for work to be done in such context, without realizing that a vertical force F cannot cause a horizontal displacement Δx .

4.2.2 Levels of Conceptual and Procedural knowledge exhibited by E and C-groups in answering items (1.0 – 2.2)

According to Reif and Allen (1992) students' difficulties may not be due to erratic performances or lack of available knowledge, but due to their deficiencies in interpreting the knowledge they have. As discussed earlier in Chapter 2 (section 2.4.4), Ausubel (1963) calls the ability of teachers and students to connect concepts – meaningful learning, which goes beyond simple presentation of factual knowledge (Bransford *et al.*, 1999; Lambert & McCombs, 1998). To Mayer (2002) meaningful learning occurs when students have the ability to build the knowledge and cognitive processes needed for successful problem solving.

The question of whether the pre-service teachers of the present study have the ability to build knowledge necessary for problem solving in physics is of course, a major concern in many teacher training institution particularly in the institution where this study was conducted. For example, at the post and pre-test, pre-service teachers marked (E4, E5, and E6) showed deficient factual knowledge and cognitive processes needed to answer questions labelled minor problems (e.g. D1 as discussed in Chapter 3). The (D1) – minor problems refer to those items (1.0 – 2.2) that required Factual Knowledge and Cognitive processes to answer them. Table 4.1 is an example of deficient Factual Knowledge and Cognitive processes exhibited by a pre-service teacher marked (E4).

Table 4.1 Levels of Conceptual and Procedural knowledge exhibited by E4

| The Knowledge Dimension | The Cognitive Process Dimension | | | | | | | | | | | |
|------------------------------|---------------------------------|-----------|---------------|-----------|------------|-----------|------------|-----------|-------------|-----------|-----------|---|
| | 1. Remember | | 2. Understand | | 3. Apply | | 4. Analyze | | 5. Evaluate | | 6. Create | |
| | <i>PRT</i> | <i>PT</i> | <i>PRT</i> | <i>PT</i> | <i>PRT</i> | <i>PT</i> | <i>PRT</i> | <i>PT</i> | <i>PRT</i> | <i>PT</i> | | |
| Factual Knowledge (D1) | √ | √ | x | x | x | x | x | x | x | x | x | – |
| Conceptual Knowledge (D2) | x | x | x | x | x | x | x | x | x | x | x | – |
| Procedural knowledge (D2) | x | x | x | x | x | x | x | x | x | x | x | – |
| Metacognitive Knowledge (D3) | x | x | x | x | x | x | x | x | x | x | x | – |

Key: E4/M: *PRT* = Pre-test, *PT* = Post-test; √ = ability displayed; x = lack of ability

Table 4.1 helped to identify areas of difficulties encountered by the pre-service teacher E4 while solving mathematical problems in physical sciences (work-energy). The table made explicit the pre-service teacher's conceptual and procedural discrepancies with respect to the way he build knowledge and strategic connections needed for answering the PSAT items. At pre-post tests, the pre-service teacher (E4) was able to remember concepts using his factual knowledge, but could not go beyond remembering. He was not able to attain other levels of the cognitive processes dimension such as understanding, applying, analysing and evaluating. This also means that all the PSAT items that need the later cognitive process could not be answered by the pre-service teacher. There is also the lack of ability by the pre-service teacher to produce conceptual, procedural and metacognitive knowledge needed to exhibit his conceptual change or exchange.

The cross signs (\times) marked on conceptual knowledge (D2), procedural knowledge (D2) and metacognitive knowledge (D3) versus five out of the six cognitive process dimension revealed the lack of knowledge within the knowledge domain that the pre-service teacher exhibited while solving major problems (D2) and atypical problems (D3). This, of course, shows that the pre-service teacher E4 had a very poor mathematical and science knowledge retention, transferability and application across the spectrum of cognitive domain in the area of basic mechanics tested (work-energy).

4.3 Research Questions

In Chapter 1 of the present study, three research questions were posed to investigate pre-service teachers' conceptual and procedural difficulties that impede their abilities to solve mathematical problems in physical science basic mechanics. Five content-based problems (3.1 – 3.5, of appendix C) were used to test the levels of difficulties labelled (D₁, D₂ and D₃, as pointed out in chapter 3). The five problems were mathematically dialectic. These problems provided a common basis tests for comparison with the E-group and the C-group respectively. Following the arguments raised earlier in (section 4.1) by various scholars whose findings conform to the research questions and content-based problems used. The three research questions will be answered with respect to the pre-service teachers':

- a) prior conception of basic mechanics (i.e. work and energy) at the level taught abilities to represent/demonstrate problem-solving strategy both qualitatively and quantitatively;
- b) identification of key concepts of the problem statement (as in section 2.4.1);
- c) interpretation of data (known and unknown quantities, as in section 2.4.2);
- d) modeling maths-in-science as solving strategy (E-group, as in section 2.4.3).

Table 4.2 Overall Results on PSAT items used for testing CAPD

| Group | № per group | Mean Scores | | Standard Deviation | |
|---------------------|-------------|----------------------|---------------------|--------------------|-------------|
| | | Pre-test | Post-test | Pre-test | Post-test |
| E-group | 7 | 7.9 | 17.14 | 3.87 | 9.62 |
| C-group | 9 | 12.6 | 21.7 | 4.34 | 5.12 |
| t-test 2- tailed | 16 | $t_{value} = -2.143$ | $t_{value} = -1.21$ | | |

Alpha = .05, t critical= -1.76; $df = 14$

The result shown in Table 4.2 was obtained from the 40 marks PSAT items used to collect data from 16 second- and third-year pre-service teachers in a teacher education program. As in Table 4.2, the C-group obtained a mean pre-test score of 12.6, with a standard deviation of 4.34 while their counterpart the E-group had a mean pre-test score of 7.9, with a standard deviation of 3.87. At the post-test, a little improvement was noted in both groups (E and C)'s performances, the mean scores as well as standard deviation obtained by both groups varied quite considerably-i.e. is more noticeable in E and C. It may be said that the pre-tests are different but, the post-tests are not (Table 4.2). Even though the average performance of the C-group at post-test ($M_{posttest} = 21.7$, $SD_{posttest} = 5.12$) was better than the E-group where the average was 17.14, SD was much higher in the latter.

Further, a null hypothesis was established to test the effect that the performances of both groups E and C. In that regard, t-values at pre-post-tests less than t-critical were obtained resulting a rejection of the null hypothesis suggesting that the

performances of E and C-group in the PSAT are statistically different at $\alpha = .05$. Thus, further descriptive statistics was carried out to gauge results and discussions (see Tables 4.5 and 4.6).

4.3.1 RESEARCH QUESTION 1:

The first research question is posed as:

What conceptual difficulties do pre-service physical science teachers exhibit while solving mathematical problems in physical science?

The question was to determine pre-service teachers' conceptual difficulties with basic mechanics. Two items (3.1 and 3.3) of the five items enriched with possible confusions were intentionally used to track pre-service teachers' conceptual difficulties. In the IDEAL strategy discussed in Chapter 3, the solution to item 3.1 (a free-body-diagram) becomes the focus of attention while item 3.3 shared visible features of conceptual difficulties. For the two items, pre-service teachers were asked to draw a free-body-diagram to show all the forces acting on a truck while it travels down an inclined road to the point it reaches the bottom (item 3.1), and to calculate the work done on the truck by the frictional force using the work-energy theorem (item 3.2). Below are some of the conceptual difficulties that the pre-service teachers encountered.

4.3.2 Pre-Service Teachers' Conceptual Difficulties On (Items 3.1 & 3.3)

Pre-service teachers marked (E3, E9, C1, C2 & C9) were unable to . . .

1. construct a complete Free- Body- Diagram to represent all the individual forces acting on the truck as it travels down the inclined road (item 3.1). Those who did could not indicate them at the relevant position on the diagram.
2. identify the unknown variables. Those who did could not interpret the information for what they are stand for.
3. analyse item 3.3 and use algebraic expressions and the associated physics concepts (unable to make good subject/content connections as a solving strategy)
4. differentiate between acceleration in ($m \cdot s^{-2}$) and velocity in ($m \cdot s^{-1}$), a common misconception that led to wrong solutions to items 3.2 and 3.3.

4.3.3 Discussion on pre-service teachers' conceptual difficulties

A significant number of pre-service teachers had common conceptual difficulties as listed in (section 4.3.2). I have categorized such conceptual difficulties into four areas and will discuss them accordingly starting with the first.

4.3.3.1 Pre-service teachers' deficient knowledge on constructing a Free-Body-Diagram

According to Larkin and Simon (1987), they assert that experienced problem solvers of basic mechanics sometimes draw forces on top of objects in real world diagrams, thus making abstract physics concepts visible in their real world location. In the IDEAL strategy discussed earlier, a correct free-body-diagram as part of heuristics (i.e. problem-solving strategy) can create links between different parts of the problem and make visible features of math-in-science concepts accessible to the problem solver. The problem context used to test the pre-service teachers' knowledge of constructing a free-body-diagram as part of a problem-solving strategy was item 3.1. Pre-service teachers were asked to draw a free-body-diagram to show all the forces acting on a goods-truck travelling down on an inclined road. In assessing item 3.1, number of questions was used as tool guide, for example, does the force diagram include all the relevant forces? (2) Are the vector descriptions used to relate all the relevant forces?

At pre-test, eleven out of sixteen pre-service teachers tested on item 3.1 were unable to construct and represent a problem statement on a free-body-diagram. Those who attempted the item were unable to complete it. Others choose to leave the section blank and carried on with solving the sub-items. Even at that, solutions they provided showed evidence of lack of knowledge in item 3.1. A lack of understanding of item 3.1 will hinder the pre-service teachers' abilities to conceptually link mathematical concepts (e.g. basic trigonometry ratio) and physics. This inference is supported by the free-body-diagram provided by the E2 at pre-test and post-test level (see Figures 4.3 and 4.4 respectively).

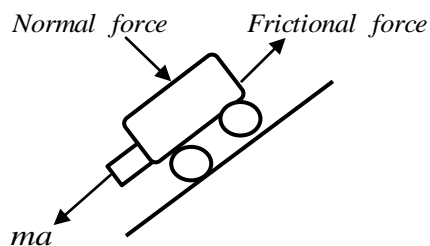


Figure 4.3 Free-Body-Diagram Drawn by pre-service teacher E2 (Pre-test Level)

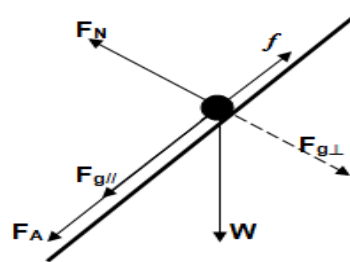


Figure 4.4 Free-Body-Diagram drawn by pre-service teacher E2 (Post-test Level)

It is clear from the diagram drawn by the pre-service teacher (E2) at pre-test level (Figure 4.3) that he would encounter much difficulties compare to his post-test status. Hence at pre-test level, his physical representation of the problem statement being drawn falls short of data needed to solve successor items (3.2-3.5). Physical representation (Free-Body-Diagram/Force Diagram) function both passively and actively (Bransford & Johnson, 1973). Passively as a format into which information must be fit and actively as a plan for directing one's attention while conducting purposeful search of present and missing data (Neisser, 1976). The pre-service teacher (E2's) inability at pre-test level to draw a free-body-diagram may be attributed to his lack of initial plausibility to items 1.0, 1.1 and 1.2.1. Initial plausibility can be thought of as the anticipated degree of fit of a new conception into an existing conceptual ecology (Posner *at al.*, 1982).

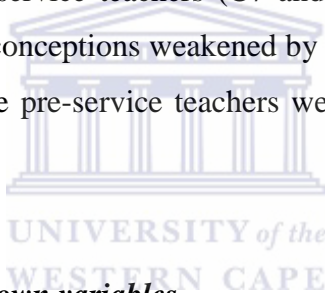
4.3.3.2 Pre-service teacher (E2's) - Dissatisfaction with Existing Conceptions

The physical representation (free-body-diagram) which E2 drew at post-test level, functions actively to direct his attention to consider what data is present and what data is missing, which could be used to clear up difficulties in his solution to successor items (3.2 – 3.5). Generally, a new conception is unlikely to displace an old one, unless the old one encounters difficulties (Driver, 1973; Hewson, 1992).

It is change of this kind (in Figure 4.4) I have referred elsewhere that Hewson (1992) called "conceptual exchange." For example, in both free-body-diagrams (Figures 4.3 and 4.4), drawn by E2 shows that the pre-service teacher had gone from not knowing an idea to knowing it. Also, it can be assumed that the pre-service teacher (E2) must have first view his existing conception (Figure 4.3 at pre-test level) with some

dissatisfaction before he seriously consider a new one (Figure 4.4 at post-test level). Such a case would entail conceptual exchange, and there is common agreement in the literature that the process of a student exchanging one idea for another is conceptual change. One major source of dissatisfaction is the anomaly (Driver, 1973).

According to Posner *et al.* (1982), an anomaly exists when a person is unable to assimilate something that is presumed assailable or put simply, when a person cannot make sense of something. Further, they have explained that when a person (student) faced with an anomaly, the individual (student) has several alternatives. In the case of the pre-service teacher (E2), he must have exercised some fundamental revisions (i.e. accommodation) in order for him to eliminate the conflict. Even this has been reported by Posner and associates to be difficult thing to do (pp.221). It is no wonder that the pre-service teachers (C7 and C8) discussed earlier in (section 4.2.1) find their current conceptions weakened by anomalies. There is little evidence in the interviews that the pre-service teachers were aware of anomalies during the pre-post tests.



4.3.4 Identify the unknown variables

Pre-service teachers in this study did not have much difficulty in identifying the normal force (F_N) among other forces. However the common confusion of net force (i.e. identifying the sum of forces that have impact on the truck's motion) was observed in all the four items tested. For example, at pre-test level, the pre-service teacher E2 discussed earlier could not represent all the forces (Figure 4.3) that had impact on the truck's motion except the frictional force. This pre-service teacher believed that net force ($F_{net} = ma$) is the same as applied force or force of gravity parallel to the inclined (see Figure 4.3). Pre-service teacher C8's drawing at pre-test level indicated that the applied force (F_A) has the same impact as the frictional force (f), but the direction was opposite to that of the applied force. He goes on to indicate the force of gravity (W) in place of force of gravity perpendicular to the inclined ($F_g \perp$). A similar interpretation was found with pre-service teachers (E3,

E9, C1, C2 & C9) who were of the opinion that the magnitude of the two forces ($F_{g\parallel}$) and ($F_{g\perp}$) are the same in terms of interaction. Below is the physical representation of item 3.1.1 (Figure 4.5) provided by pre-service teacher (C8) and Figure 4.6 represent the correct free-body-diagram:

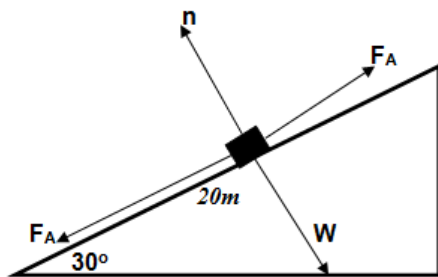


Figure 4.5 Free-Body-Diagram Drawn by pre-service teacher C8 (Incorrect)

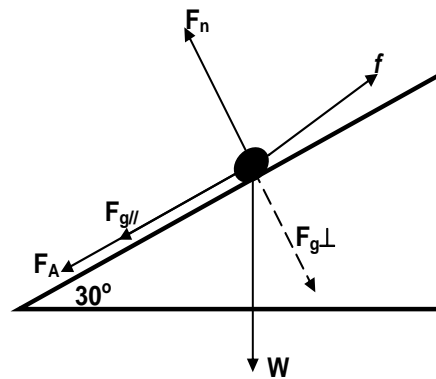


Figure 4.6 Correct Free-Body-Diagram expected from C8 (at pre-test)

Here, it is not clear what assumption the pre-service teacher (C8) carried out, but one thing that is conceivable is that the pre-service teacher C8 might have faced with unresolved anomalies. The main problem statement of item 3.1.1 which the pre-service teacher (C8) responded in PSAT instrument (section C) explains that a constant frictional force opposes the truck's movement. One expected that such statement should have helped the pre-service teacher to know that there must be a frictional force retarding the motion of the truck otherwise the truck would accelerate down the inclined road under the action of its own weight. In that regard, the angle (30°) must be related to the coefficient of friction. For the weight of the truck due to gravity (W), the pre-service teacher might have seen no difference regarding the position of the truck being on (an incline) and not on a horizontal surface. This is evident of alternative conception. For example, in Figure 4.5, the normal force would have the same effect with the force of gravity perpendicular to the incline (i.e. $F_N = F_{g\perp}$) while if the truck stands on a horizontal surface, then the pre-service teacher's assumption of ($n = W$) would have made sense.

4.3.5 Analysing item 3.3: The Pre-service teachers' use of algebraic expressions and the associated physics concepts

The instructional literature recommends several strategies to help pre-service teachers integrate the conceptual and procedural aspects of problem solving to counter mathematical difficulties they tend to face in solving math-in-science problems. It was the contention of McDermott, (1993) that the algebraic formalism should be postponed until after the qualitative understanding of the concept in question is developed. This argument was translated into Figure 3.8 as a benchmark (constructing meaning of key-concepts in a problem statement), a phase that could be a counterproductive for pre-service teachers with poor mathematical skills.

In efforts to inculcate the later, number of questions was prompted while assessing solutions to problems provided by the pre-service teachers. For example, (1) does the solution indicate that sufficient equations were assembled before the algebraic manipulations of equations were undertaken? (2) Is the essential information needed for a solution present? For example, does the physics description reveal a clear understanding of physics concepts and relations? In what followed in their respective analyses of item 3.3, fewer pre-service teachers (C1, E2 and E7) were able to analyze item 3.3 and use algebraic expressions and associated physics concepts moderately.

4.3.6 Pre-service teachers' (C1, E2 and E7): Fruitfulness of New Conception

First, at post-test there are good reasons to suppose that the pre-service teachers (C1, E2 and E7) had taken initial step toward a new conception by gaining more insights on how to resolve their anomalies. Hence anomalies provide the sort of cognitive conflict that prepares the student's conceptual ecology for an accommodation (Kuhn, 1973). Part of the evidence to support this view comes from their abilities to actively translate the free-body-diagram into the IDEAL steps which helped them to make a schematic representation of the concrete situation. It is of interest that they were able to indicate the numerical data and abstract concepts at relevant locations on the diagram they have drawn. This seems to have helped them gain new insights and discoveries of required translations between semiotic and appropriate physics concepts. Next, after constructing, modifying and coordinating their schemata, they

translated the semiotic-language representation to a math-in-science operation (i.e. problem solved algebraically).

Finally, two notable characteristics of conceptual exchange exhibited by the pre-service teachers (E2 and E7) are (Table 4.4, p.120 and Figure 4.8, p.118). Thus even when as is generally the case with the pre-service teacher (C8) the same can be said (see Figure 4.8, p.118). The steps taken by E2 and C8 (as in Figure 4.8) encouraged intellectual engagement, which prompted them to resolve apparent anomalies while contemplating solution for the problems. To check the reasonableness of their numerical answer obtained, the mathematical solution they provided in (Figure 4.8) shows that they had translated concrete steps they took back and forth to the their solving strategy model (i.e. math-in-science instructional model). It was also evident in their solutions that they had employ the IDEAL steps and were able to translate multiple steps between the four domains of knowledge (Table 2.2, p.42), avoiding the trap of algebraic problem solving (as in Figure 3.8).

4.3.7 Pre-service teachers' lack of differentiation among acceleration and velocity

Apart from other potential source of errors acquired by the pre-service teachers while analysing, interpreting, and solving item 3.2 was their inability to distinguish between acceleration and velocity in terms of unit quantities. Many pre-service teachers had confusion between acceleration and velocity as they took $v = 2m/s^2$ instead of constant acceleration (a) that the quantity represents. Thus, pre-service teachers who did so, have more difficulty solving item 3.2, which resulted incorrect solution and lengthy steps.

The errors above have been reported in a plethora of studies (e.g. Trowbridge & McDermott, 1981; Whitaker, 1983). To solve item 3.2, five pre-service teachers used the correct definition of kinetic energy and equation of motion as required in the item ($K = \frac{1}{2}mv^2$) and ($v_f^2 = v_i^2 + 2a\Delta x$), but failed to use either properly. Four more pre-service teachers used the wrong equation of motion involving time. For example, (E1, C3, E3 and E4) employed ($v_f = v_i + at$), making it more

difficult to find two unknown variables (v_f) and (t), of which (t) variable is dispensable. With such challenge, progressing to the next calculation that required them to determine the kinetic energy of the goods-truck as it reaches the bottom of the inclined road became a mountain to climb. If, however, they selected the correct formula ($v_f^2 = v_i^2 + 2a\Delta x$), then there would only be two desired unknown variables (i.e. v_f and K).

On the other hand, a formula can be selected because it contains the desired unknown. If all the other variables in the formula are known, then the problem is solved. If not, the unknown variable becomes a new desired variable. To take an example, for the pre-service teachers to solve item 3.2, there are two formulae needed ($v_f^2 = v_i^2 + 2a\Delta x$) and ($K = \frac{1}{2}mv_f^2$). One formula relating the variables v_f , v_i , a , and Δx and the other K , m , and v_f :

$$(v_f^2 = v_i^2 + 2a\Delta x) \quad \text{Equation (1)}$$

$$(K = \frac{1}{2}mv_f^2) \quad \text{Equation (2)}$$



In the main problem statement of which item 3.2 is a sub-question, variables v_i , a , and Δx were given (the knowns) and v_f was the desired variable (the known). The question asked that kinetic energy of the truck be calculated as the truck reaches the bottom of the inclined road. The first formula Equation (1) contains the desired unknown (v_f) needed to solve for the desired answer (K) in the second equation. The pre-service teacher using IDEAL solving strategy versus math-in-science instructional model would choose Equation 1 first because v_i , a , and Δx were known, allowing the calculation of v_f .

Inasmuch as v_f is now known, Equation 2 can be selected and used to calculate the desired answer (K). By contrast, pre-service teachers who selected this formula ($v_f = v_i + at$) instead of ($v_f^2 = v_i^2 + 2a\Delta x$) were not able to resolve their anomalies, but stuck with more confusion and conceptual difficulties. Even their

responses as in table 3.5 are part of the evidence to this view. Thus, their responses share similar characteristics to those reported in a previous study (Reif and Allen, 1992). Although, a slight improvement at the post-test level was observed, twelve pre-service teachers were able to use the quantity of acceleration correctly and attempted the item correctly.

4.4 RESEARCH QUESTION 2:

What conceptual and procedural discrepancies in their conceptions of math-in-science are evident in their solving physical science problems?

The second research question was investigated using all the items (3.1 – 3.5). These items consist of problems that require conceptual and procedural knowledge with a sophisticated level of mathematics. Apart from solving the mechanics problems each question from the items (3.2 – 3.5) asks that pre-service teachers to explain the strategic steps they take to arrival at their answers. According to the responses to items (3.2 – 3.5) of the PSAT, it is not difficult to see from Tables 3.5 and (3.6, Appendix H) that there is little correlation between n (the number of solved problems) and N (pre-service teachers' success in answering conceptual and procedural questions correctly) as shown in Figure 4.7. The contents of Tables 3.5 and 3.6 will be explained in more details as each item is discussed.

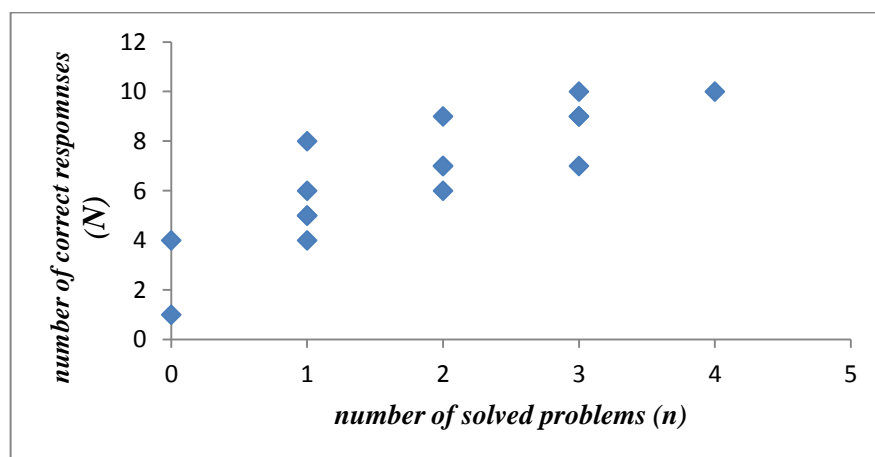


Figure 4.7 Scatter Plot of Number of Solved Problems (n) Versus Number of Correct Responses (N)

4.4.1 Discussion on Items Testing Conceptual and Procedural Difficulties

As pointed out earlier in Chapter 3 (description of problem solving-strategy), of all the tested items in the pre-post PSAT tests, item 3.3 was the most challenging in terms of the depth of both Physics and Mathematical knowledge and skills needed to solve it. The need for the pre-service teachers to solve item 3.3 was highly anticipated in the study as it required a holistic applications of all the labelled steps depicted in Figure 3.8 (titled *conceptual and procedural obstacles can lie deeper*).

The pre-service teachers' abilities to solve item 3.3 at the pre-post tests showed a minor improvement for both groups (C and E groups). However, the best problem solver of (item 3.3) in each group with the inclusion of (items 3.2, 3.4 and 3.5) was defined as the pre-service teacher who has improved his/her conceptual ecology and has satisfied the criteria mentioned in Chapter 3 (section 3.10.3, quantitative descriptions of PSAT pre-test & post-test analysis). He/she does not only have factual, conceptual and procedural knowledge, but has strategies knowledge and has acquired individual problem solving skills at the level taught.

In the pre-post-tests, there were two best problem solvers (C1 and C8) of all the tested items (3.1 – 3.5), in particular item 3.3. The two pre-service teachers were able to show correctly different forces acting on the truck as it travels down the inclined road. Over half of the pre-service teachers showed various forces without understanding of their impact on the truck's motion.

One strategic approach of solving items (3.2 – 3.5) with less mental effort is the ability of the solver to retrieve knowledge of item (3.1), a prerequisite for achieving both conceptual and procedural skills needed to solve all the items. It was evident that all pre-service teachers who failed to construct a free-body-diagram of item 3.1 also failed to solve correctly items (3.2 – 3.5). With C5 and E2 followed as the second best problem solvers, a great improvement on their conceptual and procedural difficulties faced at the pre-test. For the most improvement at the post-test on conceptual and procedural knowledge, E7 outperformed all pre-service teachers in all the items tested, (see Descriptions of PSAT pre-post-test analysis, Tables 3.5 and 3.6 Appendix H respectively).

Table 4.3 Levels of Conceptual and Procedural knowledge exhibited by E7at post-test

| The Knowledge Dimension | The Cognitive Process Dimension | | | | | | | | | | |
|------------------------------|---------------------------------|-----------|---------------|-----------|------------|-----------|------------|-----------|-------------|-----------|-----------|
| | 1. Remember | | 2. Understand | | 3. Apply | | 4. Analyze | | 5. Evaluate | | 6. Create |
| | <i>PRT</i> | <i>PT</i> | <i>PRT</i> | <i>PT</i> | <i>PRT</i> | <i>PT</i> | <i>PRT</i> | <i>PT</i> | <i>PRT</i> | <i>PT</i> | |
| Factual Knowledge (D1) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | x | ✓ | x | ✓ | – |
| Conceptual Knowledge (D2) | ✓ | ✓ | x | ✓ | x | ✓ | x | ✓ | x | x | – |
| Procedural knowledge (D2) | ✓ | ✓ | ✓ | ✓ | x | ✓ | x | ✓ | x | ✓ | – |
| Metacognitive Knowledge (D3) | ✓ | ✓ | x | ✓ | x | ✓ | x | ✓ | x | ✓ | – |

Key: E4/M: *PRT* = Pre-test, *PT* = Post-test; ✓ = ability displayed; x = lack of ability

Table 4.3 revealed the levels of conceptual and procedural knowledge that E7 demonstrated while solving mathematical problems in physical sciences relating to work-energy. In the pre-post-tests, E7 had no difficulties in responding to the PSAT items of low cognitive demand. It is clear from the table that within the factual knowledge domain, he had little or no problem remembering, understanding concepts and applying his existing knowledge into the new concepts, but failed to analyse and evaluate the problem. As he climbs the ladder of Knowledge and Cognitive Process Dimension, he experienced conceptual and procedural obstacles (difficulties) resulting from his unresolved anomalies, which transpired from his inabilities to analyse and evaluate at Factual Knowledge level. He showed a lack of understanding when he needed to produce conceptual knowledge to move on to apply, analyse and evaluate the problem. However, he showed he had understanding on how to proceed, but his inabilities to apply, analyse and evaluate at procedural level created setbacks. These deficiencies were noted mainly on items (3.2 – 3.5), which were categorised in terms of levels of difficulties as major difficulty (D2) and atypical difficulty (D3).

For example, in item 3.3 at pre-test level, E7 believed that because the truck undergoes a constant acceleration of $2m/s^2$ while travelling down the inclined road, therefore the resultant force F_{net} of the truck is the same as ($F_{net} = ma$). Although the equation he provided based on Newton's second law was correct, he could not fit it into the problem context or relate it in such a way that shows it has the same effect

with the sum of all the individual forces acting on the truck. As a result, he could not proceed to solve the problem (i.e. he encountered procedural difficulty).

For E7, the resultant force (F_{net}) is equal to sum of the applied force (F_A) and frictional force (f). This was not really the case in item 3.3, rather the resultant force (F_{net}) was equal to the sum of the applied force (F_A), frictional force (f) and force of gravity parallel to the inclined ($F_g \perp$). In that regard, E7 either had fail to include force of gravity parallel to the inclined ($F_g \perp$) or might have thought the applied force (F_A) has the same effect with it or he saw no difference between the two forces. In view that mass and acceleration were given in the main question; E2 assimilated the same notion with E7. Part of evidence to support this view in the case of E2 can be seen in the free-body-diagram he drew (Figure 4.3) and the solution he provided (Figure 4.8). It could also be seen that he encountered fewer problems in analysing and evaluating problem concepts compare to E4 discussed earlier in Table 4.1

Further, at pre-test level E7 was not able to attain other levels of the metacognitive knowledge to exhibit understanding, applying, analysing and evaluating to solve problems of major difficulties (D2) and atypical difficulties (D3). At post-test, there was evidence of conceptual exchange which must have resulted from the way the pre-service teacher use his existing knowledge (i.e. his conceptual ecology), to ensure that the new conception is intelligible, plausible and fruitful.

The tick signs (\surd) marked on conceptual knowledge (D2), procedural knowledge (D2) and metacognitive knowledge (D3) versus five out of the six cognitive process dimension revealed the ability of the pre-service teacher's knowledge within the knowledge domain. Unlike E4, he had little problem to demonstrate mathematical and science knowledge retention, transferability and application across the spectrum of cognitive domain in the area of basic mechanics tested (work-energy).

Below are conceptual and procedural difficulties encountered by some of the pre-service teachers (marked by E3, E9, C1, C2 & C9) were unable to:

1. write down the relevant equation(s)
2. substitute numerical values and solve the trigonometry equations algebraically.
3. use numerical answer(s) they calculated at some stages to solve follow-up questions.
4. Interpret numerical answers to see whether the answer(s) they got make sense or not.

4.5 RESEARCH QUESTION 3:

What strategic connections do they make between relevant mathematical and physical science concepts while solving physical science problems?

The third research question calls for an emphasis on mathematics-science connections. Connections between disciplines are especially important for teachers, because they should understand how a given idea relates to other ideas within the same subject area and to ideas in other subjects as well. For example, a concrete understanding of resolutions of motion in two dimensions equally requires basic understanding of trigonometry. Junkins (2007) argues that mathematics is the language of science and science classes often provide the application of mathematics and vice versa. It is in the science classroom where students discover “oh, so this is why we learned that in algebra ...”

In many cases students often discover that it is one or more mathematics skills that initially block their ability to understand and internalize new science concepts. Nonetheless, connecting mathematics and science while solving physical science problems is not something new, various scholars, (Bing and Redish, 2009; McDermott, *et al.*, 1987; Taplin, 1995;) studied different ways of how students frame the use of mathematics in physics while others, McDermott, (1993) was concerned about students recognizing when to use mathematics in physics. A lack of mathematical skills can have a negative impact on students’ abilities to solve complex problems in physical science and can greatly hinder a deeper understanding of many important concepts; especially those in physical science (see Junkins,

2007). There is also the need to consider the following multiple questions while assessing the solutions provided by the pre-service teachers for all the four items.

Questions include:

- (1) Aside from minor mistakes, is mathematics used reasonable? Or does the solution employ invalid mathematical claims in order to obtain an answer (e.g. set $v = 2m/s^2$ instead of $v = 2m/s$)?
- (2) Does the solution include an indication of how to combine equations to obtain an answer? For example, are the described forces appropriately included in specific force equations?

Thus, the third research question was investigated using items (3.2 – 3.5), hence these four items have applications of both conceptual and procedural mathematical skills in them. Enriched with conceptual and procedural mathematical skills are items (3.2, 3.3 and 3.4).

At post-test, only 4 pre-service teachers (C1, C8, E2 and E7) out of 16 (25%) were able to provide correct equation (these pre-service teachers stated the correct nature and direction of all the forces acting on the truck) and use both conceptual and procedural mathematics skills to solve the problem. This indicates that these pre-service teachers did not assume that the absence of other forces impact on the truck's motion meant the absence of net force. The inference is supported by the equations provided by E3, C2, and E4 who were of the opinion that because net force is the sum of all the individual forces acting on an object, thus, inclusive of all the forces regardless of whether they have any impact on the object's motion is necessary. Of this argument they trapped with so many unknown forces and could not proceed to interpret, analyse or solve the problem.

Like item 3.3 at pre-test, zero percent of pre-service teachers attempted item 3.4 correctly, at the post-test only 4 pre-service teachers (E6, E7, C1 and C4) (25%) attempted to solve the problem, of which only pre-service teacher marked (C1) obtained a full mark. While the later items discussed so far expressed concern, the last item 3.5 was not an exception to the pre-service teachers' conceptual and procedural difficulties they encountered while solving mathematical problems in physics mechanics. Before item 3.5 can be discussed, it is worth mentioning here

that item 3.5 was a sub-question (follow-up question) of item 3.3. Simply, a pre-service teacher who could not solve item 3.3 will not be able to solve item 3.5, hence numerical answer obtained from item 3.3 is needed to solve item 3.5.

Similarly, at pre-test zero percent of pre-service teachers attempted item 3.5 correctly, at post-test only 5 pre-service teachers attempted the problem partially as they were not able to arrive at the correct numerical answer. A question that is formidable to ask in respect to items 3.3 versus 3.5 is: *why those pre-service teachers whose responses were correct for item 3.3 at post-test level are not able to solve item 3.5*. One major reason that can be attributed to such inabilities to solve the later item in particular is that C1, C8, E2 and E7 who were able to solve item 3.3 could not use their numerical answer(s) that they calculated in item 3.3 to solve follow-up question.

Perhaps the pre-service teachers might have manipulated symbols to solve the problem, while the concrete understanding of problem situation is seldom present. However, manipulation of symbols as an approach used by most of the pre-service teachers (E and C-groups) could not provide procedural fluency or mathematical reasoning and thinking that often accompanies successful approaches reported in the literature (Bing & Redish, 2009; Martinez-Torregrosa *et al.*, 2006; McDermott 1993; Redish, 2005; Selvaratnam, 2011).

According to Huntley, (1998), her study explicates the benefits of emphasising mathematics and science connections perceived by college educators. She has asked “what should be the nature of mathematics and science connections?” Her findings suggest that the benefits of emphasizing mathematics and science connections are vitally important in view of McBride and Silverman (1991) who asserted that such connections are important for four reasons:

- (1) Science and mathematics are closely related systems of thought and are naturally correlated in the physics world.
- (2) Mathematics can provide students with concrete examples of abstract mathematical ideas that can improve learning of science concepts.
- (3) Mathematics can enable students to achieve deeper understanding of science concepts by providing ways to quantify and explain science relationships.
- (4) Mathematics activities illustrating science concepts can provide relevancy and-

motivation for learning science (p. 286-287).

For example, Figure 4.8 represents two separate responses provided by E2 and C8 at pre-post-tests for item 3.3. At pre-test level both pre-service teachers could not respond to the item correctly, C8 attempt showed lack of conceptual knowledge. Although he produced procedural skills as evidence of his mathematical skills in manipulating symbols, yet a lack of concrete understanding of the item was evident.

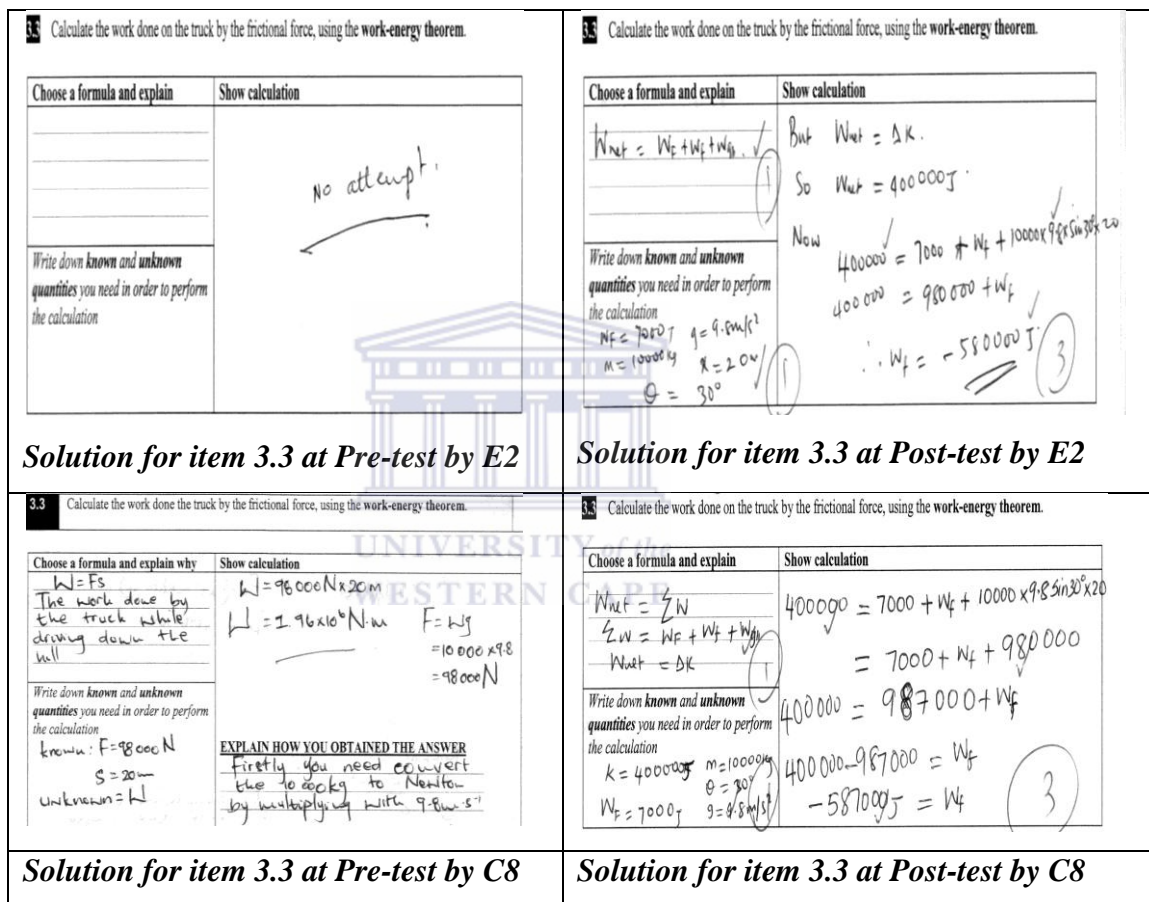


Figure 4.8 Solution to item 3.3 provided by E2 and C8 at pre-post-tests

Also, there is still the problem of both groups (E/C) not able to make estimations to check their math-in-science calculations and determine if an answer is reasonable or not; most pre-service teachers let ridiculous answers stand without as much as a blink of a concern. This reflects a basic lack of understanding hidden beneath their abilities to do math-in-science equations. Even those who were successful in solving the two items at post-test level there seem to be a lack of basic understanding. One

common explanation is that everyday experience seems to contradict physical principles as pointed out in discussions of items 2.1 and 2.2 respectively.

Furthermore, as in Table 4.4, a comparison of five selected E/C-group average problem solvers on the five items (3.1 – 3.5) was tabulated to the effect that their performances are equally dispersed. As shown in the Table 4.4, two pre-service teachers (one from C-group and the other from E-group) were paired on the basis of the following observations: (1) similar problem-solving approach, (2) similar mistake/misinterpretation of data per item, (3) similar conceptual and procedural difficulties encountered, (4) abilities to create strategic connections between Mathematics and Physics concepts, (5) shared similar views on written items that required explanation of steps leading to solution of the problem, and (6) similar estimation of the correct/wrong numerical answer(s) obtained.

The results in Table 4.4 were obtained from 30 marks allocated to the five items (3.1 – 3.5) aimed at testing pre-service teachers conceptual and procedural difficulties. A Microsoft office EXCEL programme – Analysis ToolPak-VBA was used to perform a descriptive statistics for t-test to test for significant differences. For all the five items, the mean problem-solving score of the E-group at pre-test score was 4.14 with a standard deviation of 3.4 while the C-group had a mean pre-test score of 6.67, with a standard deviation of 3.

The mean difference between the E and C pre-test scores was -2.53 and -2.45 at the post-test against the E-group indicating no improvement on the E-group's conceptual and procedural difficulties with the exceptions of E2, E6 and E7. Thus, this was not significant at $t(14)$ equal to -0.88, $\alpha=.05$. The average performance of the C-group both at pre-test ($M_{pretest} = 6.67$; $SD_{pretest} = 3.0$) and post-test ($M_{posttest} = 13.88$, $SD_{posttest} = 4.82$) was better than the E-group (see Table 4.4). In so far as the most challenging item 3.3 is concerned, there was no significant difference between the average performances C and E-group at pre-test level. However, there was little improvement on item 3.4 at pre-test and 3.2 at the post test. The relevant variables in the experiment were similar as far as possible for both E and C groups; the main difference being the method of instruction where the C group was exposed to the direct instruction method and the E group to the use of math-in-science model.

Table 4.4 Performances of Five E and C-Groups on Items (3.1 – 3.5)

| Items | Grp | Mean | SD | Mean Diff. | S.D Error | T-value | Sig. (2-tailed) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|------------------------------|----------|--------------|-------------|--------------|-------------|--------------|--------------------|------------------------------|----------|--------------|-------------|--------------|-------------|--------------|-------------|----------|--------------|-------------|------------------------------|----------|--------------|-------------|--------------|-------------|--------------|-------------|----------|--------------|-------------|------------------------------|----------|--------------|-------------|--------------|-------------|--------------|-------------|----------|--------------|-------------|------------------------------|----------|--------------|-------------|--------------|-------------|--------------|-------------|----------|--------------|-------------|------------------------------|----------|--------------|-------------|--------------|-------------|--------------|-------------|----------|--------------|-------------|------------------------------|----------|--------------|-------------|--------------|------------|--------------|------------|----------|--------------|-------------|------------------------------|----------|--------------|-------------|--------------|------------|--------------|------------|----------|--------------|-------------|------------------------------|----------|--------------|-------------|--------------|------------|--------------|------------|----------|--------------|-------------|------------------------------|----------|--------------|-------------|--------------|------------|--------------|------------|----------|--------------|-------------|------------------------------|----------|--------------|-------------|--------------|------------|--------------|------------|----------|--------------|-------------|------------------------------|----------|--------------|-------------|--------------|------------|
| 3.1 (level D1) | C | 2 | .87 | -0.57 | .66 | -1.23 | .24 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | E | 1.43 | .98 | | | | | 3.2 (level D3) | C | 3.67 | 2.55 | -1.1 | 1.96 | -0.80 | .44 | E | 2.57 | 2.94 | 3.3 (level D3) | C | 0.22 | .44 | -0.22 | .15 | -1.32 | .21 | E | 0 | 0 | 3.4 (level D3) | C | 0.67 | .70 | -0.53 | .38 | -1.76 | .09* | E | 0.14 | .38 | 3.5 (level D2) | C | 0.11 | .33 | -0.11 | .11 | -0.88 | .40 | E | 0 | 0 | TOTAL (Pre-test) | C | 6.67 | 3.00 | -2.53 | 2.52 | -0.88 | 0.40 | E | 4.14 | 3.4 | 3.1 (level D1) | C | 2.44 | .88 | -0.01 | .01 | -0.04 | 0.97 | E | 2.43 | .79 | 3.2 (level D3) | C | 5.33 | 1.41 | -1.47 | .39 | -1.6 | 0.13* | E | 3.86 | 2.27 | 3.3 (level D3) | C | 2.67 | 1.66 | -0.67 | .40 | -0.64 | 0.53 | E | 2 | 2.52 | 3.4 (level D3) | C | 2 | 1.8 | -0.29 | .11 | -0.31 | 0.76 | E | 1.71 | 1.9 | 3.5 (level D2) | C | 1.44 | 1.51 | -0.01 | .07 | -0.021 | 0.98 | E | 1.43 | 1.51 | TOTAL (Post-test) | C | 13.88 | 4.82 | -2.45 | 1.7 |
| 3.2 (level D3) | C | 3.67 | 2.55 | -1.1 | 1.96 | -0.80 | .44 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | E | 2.57 | 2.94 | | | | | 3.3 (level D3) | C | 0.22 | .44 | -0.22 | .15 | -1.32 | .21 | E | 0 | 0 | 3.4 (level D3) | C | 0.67 | .70 | -0.53 | .38 | -1.76 | .09* | E | 0.14 | .38 | 3.5 (level D2) | C | 0.11 | .33 | -0.11 | .11 | -0.88 | .40 | E | 0 | 0 | TOTAL (Pre-test) | C | 6.67 | 3.00 | -2.53 | 2.52 | -0.88 | 0.40 | E | 4.14 | 3.4 | 3.1 (level D1) | C | 2.44 | .88 | -0.01 | .01 | -0.04 | 0.97 | E | 2.43 | .79 | 3.2 (level D3) | C | 5.33 | 1.41 | -1.47 | .39 | -1.6 | 0.13* | E | 3.86 | 2.27 | 3.3 (level D3) | C | 2.67 | 1.66 | -0.67 | .40 | -0.64 | 0.53 | E | 2 | 2.52 | 3.4 (level D3) | C | 2 | 1.8 | -0.29 | .11 | -0.31 | 0.76 | E | 1.71 | 1.9 | 3.5 (level D2) | C | 1.44 | 1.51 | -0.01 | .07 | -0.021 | 0.98 | E | 1.43 | 1.51 | TOTAL (Post-test) | C | 13.88 | 4.82 | -2.45 | 1.7 | -1.33 | .22 | E | 11.43 | 7.25 | | | | | | |
| 3.3 (level D3) | C | 0.22 | .44 | -0.22 | .15 | -1.32 | .21 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | E | 0 | 0 | | | | | 3.4 (level D3) | C | 0.67 | .70 | -0.53 | .38 | -1.76 | .09* | E | 0.14 | .38 | 3.5 (level D2) | C | 0.11 | .33 | -0.11 | .11 | -0.88 | .40 | E | 0 | 0 | TOTAL (Pre-test) | C | 6.67 | 3.00 | -2.53 | 2.52 | -0.88 | 0.40 | E | 4.14 | 3.4 | 3.1 (level D1) | C | 2.44 | .88 | -0.01 | .01 | -0.04 | 0.97 | E | 2.43 | .79 | 3.2 (level D3) | C | 5.33 | 1.41 | -1.47 | .39 | -1.6 | 0.13* | E | 3.86 | 2.27 | 3.3 (level D3) | C | 2.67 | 1.66 | -0.67 | .40 | -0.64 | 0.53 | E | 2 | 2.52 | 3.4 (level D3) | C | 2 | 1.8 | -0.29 | .11 | -0.31 | 0.76 | E | 1.71 | 1.9 | 3.5 (level D2) | C | 1.44 | 1.51 | -0.01 | .07 | -0.021 | 0.98 | E | 1.43 | 1.51 | TOTAL (Post-test) | C | 13.88 | 4.82 | -2.45 | 1.7 | -1.33 | .22 | E | 11.43 | 7.25 | | | | | | | | | | | | | | | | | |
| 3.4 (level D3) | C | 0.67 | .70 | -0.53 | .38 | -1.76 | .09* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | E | 0.14 | .38 | | | | | 3.5 (level D2) | C | 0.11 | .33 | -0.11 | .11 | -0.88 | .40 | E | 0 | 0 | TOTAL (Pre-test) | C | 6.67 | 3.00 | -2.53 | 2.52 | -0.88 | 0.40 | E | 4.14 | 3.4 | 3.1 (level D1) | C | 2.44 | .88 | -0.01 | .01 | -0.04 | 0.97 | E | 2.43 | .79 | 3.2 (level D3) | C | 5.33 | 1.41 | -1.47 | .39 | -1.6 | 0.13* | E | 3.86 | 2.27 | 3.3 (level D3) | C | 2.67 | 1.66 | -0.67 | .40 | -0.64 | 0.53 | E | 2 | 2.52 | 3.4 (level D3) | C | 2 | 1.8 | -0.29 | .11 | -0.31 | 0.76 | E | 1.71 | 1.9 | 3.5 (level D2) | C | 1.44 | 1.51 | -0.01 | .07 | -0.021 | 0.98 | E | 1.43 | 1.51 | TOTAL (Post-test) | C | 13.88 | 4.82 | -2.45 | 1.7 | -1.33 | .22 | E | 11.43 | 7.25 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3.5 (level D2) | C | 0.11 | .33 | -0.11 | .11 | -0.88 | .40 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | E | 0 | 0 | | | | | TOTAL (Pre-test) | C | 6.67 | 3.00 | -2.53 | 2.52 | -0.88 | 0.40 | E | 4.14 | 3.4 | 3.1 (level D1) | C | 2.44 | .88 | -0.01 | .01 | -0.04 | 0.97 | E | 2.43 | .79 | 3.2 (level D3) | C | 5.33 | 1.41 | -1.47 | .39 | -1.6 | 0.13* | E | 3.86 | 2.27 | 3.3 (level D3) | C | 2.67 | 1.66 | -0.67 | .40 | -0.64 | 0.53 | E | 2 | 2.52 | 3.4 (level D3) | C | 2 | 1.8 | -0.29 | .11 | -0.31 | 0.76 | E | 1.71 | 1.9 | 3.5 (level D2) | C | 1.44 | 1.51 | -0.01 | .07 | -0.021 | 0.98 | E | 1.43 | 1.51 | TOTAL (Post-test) | C | 13.88 | 4.82 | -2.45 | 1.7 | -1.33 | .22 | E | 11.43 | 7.25 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| TOTAL (Pre-test) | C | 6.67 | 3.00 | -2.53 | 2.52 | -0.88 | 0.40 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | E | 4.14 | 3.4 | | | | | 3.1 (level D1) | C | 2.44 | .88 | -0.01 | .01 | -0.04 | 0.97 | E | 2.43 | .79 | 3.2 (level D3) | C | 5.33 | 1.41 | -1.47 | .39 | -1.6 | 0.13* | E | 3.86 | 2.27 | 3.3 (level D3) | C | 2.67 | 1.66 | -0.67 | .40 | -0.64 | 0.53 | E | 2 | 2.52 | 3.4 (level D3) | C | 2 | 1.8 | -0.29 | .11 | -0.31 | 0.76 | E | 1.71 | 1.9 | 3.5 (level D2) | C | 1.44 | 1.51 | -0.01 | .07 | -0.021 | 0.98 | E | 1.43 | 1.51 | TOTAL (Post-test) | C | 13.88 | 4.82 | -2.45 | 1.7 | -1.33 | .22 | E | 11.43 | 7.25 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3.1 (level D1) | C | 2.44 | .88 | -0.01 | .01 | -0.04 | 0.97 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | E | 2.43 | .79 | | | | | 3.2 (level D3) | C | 5.33 | 1.41 | -1.47 | .39 | -1.6 | 0.13* | E | 3.86 | 2.27 | 3.3 (level D3) | C | 2.67 | 1.66 | -0.67 | .40 | -0.64 | 0.53 | E | 2 | 2.52 | 3.4 (level D3) | C | 2 | 1.8 | -0.29 | .11 | -0.31 | 0.76 | E | 1.71 | 1.9 | 3.5 (level D2) | C | 1.44 | 1.51 | -0.01 | .07 | -0.021 | 0.98 | E | 1.43 | 1.51 | TOTAL (Post-test) | C | 13.88 | 4.82 | -2.45 | 1.7 | -1.33 | .22 | E | 11.43 | 7.25 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3.2 (level D3) | C | 5.33 | 1.41 | -1.47 | .39 | -1.6 | 0.13* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | E | 3.86 | 2.27 | | | | | 3.3 (level D3) | C | 2.67 | 1.66 | -0.67 | .40 | -0.64 | 0.53 | E | 2 | 2.52 | 3.4 (level D3) | C | 2 | 1.8 | -0.29 | .11 | -0.31 | 0.76 | E | 1.71 | 1.9 | 3.5 (level D2) | C | 1.44 | 1.51 | -0.01 | .07 | -0.021 | 0.98 | E | 1.43 | 1.51 | TOTAL (Post-test) | C | 13.88 | 4.82 | -2.45 | 1.7 | -1.33 | .22 | E | 11.43 | 7.25 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3.3 (level D3) | C | 2.67 | 1.66 | -0.67 | .40 | -0.64 | 0.53 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | E | 2 | 2.52 | | | | | 3.4 (level D3) | C | 2 | 1.8 | -0.29 | .11 | -0.31 | 0.76 | E | 1.71 | 1.9 | 3.5 (level D2) | C | 1.44 | 1.51 | -0.01 | .07 | -0.021 | 0.98 | E | 1.43 | 1.51 | TOTAL (Post-test) | C | 13.88 | 4.82 | -2.45 | 1.7 | -1.33 | .22 | E | 11.43 | 7.25 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3.4 (level D3) | C | 2 | 1.8 | -0.29 | .11 | -0.31 | 0.76 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | E | 1.71 | 1.9 | | | | | 3.5 (level D2) | C | 1.44 | 1.51 | -0.01 | .07 | -0.021 | 0.98 | E | 1.43 | 1.51 | TOTAL (Post-test) | C | 13.88 | 4.82 | -2.45 | 1.7 | -1.33 | .22 | E | 11.43 | 7.25 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3.5 (level D2) | C | 1.44 | 1.51 | -0.01 | .07 | -0.021 | 0.98 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | E | 1.43 | 1.51 | | | | | TOTAL (Post-test) | C | 13.88 | 4.82 | -2.45 | 1.7 | -1.33 | .22 | E | 11.43 | 7.25 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| TOTAL (Post-test) | C | 13.88 | 4.82 | -2.45 | 1.7 | -1.33 | .22 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | E | 11.43 | 7.25 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Alpha = .05; $t_{critical} = 2.31$; $df = 14$; C (N= 9); E (N= 7); () indicates a significant difference*

4.6 Comparison of E & C performances on the PSAT (Items 3.1 -3.5)

In order to explain the quantitative result, it is proposed here that the null hypotheses posited in Chapter 1 have no statistical difference between the two groups (E-group and C-group) on maths-in-science problems, $H_0: E - C = 0$. Put simply, there was no difference between the pre-service teachers (E-group) who were exposed to maths-in-science model and their counterpart the C-group who were not exposed, while the alternative hypothesis (H_a) was that there would be a difference.

Table 4.5 Overall Performances of E and C-groups on PSAT items (3.1 – 3.5)

| Sample | № per group | Mean tests | | SD | |
|----------------|-------------|-----------------------|-----------------------|-----------------|------------------|
| | | <i>Pre-test</i> | <i>Post-test</i> | <i>Pre-test</i> | <i>Post-test</i> |
| E-group | 7 | 4.1 | 11.43 | 3.4 | 7.25 |
| C-group | 9 | 6.7 | 14.0 | 3.0 | 4.82 |
| <i>t-tests</i> | N = 16 | <i>t-value</i> = 1.58 | <i>t-value</i> = 0.85 | | |

Alpha = .05; *t_{critical}* = 1.76; *df* = 14

A further test was computed to estimate correlation coefficient of the five items, a correlation coefficient of 0.63 was obtained indicating a moderate degree of direct relationship between the pre-test and post-test scores by the pre-service teachers (E-group) while the correlation coefficient of their counterpart the C-group was at a very low degree 0.1. The difference in correlation coefficients between the E-group and the C-group is not due to sample size as E-group sample (N) is less than C-group sample ($N_E < N_C$), but it simply means that there is no correlation in the C-group. Since the t-value for the pre-test shown in Table 4.5 is smaller than t-critical value (1.76), the null hypothesis (H_0) posited in Chapter 1 was rejected at the $\alpha = .05$ level, but accepted at the post-test level.

4.7 Qualitative Results and Discussion

The interview questions was based on the PSAT items used for testing the pre-service teachers' conceptual and procedural difficulties they tend to encounter while solving mathematical calculations of basic mechanics (e.g. work-energy). As pointed earlier in Chapter 3 seven direct-interview questions which sought to determine the consistencies of responses provided by respondents in questionnaires were subsequently reduced to 5 interview questions so as to effect the minor changes recommended by the instrument reviewers. Only 5 pre-service teachers were randomly selected to be interviewed. Thus, discussion here is restricted to only those questions that pertained to respondents' responses.

4.7.1 Discussion: Probing Interviewees' Responses

Five interview questions were constructed around the PSAT problems (3.2 – 3.5) aimed to find out how the pre-service teachers (E and C groups) felt about the overall calculations. Here are some of their views about the overall PSAT calculations.

4.7.2 Interviewer- Item 1: Which of the following (questions 3.2 - 3.5) did you find more difficult to solve?

In order to avoid generalization, interviewees were required to specify the question number and explain why they find it difficult.

E3: *I found it so difficult to calculate all the questions because I could not remember all the necessary formulae, so I was stuck.*

E4: *I found all questions difficult and do not have a strong mathematical background to perform calculations on the tested concepts.*

C5: *I found item 3.4 difficult because of the level of the question.*

C2: *It's his first time at university to do Physical science to this level, so the gap is widely opened. I found 3.3 – 3-5 most challenging.*

E6: *I found (item 3.2) most difficult.*

Interviewer: Why did you find item 3.2 very difficult?

E6: *I was not exposed to the use of equations of motion to solve energy related problems when I was in Secondary school. So it is my first time to do so at the university.*

The claims above are representative of the kinds of problems experienced by the pre-service teachers. More than 87% of E-group and 27% of C-group claimed that the PSAT item 3.3 took them a long time to tackle because they did not know what to do. Many of the pre-service teachers complained about how difficult the PSAT was especially items 3.2 – 3.3 as pointed out during the interview by E6 and C2. However, they admitted that all the selected and tested topics have been taught. Of those who answered, more than 55% of the C-group and E7 indicated that they knew

immediately what to do. This inference also corresponds with the results obtained in tables 3.9 and 3.10.

4.7.3 Interviewer- Item 2: How did you try to overcome the difficulty you encountered in any of these items (3.2 - 3.5)?

C2: *I couldn't because I didn't have the basics.*

E3: *I tried; I guess I need more time to consult the textbook.*

E4: *I read and memorized the concepts, but I have not done much work-energy problems by myself.*

E6: *I just left the question 3.2 un-answered.*

C5: *I could not make content links where applicable and use created links to solve the problems.*

The above claims supported some of their views in the written items of the PSAT items. Three C-group (C1, C5 and C8) responded to the same to the written items stated that mathematics is essential for translating IDEAL as problem-solving strategy. Moreover, C7 also claimed that less time is consumed for most of them who do both Mathematics and Physics as compare to time taken by their counterpart (E-group) who takes Mathematical Literacy and Physics. It was the contention of E2 and E7 who infer that such argument posited by C7 is acceptable in view that their Mathematical Literacy modules do not include sophisticated algorithms (e.g. trigonometric equations). This notion supports the claim made by C5 which was also reported in the literature by other scholars (Taplin, 1995) working in the area. They found that pre-service teachers performed poorly in applying mathematical operations to unfamiliar situations. This is indicative of inadequate problem-solving skills among the pre-service teachers of his study. In the same vein, lack of mathematical skills (e.g. solving equations, working with trigonometric ratios) in solving physics problems (e.g. basic mechanics-work and energy) have contributed to students' poor performances at Grade 12 final examinations (DoE, 2011, p.117). More details on the later was discussed in Chapter 1 of the current study.

In the written items, E2 and E3 claimed that despite the level of difficulties influenced by their lack of mathematics skills in solving items 3.2 and 3.3, one must continue struggle until the problems are solved. However, E2 and E3 could not

provide or substantiate the claim ‘continue struggle’ – hence ‘continue struggle’ is not a defined approach. Also, C1 and C3 added that in order for them to overcome their difficulties encountered in items 3.2 and 3.3, they had to read the problem more than twice to help them understand clearly what the known and unknown quantities were so that suitable notation could be introduced.

As interesting as the foregoing may be, neither C1 nor C3 members were able to solve the items at pre-test level (as in Tables 3.5 and 3.6: C1 obtained 1s, 1u and 2z, C3 obtained 4z). Only at the post-test level that C1 were able to solve both items correctly and obtain full marks allocated for the items. While C3 could only attempt one out of four challenging items of the PSAT and obtained (1s and 3z). See the interpretation of his performance record in Tables 3.5 and 3.6 respectively

4.7.4 Interviewer- Item 3: Mathematical calculation in solving physical science problems has always been easy/difficult for you, why?

The aim of the item was to look at the effect of mathematics in the PSAT completed by the pre-service teachers before the interview. Three E-group interviewed claimed that they find physical science problems difficult when it comes to equations, especially when it’s more based on mathematical equations. They admitted that mathematics has timelessly hindered their abilities to perform physical science calculations since their high school days especially when the nature of the problems is complex. Here are their responses:

E4: *I have always find mathematics easy, but my inability to choose the correct formula for questions (3.2 – 3.5) put me off the right track. As a result, I had much difficulty solving the items.*

E6: *Some of the problems that need to be solved are integrated principles of maths and science. Calculation has always been my weakest link because of the integration of various science formulae, but with time I will improve my weak areas.*

C2: *I think when it comes to maths and science, I have positive attitude with the implication of mathematical problems in science.*

E4: *I am not doing Mathematics as a major at present, so I found it hard to go through these problems that involve mathematics.*

C5: *There are at times I do face equal challenges similar to those of E-group especially where complex mathematical calculations are needed to perform physical science calculations.*

Thus replication of challenges or problem carryover as used by C5 implies to a situation where the C-group find it challenging to grasp a certain mathematical content in a mathematics lecture class and yet to apply the same content knowledge to solve physical science problems. (E.g. dealing with trigonometric ratios (in Mathematics class) and using its applications in resolving vectors in two dimensions (physics class).

The inferences above support some of the findings reported in the literature by Berlin (1994). One of the findings argues that to ignore mathematics and science connection is to turn a blind eye to the fact that science is driven by mathematical calculations. In that regard, several authors have advocated similar view with evidence. For example, Mathematics can enable students to achieve deeper understanding of science concepts by providing ways to quantify and explain science relationships; it provides science with powerful tools to use in analysing data (McBride and Silverman, 1991). Put simply by Junkins (2007), mathematics forms the epistemological base for science, that is, mathematics is the language of science. Two out of the three E- group members also added that it has been long since they dealt with mathematics problems as content and that this hindered their abilities to solve the problems.

Further, E4 sought for permission to make additional comment, when granted, he added that “maths-in-science problems are so stressful and often demand a lot explanation and mathematical reasoning before they can grasp calculation concepts”. However, this notion also support some of the arguments reported in the instructional literature that because science provides mathematics with interesting problems to investigate, students who are not skilful in mathematics often struggle to interpret givens, relate cause-and-effect, and set up any initial conditional equations (Bing & Redish, 2009; Junkins, 2007; Martinez-Torregrosa *et al.*, 2006; McDermott 1993; McBride and Silverman, 1991; Redish, 2005; Taplin, 1995).

4.7.5 Interviewer- Item 4: What mathematical concepts do you need to solve problems (items 3.2 – 3.5) in work and energy?

The type of mathematical skills tested in the main problem items was basic trigonometry, application of Pythagoras theorem and algebraic expressions or manipulations. Forty percent of E-group and more than 65% of C-group stated that among other mathematical applications needed to solve the four items, understanding trigonometric concepts is very essential. And that they had found it less mental effort in solving the four items. This inference contradicts their claims after the PSAT items were marked (See Tables 3.5 and 3.6 respectively). Here are their responses:

E4: *I think I need trigonometry and others.*

Interviewer: What do you mean by “others”?

E4: *May be “equation”.*

Interviewer: Even at this, he could not explain what he meant by equation.

E6: *I think trigonometry and Pythagoras theorem.*

Interviewer: Why?

Interviewer: He barely explains the vector aspect of the force diagram which implicated trigonometry and Pythagoras theorem.

E3: *I think the mathematical concepts include the use of algebra and trigonometry.*

While the three E-group (3, 4 and 6) took much time before responding to the question, they did so relatively to the hearing of their counterpart or member of their group’s stances. For example, E3 was able to respond to the interview question soon after C2 and C5 had given their version of the item.

Similarly C2 and C5 were able to point out correctly what mathematical concepts needed in order to solve the items. It did not come as a surprise as they are taking Mathematics and Physical sciences as their area of specialization. Also despite given correct responses in the direct interview questions conducted subsequently after the PSAT, solutions provided by most of the pre-service teachers showed lack of basic

mathematics. Below are some examples of solutions provided by the E-group which indicated poor understanding or characteristics of misconception of basic trigonometry such as trig ratios (from simple SOH-CAH-TOA). Characteristics of misconceptions were summarized by (Driver & Easley, 1978) as resistance to change, persistent, well embedded in an individual's cognitive ecology, and difficult to extinguish or to see what Sungur *et al.*, (2001) call the “big picture,” even with instruction designed to address them.

For example, a pre-service teacher E4 in solving item 3.3 calculated horizontal component as $\sin\theta = \frac{F_g \perp}{W}$ which also implies that $\sin\theta = \frac{A}{H}$ instead of $\sin\theta = \frac{O}{H}$ for $\sin\theta = \frac{F_x}{W}$. In the PSAT, four sets of questions (items 3.1 – 3.4) aimed at testing the pre-service teachers' understanding of motion in two dimensions (e.g. resolution of vectors in two dimensions). These questions were intentionally separated in the hope that pre-service teachers would analyze, see connections between questions and answer each question independently.

4.7.6 Interviewer- Item 5: Mathematics is an integral part of science; did you ever face any challenges in making content/subject connection between the two subjects?

(a) If yes, what are the challenges? (b) If no, how did you make your subject/content connections?

C2: I think making connection between physical science and mathematics is not difficult if one understand the content of particular questions asked.

C5: As a mathematics and physical science pre-service teacher it was easy for me to identify the unknown symbols of the physics problems and see their relations in mathematics content.

Additionally, C2 also claimed that “most times connections across content/subjects are easily seen through definitions and when the right connections are made, everything else falls into place”.

E3: *I agreed to what my colleague (C20 have just said. You know most times those of us that are doing Mathematical Literacy and Physical science make mathematical connections in our solving procedures although it is not often realize by most of us. And in cases where we can't, solving science most complex problems become difficult.*

The claim above supports one of the findings reported by McDermott *et al.*, (1987) that students in their study found much difficulty in connecting graphs and physics (kinematics). Also, it supports a finding reported in a separate study by McBride and Silverman (1991) that science and mathematics are closely related systems of thought and are naturally correlated in the physics world (pp. 286-287).

E4: *Sometimes, but before I write my Physics exams I would always practice with my friends (fellow students) especially those that are really good in Mathematics and Physics. That is how I have managed to pass my science modules.*

E6: *It has always being a problem to me. I always struggle to see the links. As to how I managed to pass my first year science, I do exactly what my colleague (E4) just said. You see practicing together before the exam gives us more insight of how one problem can be solved differently by different people.*

Furthermore, the earlier response given by C5 was probed deeper.

4.7.7 Interviewer: *How can you relate the given to the unknown?*

C5: *That is to look at the problem and relate the given situation to the unknown by means of a pattern.*

The claim above also supports some of the findings in the literature (Bing & Redish, 2009; Martinez-Torregrosa *et al.*, 2006; Redish, 2005; Selvaratnam, 2011) namely, that it is important for teachers to understand how a given idea relates to other ideas within the same subject area as well as ideas in other subjects. It is possible to outline some general steps in the problem principles that may be useful in the solution of certain problems. These steps and principles are just common sense made explicit. Huntley (1998) explicates the benefits in her findings by she compared the beliefs of science teachers and college science students. Her findings suggest that emphasizing mathematics and science connections perceived by pre-service teachers

in undergraduate teacher education have encouraged visualization into science problem-solving, as noted many pre-service teachers at the end of the study could regard mathematics as a tool for science.

4.8 Discussion of Findings according to the Research Questions posited in Chapter 1

4.8.1 Discussion of findings according to research question 1:

What conceptual difficulties do pre-service physical science teachers demonstrate in solving mathematical problems in physical science?

Apart from conceptual difficulties pre-service teachers encountered in responding to the items 3.1 and 3.3 used for probing the first research question. One other major concern that is worth mentioning here is the gap between the physics concepts and mathematics (algebraic) expressions exhibited by the pre-service teachers while solving the items.

In physics didactic situation, teachers use mathematics where possible to introduce science concept, analyse a concept, and even to test for comprehension of the concept. Even when science teachers teach concepts using laboratory activities, mathematics is often required for full comprehension. As a result, there are often gaps between the scientific concepts and the algebraic expressions.

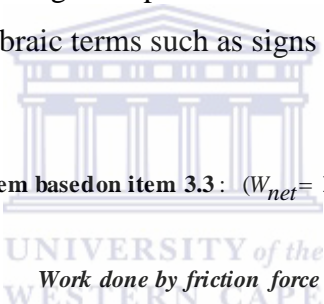
For example, Lawson and McDermott (1987) reported in their study regarding work-energy and impulse-momentum theorems that students' reasoning in solving problems was based solely on the mathematical manipulation without understanding the way physical quantities are related. In the current study, this lack of connection was observed in four different items tested on work-energy theorem, especially in item 3.3.

In view of the factors pointed out and discussed in research question 1, under the theme *pre-service teachers' conceptual difficulties*, it is conceivable that the network of mathematical concepts and the skills to connect physics concepts into concrete situations was lacked by both groups. Of the pre-service teachers who answered the four items, nearly eighty percent failed to solve all the items correctly. Of these,

about half were stuck with one or two of the below mathematical skills. In the E-group, only twenty percent attempted the item 3.3 correctly. More than 45% got zero while the remaining who tried to respond stuck with the following mathematical skills and operations:

4.8.2 The Conceptual Obstacles/difficulties . . .

1. They could not proceed where they needed skills of resolution of vectors x and y -components of net force (F_{net}) and trigonometric-equations.
2. Some who managed to apply the trigonometric skills could not go on with the next mathematical skills (e.g. algebraic equations).
3. Some who managed to resolve the vectors into x and y -components and employ trigonometric-equations could not finish the calculations.
4. And those who managed to process all the above mathematical skills could not deal with algebraic terms such as signs (\pm).



Work – energy theorem based on item 3.3: ($W_{net} = \Sigma W = W_{F_A} + W_{g_{//}} + W_{F_f}$)

Work done by friction force :

Step 1: find Kinetic energy $\Rightarrow v_f^2 = v_i^2 + 2a\Delta x \Rightarrow v_f^2 = 0^2 + 2 \times 2 \times 20 = 80$

*** use equation to find ***

$$W_{F_f} = W_{F_A} + mgsin\theta \cdot \Delta x \cos\theta - \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 \quad \{\text{Stuck zone}\}$$

↓

Step 2: $W_{F_f} = 7000 + (10000 \times 9.8 \times \sin 30^\circ \times 20 \times \cos 0^\circ) \rightarrow \{\text{from vector resolution x and y}\}$

$$- \frac{1}{2} \times (10000)(80) + \frac{1}{2} \times (10000)(0)^2 \rightarrow \{\text{Apply algebraic expression}\}$$

↓

Step 3: $W_{F_f} = 7000 + 980000 - 400000 = -587000\text{J} \rightarrow \{\text{interpreting numerical answer}\}$

↓

$\therefore W_{F_f} = 587000\text{J} \rightarrow \{\text{in opp. direction to the truck's motion}\}$

Figure 4.9 Representation of pre-service science teachers' problem solving "stuck zone"

4.8.3 Discussion of Findings According To Research Question 2:

What conceptual and procedural discrepancies in their conceptions of math-in-science do they exhibit while solving physical science problems?

This question was investigated using items (3.1 and 3.3) of the five items enriched with possible confusions. In one item (3.1), by percentage the most common difficulty encountered by pre-service teachers C-group was 44% of those who provided incorrect answers or made no attempt to the item at pre-test (3s, 3u and 3z). At the post-test about 33.4% still faced the same common difficulty (6s and 3u) out of 66.6% there were 33% of those who attempted the item fairly well, with one or two erratic representation of the forces on the relevant diagram positions. The slight drop of common difficulty could be attributed to the pre-service teachers' conceptual ecology probably influenced by cooperative group discussion during lectures after the pre-test assessment. In the same item, there was only one E-group member who made a correct attempt (E4) at pre-test, of which common difficulty faced by the group was 85.7% (3s, and 4z, for interpretation see Table 3.6 Appendix H), with 28.5% of fair attempt (E1 and E7).

Thus, at post-test the common difficulty dropped to 43% (5s, 1u and 1z for interpretation see Table 3.5) with similar percentage for fair attempt as in the pre-test, but with different pre-service teachers marked (E2 and E6). Traces of what could have minimized the percentage of common difficulty for the E-group at the post-test may be attributed to the intervention the group had received prior to the post-test. In the second item (3.3), the question required semiotic application of math-in-science vector equations influenced by conceptual understanding of trigonometric equations, Pythagoras theorem and algebraic expressions.

If, however, a pre-service teacher has setup equation for item 3.3 as $W_{F_f} = W_{F_A} + mg \sin \theta_1 \cdot \Delta x \cos \theta_2 - \frac{1}{2} m v_f^2 - \frac{1}{2} m v_i^2$, it is clear that he has overcome or encountered no conceptual difficulty so far and can produce the required procedural skills to solve the problem. This was a common situation for (C1, C5, C7, C8, E2, E6 and E7). However, three of these (E6, C5 and C7) were unable to connect between conceptual and procedural knowledge appropriately.

Hiebert & Lefevre (1986) have explained that such pre-service teachers may have some understanding of the mathematical concept but not solve the problem, or they may be able to perform some tasks but may not understand what they are doing.

Herscovics describes the problem above as “cognitive obstacles.” Such obstacles are rooted in the structure of mathematical content itself. In other words, they cannot be removed or avoided because of their constitutive role for the knowledge to be constructed (Pridiger, 2004b). Pridiger (2006) responding to the same notion have explained that the challenges posed by such cognitive or epistemological obstacles demand the reconstruction of prior knowledge.

4.8.4 Discussion of Findings According To Research Question 3:

What strategic connections do the pre-service teachers make between relevant mathematical and physical science concepts while solving physical science problems?

In terms of strategic connections between mathematics and science, all the four items (3.2 – 3.5) expected the pre-service science teachers to apply their basic understanding of trigonometry and algebraic expression in order to perform the mathematical calculations needed to solve the problems. Understanding of vector diagrams is essential for resolution of different components and was hinted in items structures. Six pre-service teachers out of 16 (37.5%) at pre-test and 12(75%) at post-test attempted item 3.2 correctly. The issue of pre-service teachers’ problem solving without their understanding of different subjects/contents connections was one of the major concerns. Concern with poor conceptual understanding that often lead to poor problem solving strategies in physical science calculations. As others (Goldberg and McDermott, 1987, p.108; McDermott, 1984, p.24) have noted, the specific errors in students’ thinking are not always detected unless there are follow-up questions.

For example, in item 3.3, no pre-service teacher could solve the problem; others chose to avoid the question completely. Very few who attempted the item had common conceptual difficulties (2 & 3 as listed in section 4.3.2; also see Table 4.6-Appendix I). With the exception of pre-service teachers (marked by C7 and E6) who attempted the problem partially, but failed to give the nature and direction of the

forces acting on the truck as it travels down to the bottom of the inclined road. It is conceivable that C7 and E6 may have wanted to answer that there were no net forces acting on the truck concerned in the item 3.3 and, thus, would not choose an equation (formula) that indicated the presence of any force. However, the equations they provided to solve the problem indicate that such was not the case.

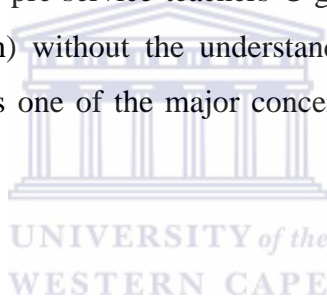
In my opinion, a more conceptually fruitful approach for a situation such as in item 3.3 can be a blend of IDEAL strategy and the use of math-in-science model. The successful E-group (E2 and E7) who were able to solve item 3.3 did so relative to: (1) invoking the correct work-energy theorem, (2) identifying the combination of the main concepts and the sub-concepts (e.g. $W_{net} = \Sigma W = W_{F_A} + W_{g_{||}} + W_{F_f}$) and to show the interrelationship of these math-in-science knowledge structures, (3) mapping concept of change in kinetic energy ($W_{net} = \Delta K = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$) of the truck required in item (3.2), and (4) combining the sum of work done by the applied force and force of gravity parallel to the inclined. Having exhibited such abilities, they faced little or no difficulties connecting concepts ensuing what Ausubel (1963) calls meaningful learning. To move from item 3.1 to 3.3, it is conceivable they had little or no difficulties recognizing patterns, making new connections and visualizing the unknown variable ($W_f = -f \Delta x$) work done by friction.

More than 45% of E-group who attempted the items could not complement when and how to use particular mathematical skills to link conceptual knowledge to procedural skills besides manipulating figures. Others fall short of retrieving identified key concepts they formulated in item 3.2. Only about 25% made successful attempts to retrieve close related math-in-science concepts and transfer their interpreted data into calculation.

With the latter, two C-group (C1 and C8) had little or no difficulties in solving item 3.3. However, there was a bit of concern in the way C8 interpreted his data, although, it was evident in the final solution he provided that he mistakenly overlooked a-would-have-been short approach to solve the problem than a lengthy steps he took. This inference supports his responses in the direct interview question when he was asked: did you encounter any difficulties in solving any of the items

(3.2 - 3.5)? If yes how did you try to overcome them? If no, why not? He responded that he followed a long approach due to the choice of formulae he chose instead of a short web formula that connected all the concepts (e.g. $W_{net} = \Sigma W = W_{F_A} + W_{g_{//}} + W_{F_f}$). In that regard, he solved four set of solutions of work done individually and could have created common mistakes of algebraic sign (\pm) except that he was skilful in mathematics.

The linking process of the four solutions using a single formula occurs between two pieces of information that exist between items 3.1 (e.g. constructing meaning, identifying, interpreting, analyzing vector component of forces) and 3.2 (laws, rules, application of theorem, algorithms as in Figure 3.8). As knowledge of these two items consist of the form and symbolic language of mathematics as well as qualitative and quantitative understanding of problem-solving strategy needed to solve item 3.3. Of other pre-service teachers C-group, the application of algebraic formalism (manipulation) without the understanding of math-in-science concepts was exhibited. Such was one of the major concerns that the study endeavoured to address.



4.9 Summary

The primary purpose of this study was to investigate the second and third pre-service teachers' conceptual and procedural difficulties that impede their abilities to solve mathematical problems in physics basic mechanics (e.g. work and energy). Three research questions were used. In order to test the research questions, instruments, techniques and methods of instructions were examined by those who have commendable knowledge of science and mathematics. Instruments were modified following the inputs of the evaluators. Data were collected in two sections of the instrument (PSAT), sections A and B. Similar tests of basic math and mechanics used in previous studies (e.g. Jewett, 2008; Heller *et al.*, 1992; Kim and Pak, 2002) were given to have a common basis for comparison.

It has become a commonplace belief that students' conceptual difficulties in solving basic mechanics are not something new. Similar studies since 80s revealed that such problems are on-going concern with no immediate solution (Lawson *et al.*, 1987,

p.811-817; Larkin *et al.*, 1980; Larkin *et al.*, 1987). Even in South Africa where the present study was conducted such problems have been documented among teachers who teach physical sciences or mathematics (see Adler and Reed, 2002; Breen, 1999; Pendlebury, 1998; Selvaratnam, 2011; Taylor and Vinjevold, 1999 as detailed in Chapters 1 and 2).

Elsewhere both teachers and students have had common conceptual and procedural difficulties while solving mathematical problems in basic mechanics (Arons, 1997; McBride & Silverman, 1991; Taplin, 1995). Presently, there are no short cuts, but there do exist better or worse ways of learning physics concepts such as mechanics (Redish, 1999). Active learning is said to be essential for a significant conceptual change to occur (Posner, Strike, Hewson & Gertzog 1982). For example, an effective instructional strategy for obtaining the necessary intellectual commitment from students is to generate a conceptual conflict and require them to resolve it. Such an approach has also enunciated elements of difficulties in practice. Posner *et al.* (1982) and Hewson & Hewson (1989, 1991) have sought to unravel the mystery of why the approach (conceptual change) is so difficult. Hewson (1992) as outlined in chapter 1 has outlined at least three elements that are necessary for a conceptual change instruction to be successful.

In the current study conceptual and procedural difficulties were investigated by exploring work-energy conceptions held by a group of pre-service teachers (Section A) enrolled in a physics course. In section B, they were asked to solve 5 work-energy problems and explain how their procedural steps could lead to the type of solution(s) expected. The result obtained in both sections (A and B) of PSAT show that there was little correlation between their math-in-science conceptual and procedural understanding of work-energy concepts. In other words, work-energy problems enriched with mathematical calculations were not successfully solved.

According to the display of their written explanations in response to the questions probing conceptual and procedural difficulties, the pre-service teachers have much difficulty in using physics and mathematical principles side by side to solve problems. [In process of justifying conceptual and procedural steps of problems solved and written explanations provided by the pre-service teachers common difficulties as will be highlighted and discussed in detail in Chapter 5 were observed.

Many of these difficulties and their nature of occurrence will also be discussed in Chapter 5.

The result from this study provides evidence that corroborates earlier findings in the area (e.g. Heller *et al.*, 1992; Kim & Pak, 2002; Larkin *et al.*, 1987; Lawson *et al.*, 1987; Junkins, 2007; McDermott, 1993; Redish, 1999; Reif and Allen, 1992; Selvaratnam, 2011). The findings show that many of the pre-service teachers still have conceptual and procedural difficulties in solving mathematical problems in physics especially mechanics even after instructional materials have been simplified. Also, by using a revised Bloom's taxonomy, it was observed that though a pre-service teacher may have the required conceptual knowledge needed to solve a given problem he/she lack the necessary procedural knowledge bring this about (Tables 4.1 and 4.4). Chapter 5 provides presents the conclusion and implications of the findings for teacher training and instructional practice. Finally, it suggests some recommendations for future investigations in the area.



CHAPTER 5

CONCLUSION, IMPLICATIONS AND RECOMMENDATIONS

5.1 Overview

The aim of the study was to investigate conceptual and procedural difficulties that second and third year pre-service teachers in a university in the Western Cape tend to encounter in solving mathematical problems in physics. The objective of the program is that the prospective teachers being trained in the institution do not only acquire necessary content knowledge but also pedagogical content knowledge to teach physical sciences at the secondary school level.

In pursuance of the objective above both qualitative and quantitative data were collected, analysed and discussed. This chapter summarise the major findings and their implications for teacher education and instructional practice. It also suggests recommendations for future studies in the area.

5.2 Summary of the findings:

- Common misconceptions held by the pre-service teachers on basic mechanics (work and energy) at the level taught:
 - (i) Many of the pre-service teachers involved in the study still held misconceptions or alternative conceptions of mechanics derived from common sense experiences.
 - (ii) More than 60% held incorrect scientific definition of work. To these pre-service teachers, work is energy used or product of force (F) and energy transformed.
 - (iii) Many the pre-service teachers confidently provided seemingly rational explanations to scientifically correct responses of work done. This was largely because these were consistent with their intuitive, sensory experiences. However, when these ideas were probed further (e.g. items 2.1 and 2.2 of PSAT section A- Appendix B), many of

them (e.g. E4, E9, C1, C2, C9) were unable to give coherent explanations of their ideas.

- (iv) Regarding mathematical expression (equation) of work done, nearly 40% held incorrect mathematical equation of work done, e.g. C1 stated that $W = \text{energy} / \text{distance covered} \text{ or } J / \Delta x$.
 - (v) In terms of math-in-science connections, many pre-service teachers failed to realize that when a force F causes motion at right angles to itself, it does not do any work, hence F is perpendicular to the displacement (Δx).
- Conceptual difficulties that the pre-service physical science teachers demonstrated in solving mathematical problems in physical science include the following:

The pre-service teachers (e.g. E3, E9, C1, C2 & C9) were unable to:

- (i) Construct a complete Free- Body- Diagram to represent all the individual forces acting on the truck as it travels down the inclined road (item 3.1). Those who did could not indicate them at the relevant position on the diagram.
- (ii) Identify the unknown variables. Those who did could not interpret the information for what they stand for.
- (iii) Analyse item 3.3 of the PSAT (section B-Appendix C) in terms of vector resolution of x and y - components.
- (iv) Conceptually link mathematical concepts e.g. basic trigonometry ratio and physics so as to make subject/content connections as a solving strategy.
- (v) Differentiate between acceleration in ($\text{m} \cdot \text{s}^{-2}$) and velocity in ($\text{m} \cdot \text{s}^{-1}$), a common misconception that led to wrong solutions to items 3.2 and 3.3 (e.g. see PSAT section B of Appendix C).
- (vi) Identify the net force F_{net} (i.e. the sum of all the forces that have impact on the truck's motion). This was observed in all the four items

tested, even though they did not have much difficulty in identifying the normal force (F_N) among other forces.

- Conceptual and procedural discrepancies in their conceptions of math-in-science that the pre-service teachers exhibited in solving physics problems are listed below:

They (e.g. E3, E9, C1, C2 & C9) were unable to:

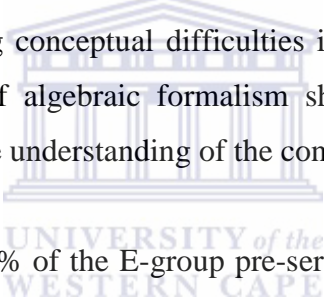
- (i) Write down the relevant equation(s) (e.g. $W_{F_f} = W_{F_A} + mg \sin \theta \cdot \Delta x \cos \vec{\theta} - \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$).
- (ii) Substitute numerical values and solve the trigonometry equations algebraically.
- (iii) Use numerical answer(s) they calculated at some stages to solve follow-up questions.
- (iv) Evaluate numerical answers to see whether the answer(s) they got make sense or not.

- Making strategic connections between relevant mathematical and physics concepts while solving work-energy problems.

- (i) Some of the pre-service teachers (e.g. E3, C2 and E4) provided solutions that contain invalid mathematical operation contrary to the algorithms steps depicted in Figure 3.8.
- (ii) In terms of algebraic formalism, the pre-service teachers (e.g. E3, C2 and E4) assumed that because net force is the sum of all the individual forces acting on an object, they set up wrong math-in-science equation that included all the forces acting on the truck regardless of whether such forces have impact on the truck's motion or not. Enunciated consequences of such wrong approach resulted in them being trapped with so many unknown forces, unable to proceed to interpret, analyse or solve the problem.
- (iii) They (e.g. C1, C8, E2 and E7) who had no problems of the later (ii) encountered setback in using their numerical answers obtained to

solve follow-up/ (sub) – question. Pieces of evidence extracted from their procedural steps leading to solution and related findings from the instructional literature (e.g. Bing & Redish, 2009; Martinez-Torregrosa *et al.*, 2006; McDermott 1993; Redish, 2005) suggest that such pre-service teachers might have manipulated symbols to obtain numerical answers and had little understanding of the problem situation.

Of course, the assertion above is not unequivocal. If it holds true as to what has transpired between the conceptual and procedural processes of the said pre-service teachers, then, the contention of McDermott (1993), which the present study attempted to inculcate among the pre-service teachers as a prompting tool to solving strategy has proved little success. In that regard, McDermott (1993), addressing conceptual difficulties in basic mechanics suggested that the use of algebraic formalism should be postponed until after a qualitative understanding of the concept in question is developed.

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- (iv) Nearly 57% of the E-group pre-service teachers seemed to subscribe to at least one metaphor in writing the equation of work done by friction as ($W_{net} = \Sigma W = W_{F_A} + W_{g//} + W_{F_f}$). Thus, only a few of them encountered minor difficulty to rearrange the setup equation so as to make the desirable symbol (W_{F_f}), work done by friction the subject of the formula. Following the memorandum rubrics, marks were deducted reasonably for all the erratic procedural steps leading to solution(s).
- (v) In terms of the curriculum policy of the teacher education program at the institution, Mathematics is one of the elective subjects. The pre-service teachers E-group responding to one of the items (3.3 of PSAT-section B of Appendix C) revealed that their choice of Mathematical Literacy and Physical sciences was because they find Mathematics very difficult since their high school days.

5.3 Implications for Teaching and Learning

It is evident from these findings that pre-service teachers still retain conceptual difficulties in physics mechanics, which confirm some of the findings found elsewhere in studies related to the present, namely (Kim and Pak, 2002; Redish, 2005). Similarly to the present study, pre-service teachers encountered difficulty in using algebraic expressions and the associated physics concepts even when concepts are made explicit. The pre-service teachers still face with epistemological obstacles, inabilities to link math-in-science concepts, pedagogic incompetency and inability to apply content knowledge at the level taught (e.g. Alant, 2004; Bell & Janvier, 1981; Brousseau, 1976; Junkins 2007; McBride *et al.*, 2010; McDermott, 1991; Sierpiska, 1994). Reif and Allen (1992) have explained that such difficulties are not due to erratic performances or lack of available knowledge, but due to their deficiencies in interpreting the knowledge they have. Such inferences were evident in one of the findings on conceptual difficulties encountered by the pre-service teachers in research question 1. For example, some pre-service teachers found it difficult to identify the unknown variables. Those who did could not interpret the information for what they are stand for.

The findings of this study corroborate a plethora of earlier findings in the area (Jewett, 2008), exposed approach that hoped can reduce conceptual difficulties and inconsistencies for the student. McDermott (1993) revealed how to overcome students' persistent conceptual and procedural difficulties by probing the cause-and-effect. Others (Lawson *et al.*, 1987, p.811-817; and Larkin *et al.*, 1983) have studied the genesis of students' conceptual and procedural difficulties in basic mechanics. While Bing & Redish (2009), Martinez-Torregrosa *et al.* (2006), Redish (2005) and Selvaratnam (2011) studies focused on students' and teachers' inability to conceptually link the equations, diagrams, or graphs used in physics with the situations they represent. However, none of these studies have provided any mechanism that achieved optimal result that can be use to address pre-service teachers who still retain conceptual and procedural difficulties in basic mechanics even after instructions are made explicit or simplified.

Evidence that have emerged from the present study indicates that most of the pre-service teachers had poor conceptual and procedural difficulties in solving physics

mechanics (e.g. work-energy concepts and problems). Some evidence noted in this regard include (E1, C3, E3 and E4) conceptual difficulties, lack of differentiation among acceleration and velocity, in attempt to solve item 3.2 of the PSAT (enriched with conceptual and procedural mathematical skills), they employed the wrong formula ($v_f = v_i + at$) instead of ($v_f^2 = v_i^2 + 2a\Delta y$), making it more difficult to find two unknown variables (v_f) and (t). As a result, they could not solve the desirable problem; hence final velocity (v_f) of the truck is needed in order to calculate the kinetic energy of the truck at the bottom of the inclined road. Traces of their lack of differentiation among acceleration and velocity might be linked to their responses in the PSAT items (section A – Appendix B) that tested the conception of basic mechanics they hold before the post-test. Drawing from that perspective, it might be necessary to recap on the said responses.

For example, with the exception of E1, pre-service teachers (E3, E4 and C3) responses on item 2.2 that ask them to explain with reasons if work is done or not by a waiter carrying a tray full of meals above his head by one arm across the room showed evidence of deficiencies in interpreting common experiences. They seem to confuse everyday life and sciences, without realizing the contradiction between the scientific conception of work done and common knowledge about work. They believed that work is being done by the waiter hence F is applied and distance (Δx) is covered as the waiter walks across the room. These misconceptions also referred to as “naïve conceptions” (e.g. Driver and Erickson, 1983) were already identified by other researchers (e.g. Adams, 2003; Ogunniyi and Fadkudze, 2000; Gunstone, 1988). Other difficulties seem to be associated with general learning problems and the way they relate scientific conception of sciences and everyday life sciences.

5.4 Implications and Recommendations for Higher Education

As has found elsewhere in the instructional literature, Kim and Pak (2002) reached a conclusion in their study similar to the present study and asserted that “students do not overcome conceptual difficulties after solving 1000 traditional problems”. Reif and Allen (1992) asserted that students’ difficulties are not due to erratic performances or lack of available knowledge, but due to their deficiencies in interpreting the knowledge they have. McDermott (1993) explained that deep-seated

conceptual difficulties cannot be overcome through assertion by an instructor. In general there are no short cuts, but there do exist better or worse ways of learning physics concepts such as mechanics (Redish, 1999). Active learning has said to be essential for a significant conceptual change to occur (e.g. effective instructional strategy for obtaining the necessary intellectual commitment from students is to generate a conceptual conflict and require them to resolve it, p.4).

An active engagement in learning, rather than passive reception, has been researched by various scholars (e.g. Heller *et al.*, 1992; Madelen, 2012; Onwu & Ogunniyi, 2006, p.131; Ogunniyi, 2009). Several studies have also shown that teaching problem-solving through cooperative grouping can facilitate conceptual understanding as well as reduce the difficulties they tend to encounter while working on mechanics (Brown & Palincsar, 1989; Johnson & Johnson, 1989; Heller *et al.*, 1992; Lunetta, 1990). Although this has not been demonstrated convincingly in the present study some progress has been made which could inform future studies in the area.

Junkins (2007) has stressed the importance of developing integrated mathematics and physical science courses that will enable students to see the practical applications of mathematics skills in the learning of physical science. The study provides immediate diagnostic assessment to teachers and feedback to students. The refinement of developing integrated mathematics and physical science courses include topics from Algebra I, Algebra II, Geometry, Statistics, and Trigonometry. It is conceivable that the relevance of the diagnostic mathematics topics will enable students to understand the importance of math-in-science in discovering accurate, data-driven and scientific conclusions.

5.5 Implication for Curriculum and Further Research

Regular curriculum renewal, which must consider new competencies, standards and trends, regional and international, is increasingly becoming a must in most educational systems of the world as a means of coping with various socio-cultural changes. The South African National Curriculum Statement (NCS 2005) and the subsequent curriculum policy documents Revised National Curriculum Statement (RNCS) for grade 10 - 12 physical science portrays a teaching pedagogy that promotes development of critical thinking and scientific reasoning and strategic

abilities among students. Also, this mandate is clearly spelt out in the Curriculum Assessment Policy Statement (CAPS) as well as the Examination Guidelines for 2014 CAPS. This scenario was the motivation for this study. In other words, the study should be construed as an attempt to equip the pre-service teachers with instructional strategies compatible with the demands of the new physical science curriculum with specific focus on mechanics.

According to Cobern (1996), school science is meaningful to the extent that it is made relevant to the learners' life worlds. In that regard, the findings in this study indicate that many of the pre-service teachers may struggle to implement and deliver such curriculum, considering the level of their competences with the physical science contents that they are likely to teach after qualifying. However, for teachers to assist learners to meet curriculum needs in respect to the societal demand, more studies that aimed at investigating the areas of learning difficulties among the pre-service teachers are deemed necessary to be conducted.

One other finding that emerged from the present study was the E-group view of Mathematics and Physical sciences combination and what might be necessary to motivate them. It is on this basis that McBride and Silverman (1991) asserted that mathematics activities illustrating science concepts can provide relevancy and motivation for learning science (p. 286-287).

The results of this study support the following conclusions:

1. There is a lack of recognition of mathematics applications in physics basic mechanics exhibited by pre-service teachers' calculations especially the E-group. (Section 4.8.2).
2. Pre-service teachers E- group tend to believe that work done to move an object to a desirable position on a frictionless surface is always $W = F\Delta x$ regardless of the direction of force(s).
3. There is little distinction made by both groups about assigning units to quantities which precedes common errors. (Finding emerged from marking PSAT 3.2 and 3.3)

4. Pre-service science teachers (E- group) seem to be aware that the effect of mathematics hinders their abilities to perform most science calculations. (See interview item 4, performance Table 3.5).
5. Both the E and C-groups have distinctive concern in teaching and learning of physical science content. Thus E-group face with more challenges than the C-group, (See Tables 3.5 and 3.6).

5.6 Final Thoughts

Even for successful problem solvers there seems to be a lack of basic conceptual understanding of physical science problems with complex mathematics. Especially in such cases where more than one type of mathematical skills is needed to perform physical science calculations. See discussion on items 3.2 and 3.3 of the PSAT 9section B of Appendix C) and Figure 4.9 – representation of stuck zone. It is true that most examples studied in science are idealized. For example, students are often asked to ignore the effects of air resistance or friction in some calculations while the events they observe may be dominated by these very forces like the case of (items 3.3 and 3.5) in (section B – Appendix C) of the PSAT. Perhaps not enough time is spent analyzing more realistic examples that show how the physical principles we learn in one subject can be used to explain another. That is, making subject/content connections.

5.6.1 Questions Emerge From the Findings

Looking at the nature of the findings; challenges and concerns, the following questions fall out of the scope of the study. Yet, they are not formidable to ask or reincarnate the attention of what might have been debated or will be someday debated for the betterment of quality science teachers that can help develop creative and critical thinking among learners. Concerns that preceded the following questions are: (i) the pre-service teachers (E- group) seem to be aware that the lack of basic mathematics hinders their abilities to understand most of the physical science calculation concepts. (ii) they revealed that most times they are unable to recognize the appropriate mathematical skills needed to solve science problems. (See interview item 4). Again see Tables 3.5 and 3.6. The questions are:

1. Should the department being researched continue to accept or register pre-service physical science teachers on the basis of mathematics as elective major?
2. Should mathematics be made non-elective for the specialization in physical science education?

Many of the findings so far are inconclusive and need further verification or they raise more questions than answers. Hence, this study was carried out with the sole aim of contributing further knowledge and insight in the area. It neither assumes that all the answers will be found to all the problems associated with the pre-service science teachers' conceptual and procedural difficulties nor does it in any way pretend that the answers might apply to varied contexts. Rather, it is an attempt to provide baseline data in an area that has been under-researched, especially in this country (South Africa).

In conclusion, if pre-service science teachers are not skilful in mathematics, an understanding of science concepts may be impossible (Junkins, 2007; Redish, 2005; McDermott, 1993; Taplin, 1995; Rutherford and Ahlgren 1989, 1990).

5.7 Limitations

As stated earlier, this study has evolved from my experience in teaching physical science to second- and third-year pre-service teachers. This study therefore, is situated in the context of studies that have shown that conceptual math-in science obstacles are not limited to learners but are also prevalent among pre-service and practising teachers (e.g. Jones, 1995; Simon, 1993; Taplin, 1995). It would be ideal to have carried the study in all the four teacher training institutions in the Western Cape Province by using a larger sample but logistical and resource constraints did not permit me to do this. In terms of the sample size, there were only 16 pre-service teachers registered for Physical sciences (II) and (III) at the time of the study. Seven of the pre-service teachers were third year undergraduate students and nine were second year undergraduate students. Both groups were exposed to basic mechanics at the level taught.

The concerns that triggered the present study as have already highlighted in Chapter 1 were observed in teaching Physical sciences (II) and (III) basic mechanics (e.g. work-energy). One may argue that since both E-group and C-group participants in the study are my students and coming from the same faculty, they might communicate with each other and share knowledge gained through the intervention sessions (including the use of mathematical modelling and other exemplary materials) the validity and reliability of the study will be greatly compromised. However, with the situation in the Further Education and Training (FET) faculty, this problem is not likely to occur. First, the education faculty at the time of the study was offering FET programs on two separate campuses situated far from each other. The third year (Experimental group) stationed at the main campus of the university far away from where their counterpart (second year – control group) is situated. Neither of the two groups was told they have counterpart elsewhere, thus each group was treated as if they were sole data contributor of the study. This proved useful in giving peace of mind about possible sources of data contamination.

According to Ogunniyi (1992) research in the social sciences (including education) are fraught with a congeries of extraneous variable such as history, maturation, high mortality rate, unpredictability of humans who often act and react to contextual changes, lack of universal theories about human behaviours, problems associated with formulating terms or variables with precise operational definitions etc. Despite these constraints, it is hoped that the findings of the study would provide useful insights to research efforts directed at ameliorating mathematically related obstacles which prevent pre-service physical science teachers from solving physical science problems in an effective manner.

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INFORMATION AND INSTRUCTIONS

Read the following instructions carefully before using this learning journal:

1. What is a learning journal?

A Learning Journal is a diary comprising of a student's self-report and reflections of his/her learning processes.

2. Purpose of a Learning Journal for this study.

- The learning journal can help you as a student to analyze, assess and reflect upon your own learning process and thus enhance your learning of concepts.
- The learning journal can also help me as a researcher to follow and evaluate your learning processes, conceptual difficulties you encounter in solving mathematical problems in physical science.

Accordingly, this learning journal is your personal reflection of your learning processes you used for overcoming conceptual difficulties in solving mathematical problems in physical science. The journal should be written individually as instructed. It will be treated anonymously in my thesis.

3. Working on Learning Journal.

You are encouraged to make notes separately as you study each section of the journal and once you are satisfied with your solution/answer/response, then you can write it down according to the instruction. **Write legibly and neatly.**

4. Collection of Learning Journal

You will be expected to hand in this Learning Journal at the end of each session throughout the study and collect it at the start of each session.

| Topic under study | Concept(s) under study | Enter student level | | |
|-------------------|--------------------------|----------------------|--|----------------------|
| Mechanics | Work & Energy | 2 nd year | | 3 rd year |

Which of the following programmes are you enrolled in with Physical science?

Mark an X. Mathematics (), Mathematical Literacy (),

Other Subject that is not Mathematics or Mathematical Literacy ()

Gender: Male () Female ()

Age: 16 – 20 () 21 – 25 () 26 – 30 () 31 – 35 () 36 – 40 ()

Indicate your cultural group:

Black African () Coloured () Indian () White () Other ()

Indicate your home language (the language you speak most frequently at home:

Afrikaans () English () Isixhosa () IsiZulu ()

IsiNdebele () Tshivenda () Xitsonga () Setswana ()

Sesotho () Other ()

Indicate your disability status: (*Disability means moderate severe limitation in a person's ability to function or ability to perform daily life activities as a result of a physical, impairment*).

Sight () Hearing () Others (specify) _____

Province where you matriculated:

E/Cape () N/Cape () Gauteng () Free State () W/cape ()

Year of matriculation:

1990 – 1994 () 1995 – 1999 () 2000 – 2004 () 2005 – 2009 ()

2010 - 2011 ()

Where is your high school situated?

Urban area () Rural area () Pre-urban area ()

Specify if others: _____

ACTIVITY A: *Students search for meaning of concept(s), evaluate concepts, and link concepts to real-life.*

L1 Please describe in a few sentences, what you understand by the term “work”.

1

(2)

1.1 Write down your own definition of *work* mathematically (i.e. in equation form).

1.2 **Consider the following scenario:**

(1)

Your mother left home for work in the morning and after work she returned home and felt exhausted due to excessive work she did at her work place. ***From science perspective, your mother had done no work.***

Do you **Agree** or **Disagree**? *Mark an X.* Agree () Disagree ()

1.2.1 Explain your reason using scientific principle why you agree or disagree.

(2)

L2**Work done or Not**

2.1 A horse pulling a plow through the fields. **Work done** () **No work done** ()

Explain your reasons for (2.1): _____

(2)

2.2 A waiter carries a tray full of meals above his head by one arm across the room.

Work done () **No work done** ()

Explain your reasons for (2.2): _____

(2)

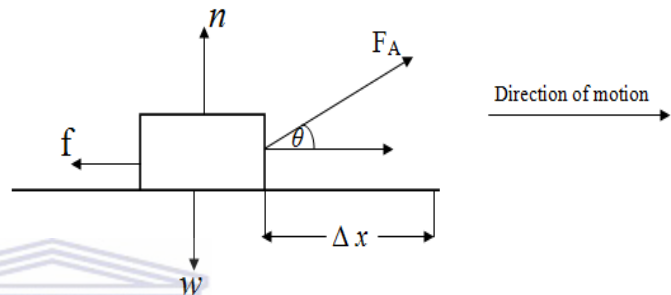
L3 WORK & ENERGY → WORK-ENERGY THEOREM PROBLEMS

CONSIDER THE FOLLOWING SPECIAL CASES:

1. $\theta = 0^\circ$ (When F and Δx have the same direction. F does positive work)
2. $\theta = 90^\circ$ (When F is perpendicular to Δx . F does NO work or Zero work.)
3. $\theta = 180^\circ$ (When F and Δx have opposite direction. F does negative work)

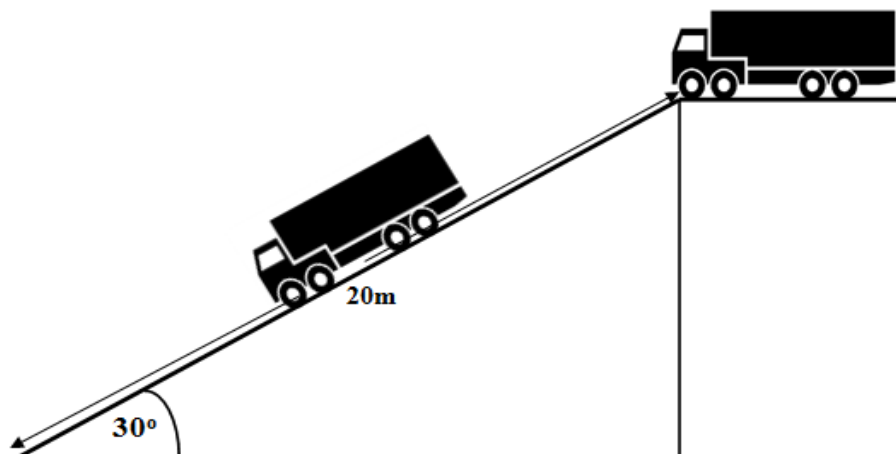
TOTAL WORK (W_{net}) → WHEN SEVERAL FORCES ACT ON AN OBJECT

| |
|--|
| <p>KEY:</p> <p>w: → Weight of object</p> <p>f: → Frictional force</p> <p>n: → Normal force</p> <p>F_A → Applied force</p> <p>Δx → Displacement of object</p> |
|--|



L3.1

The transportation of goods by trucks adds to the traffic problems on our roads. A 10 000kg truck, starting from rest, travels down a straight inclined road of length 20m which forms an angle of 30° with the horizontal. The truck undergoes a constant acceleration of magnitude 2m/s^2 while travelling down the inclined road. The total work done by the engine of the truck to get to the bottom of the inclined road is $7 \times 10^3\text{J}$. A constant frictional force opposes the truck's movement.



| | |
|--------------|--|
| 3.1.1 | Draw a free-body diagram to show all the forces acting on the truck while travelling down the inclined road to the point it reaches the bottom. |
| | (3) |

The truck reaches the bottom of the inclined road.

| | | |
|------------|---|------------|
| 3.2 | Calculate the kinetic energy of the truck, using the equations of motion. | (7) |
|------------|---|------------|

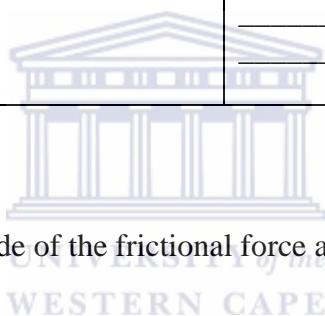
| Choose a formula and explain | Show calculation |
|--|---|
| <hr/> <hr/> <hr/> <hr/> <hr/> <hr/> | |
| <p><i>Write down known and unknown quantities you need in order to perform the calculation</i></p> | |
| | <p><u>Explain how you arrived at your answer</u></p> <hr/> <hr/> <hr/> <hr/> |

| | | |
|------------|---|------------|
| 3.3 | Calculate the work done on the truck by the frictional force, using the work-energy theorem. | (7) |
|------------|---|------------|

| Choose a formula and explain | Show calculation |
|--|---|
| <hr/> <hr/> <hr/> <hr/> | |
| <p><i>Write down known and unknown quantities you need in order to perform the calculation</i></p> | |
| | <p><u>Explain how you arrived at your answer</u></p> <hr/> <hr/> <hr/> <hr/> |

3.4 Calculate the work done on the truck by the gravitational force. (7)

| Choose a formula and explain why | Show calculation |
|--|---|
| <hr/> <hr/> <hr/> <hr/> <hr/> <hr/> <hr/> <hr/> | |
| <p><i>Write down known and unknown quantities you need in order to perform the calculation</i></p> | <p><u>Explain how you arrived at your answer</u></p> <hr/> <hr/> <hr/> <hr/> |



3.5 Calculate the magnitude of the frictional force acting on the truck. (6)

| Choose a formula and explain | Show calculation |
|--|---|
| <hr/> <hr/> <hr/> <hr/> <hr/> <hr/> <hr/> <hr/> | |
| <p><i>Write down known and unknown quantities you need in order to perform the calculation</i></p> | <p><u>Explain how you arrived at your answer</u></p> <hr/> <hr/> <hr/> <hr/> |

4.1 Which of the following (**questions 3.2 – 3.5**) did you find difficult to solve? Specify *question number* and explain why.

4.2 How did you try to overcome the difficulty?

4.3a) Mathematical calculation in solving physical science problems has always been

| | | | |
|-------------|--|------------------|--|
| <i>Easy</i> | | <i>Difficult</i> | |
|-------------|--|------------------|--|

 for me because of:



4.3b) What mathematical concepts do you need to solve problems on work and energy?

Memorandum for the PSAT items: Sections (A & B)[40 Marks]

Section A: Suggested answers

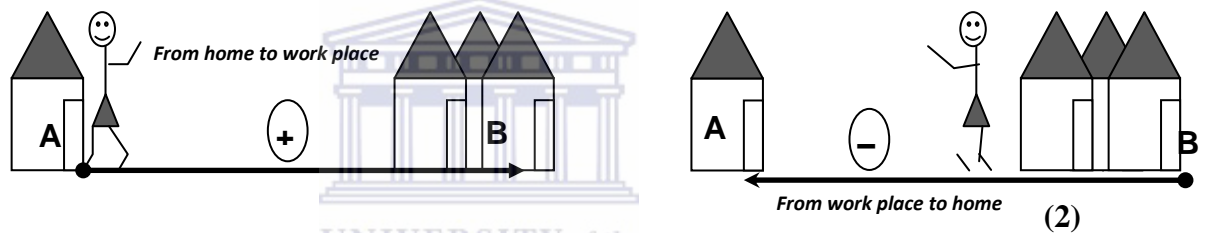
(L1)

1. Work done is the product of force (F) and displacement (Δx) in the direction (θ) of force. (2)

1.1 Mathematical expression of work done:

$$W = F \cdot \Delta x \cdot \cos \theta \quad \checkmark \quad (1)$$

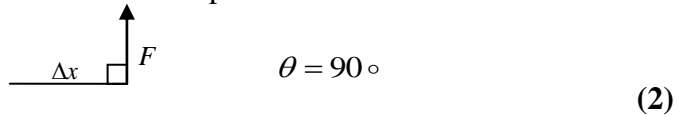
1.2 “Agree”: Taking her (the mother) point of departure as reference. Her position at the point of departure is zero ($0m$). After completing her tasks at her work place she returned home (her point of departure) ($0m$) – regardless of how much force she applied. The work done by her at the point of departure is equal zero, hence ($\Delta x = 0m$).



(L2)

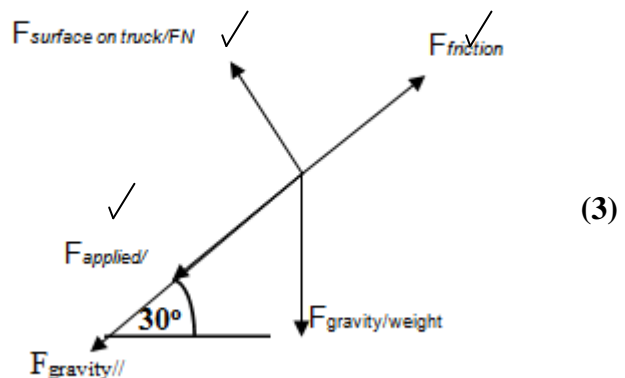
2.1 *Work is done.* Reason: The horse applied force (F) and displaced the plow from one position to another position, which is change in displacement (Δx). $W = F \cdot \Delta x \cdot \cos \theta$. (2)

2.2 No work is done. There is an upward force and there is a horizontal displacement but the force does not cause the displacement. A vertical force cannot cause horizontal displacement.



(L3)

3.1.1 Free-body-diagram



3.2 Formulae

$$K_f = \frac{1}{2}mv_f^2 \quad \checkmark \quad (\text{Formula 1})$$

$$v_f^2 = v_i^2 + 2a\Delta x \quad \checkmark \quad (\text{Formula 2})$$

The first formula (formula 1) is the correct formula required to solve kinetic energy of the truck to the point it reaches the bottom of the inclined road. Before the first formula can be used, the second formula (formula 2) must be used to calculate the final velocity of the truck as it reaches the bottom of the road.

Data:

m = mass of the truck (10 000kg)

a = constant acceleration of the truck (2m/s²)

Δx = change in displacement ($x_f - x_i$) (20m)

v_i = initial speed of the truck (0 m/s)

v_f = final speed of the truck ($v_f = ?$)

K_i = initial kinetic energy (0J), hence $v_i = 0$ m/s

K_f = final kinetic energy ($K_f = ?$) \checkmark

$$v_f^2 = v_i^2 + 2a\Delta x \Rightarrow v_f^2 = 0^2 + 2 \times 2 \times 20 = 80 \checkmark$$

$$\text{So } K_f = \frac{1}{2}mv_f^2 \Rightarrow = \frac{1}{2}10000 \times 80 = 400000J / 400kJ / 4 \times 10^5 J \checkmark$$

Explanation: Arrival at the answer: How?

Firstly, I made the right substitution with the known quantities and made the unknown (or required) quantity the subject of the formula. Thus, I transferred my first answer into the second formula in order to calculate kinetic energy. \checkmark

(7)

3.3 Using work-energy theorem

Formula:

$$(W_{net} = \Delta K = \Sigma W = F_{net} \cdot \Delta x \cdot \cos\theta) \checkmark$$

Since the instruction restricted to work-energy theorem equation.

$$W_{F_f} = W_{F_A} + W_{g_{\parallel}} - \Delta K$$

$$W_{F_f} = W_{F_A} + mg \sin \theta \cdot \Delta x \cos \vec{\theta} - \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$W_{F_f} = 7000 + (10000 \times 9.8 \times \sin 30^\circ \times 20 \times \cos 0^\circ) - \frac{1}{2} \times (10000)(80) + \frac{1}{2} \times (10000)(0)^2$$

$$W_{F_f} = 7000 + 980000 - 400000$$

$$W_{F_f} = -587000J$$

$$\therefore W_{F_f} = \mathbf{587000J}$$
 (in opp. direction to the movement of the truck)

Explanation: Arrival at the answer: How?

In this question (3.3), there are two unknown quantities. With the correct formula, I made the right substitution with the known quantities, and then made the unknown quantity the subject of the formula. I took care of the second unknown quantity ($W_{g_{\parallel}}$), which is equal to ($W_{g_{\parallel}} = mg \sin \theta \cdot \Delta x \cos \vec{\theta}$). \checkmark

(7)

3.4 To calculate the work done on the truck by the gravitational force F_g

$$W_{g_{\parallel}} = mg \sin \theta \cdot \Delta x \cos \vec{\theta} \checkmark$$

Known quantities

m = mass of the truck (10 000kg)

a = constant acceleration of the truck (2m/s^2)

Δx = change in displacement ($x_f - x_i$) (20m)

g = acceleration due to gravity (9.8m/s^2) \checkmark

θ = angle of incline (30°)

$\cos \theta = \cos 0^\circ$

Unknown quantity

$W_{g_{\parallel}} = ?$

Solution

$$W_{g_{\parallel}} = mg \sin \theta \cdot \Delta x \cos \vec{\theta} \checkmark$$

$$= (10000 \times 9.8 \times \sin 30^\circ \times 20 \times \cos 0^\circ) \checkmark$$

$$= 980000J \checkmark \checkmark$$

Explanation: Arrival at the answer: How?

Unlike question (3.3), question (3.4) is simpler, with the correct formula, I substituted the known quantities and made the known quantities and made the unknown quantity the subject of the formula and then use calculator to work out the solution. ✓

(7)

3.5 To calculate the magnitude of the frictional force (f).

Formula: $W_f = f \cdot \Delta x \cdot \cos \theta$ ✓

From previous calculation (3.3), (W_f) was computed. Work done by the frictional force (W_f) is equal to frictional force times the displacement and direction. ✓

Known quantities

$W_f = -587000J$

$\Delta x = 20m$

$\cos \theta = \theta = 180^\circ$ ✓

Unknown quantity

$f = ?$



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Solution

$W_f = f \cdot \Delta x \cdot \cos \theta$ ✓

$-587000 = f \cdot (20) \cdot \cos 180^\circ$ ✓

$\frac{-587000}{-20} = \frac{-20f}{-20}$

$f = 29350N$ ✓

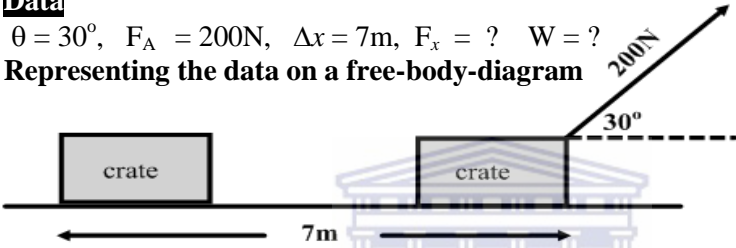

(6)

Intervention: A Three Week Lesson Plans

WEEK 1- DAY 1: Teaching concepts of work & energy (basic mechanics)

| Learner activity 1 | What to do | What you need | Time Allowed | | | | | | | | | | | | | | | | |
|---|---|--|---|-----|---------|---|--|--|--|---|--|--|--|---|--|--|--|---|----------------------------|
| <p>○ Your mother left home for work in the morning and after work she returned home and felt exhausted due to excessive work she did at her work place. From science perspective, your mother had done no work? Do you Agree or Disagree?</p> <p>Thoughts that can help you think effectively and relevantly</p> <ul style="list-style-type: none"> • What are other ways to look at the concept(s)? • What information is important? What information is missing? • Discriminating examples from non-examples. • How do you know when work is done or not? • What is your reason? How is that possible? | <ul style="list-style-type: none"> • Read through arguments provided in the regarding work. Apply the L-strategies • Discriminate & Explain the concept (work) • Think and write down everything you know, came across and can remember about work. • State your point of view and the reasons for them. <p>You must report to the class your final points of arguments decided upon.</p> | <p>Search for any info you need in the main lesson notes</p> | <p>25 mins presentation</p> <p>No overlapping of time</p> | | | | | | | | | | | | | | | | |
| Learner activity 2 | What to do | What you need | Time Allowed | | | | | | | | | | | | | | | | |
| <p>WORK OR NOT?</p> <ul style="list-style-type: none"> ○ a father pushing a grocery cart down the passageway of a grocery store ○ a freshman lifting a backpack full of books upon her shoulder ○ A teacher applies a force to a wall and becomes exhausted. ○ A waiter carries a tray full of meals above his head by one arm across the room. ○ | <p>Use a Free Body Diagram (FBD)/table to distinguish which of the statement(s) is work done or not</p> <p>Possible Report Could Look Like This:</p> <p>Make a cross sign X and state possible reason</p> <table border="1"> <thead> <tr> <th>IDEA NO.</th> <th>Work</th> <th>Not</th> <th>Reasons</th> </tr> </thead> <tbody> <tr> <td>1</td> <td></td> <td></td> <td></td> </tr> <tr> <td>2</td> <td></td> <td></td> <td></td> </tr> <tr> <td>3</td> <td></td> <td></td> <td></td> </tr> </tbody> </table> | IDEA NO. | Work | Not | Reasons | 1 | | | | 2 | | | | 3 | | | | <p>Search for any info you need in the main lesson notes</p> <p>You need to design your views clearly in tabular form/FBD</p> | <p>30mins presentation</p> |
| IDEA NO. | Work | Not | Reasons | | | | | | | | | | | | | | | | |
| 1 | | | | | | | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | | | | | | | |

WEEK 2- DAY 2: Teaching Qualitative & Quantitative Problem solving

| Problem Solving Skills | What to do & Feedback | Time |
|--|--|------------------------------------|
| <p style="text-align: center;">Calculations on: Work done</p> <p>QUESTION 1 (PROBLEM & SOLUTION)</p> <p>A person pulls a crate with a force of 200N at an angle of 30° to the horizontal. If frictional force is negligible, how much work is done as the object moves a distance of 7m?</p> <p>SOLUTION</p> <p>Data $\theta = 30^\circ$, $F_A = 200\text{N}$, $\Delta x = 7\text{m}$, $F_x = ?$ $W = ?$</p> <p>Representing the data on a free-body-diagram</p>  <p>From the FBD, the force F and displacement Δx are not in the same direction. For this reason, we must resolve the H-component to find the F parallel to displacement.</p> $\cos \theta = \frac{F_x}{F_A} \Rightarrow F_x = F_A \cos \theta$ $F_x = 200 \times \cos 30^\circ = \mathbf{173,20N}$ $\therefore W = F\Delta x = 173,20 \times 7 = \mathbf{1212,4J}$  <p>Question 2: Student Activity</p> <p>A box with a mass of 2kg is pulled at a constant velocity of 0,4m/s across a table by a string which is at an angle of 30° to the horizontal. The frictional force on the box is 6N. Calculate:</p> <p>(2.1) The work done by the gravitational force on the box when it moves a distance of 1.2m.</p> <p>_____</p> <p>_____</p> <p>_____</p> <p>_____ (4)</p> <p>_____</p> | <p>Basic mathematics skills</p> <p>Application of trigonometry (SOHCAHTOA)</p> <p>In precise: CAH</p> <p>i.e.</p> $\cos \theta = \frac{F_x}{F_A}$ <p>Alternative Method</p> $W = F_A \Delta x \cos \theta$ $= 200 \times 7 \times \cos 30^\circ$ $= \mathbf{1212,4J}$ <p><i>Devise a plan- Use Free Body Diagram where possible and write down the known and unknown quantities and then apply the solving strategies indicated above.</i></p> | <p>12 minutes</p> <p>8 minutes</p> |

WORK & ENERGY → WORK-ENERGY THEORY

Problem Solving Skills

What to do & Feedback

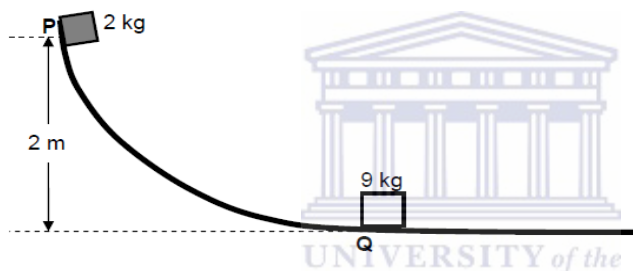
Time

- What is the relationship?
- Energy is measured in Joules (same as work) why?

Calculations on: **WORK-ENERGY**

QUESTION 3 (PROBLEM & SOLUTION)

A wooden block of mass 2 kg is released from rest at point P and slides down a curved slope from a vertical height of 2 m, as shown in the diagram below. It reaches its lowest position, point Q, at a speed of 5 m·s⁻¹



3.1) Use the work-energy theorem to calculate the work done by the average frictional force on the wooden block when it reaches point Q.

SOLUTION (3.1)

Data

Before the block at point (P) slides, the speed $v = 0\text{m}\cdot\text{s}^{-1}$
 $m = 2\text{kg}$, $h = 2\text{m}$, $E_k = ?$, $W_f = ?$ $g = 9.8\text{m}\cdot\text{s}^{-2}$, $W_{\text{net}} = ?$

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

$$mg\Delta y \cos\theta + w_f = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$(2)(9.8)(2)\cos 0^\circ + w_f = \frac{1}{2}(2)(5)^2 - \frac{1}{2}(2)(0)^2$$

$$39.2 + w_f = 25$$

$$w_f = 25 - 39.2 = -14.2\text{J}$$

(3.2) Is mechanical energy conserved while the wooden block slides down the slope? Give a reason for the answer.

SOLUTION (3.2)

No. Friction is present.

Use equation of motion

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

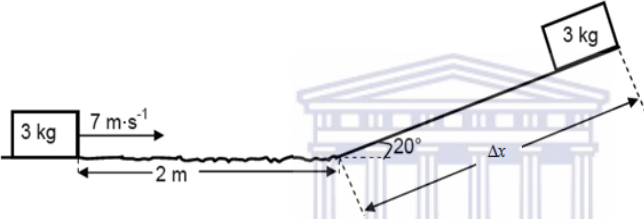
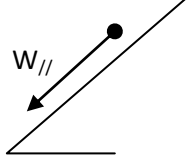
$$W_{\text{net}} = \Delta K \text{ (restriction)}$$

Or

Alternatively 3.1 can be solved using

$$-\Delta U + w_f = \Delta K$$

10 mins

| Problem Solving Skills (Week 2- day2) | What to do & Feedback | Time |
|---|--|----------------|
| <p>Question 4: Student Activity</p> <p>A 3 kg block slides at a constant velocity of $7 \text{ m}\cdot\text{s}^{-1}$ along a horizontal surface. It then strikes a rough surface, causing it to experience a constant frictional force of 30 N. The block slides 2 m under the influence of this frictional force before it moves up a frictionless ramp inclined at an angle of 20° to the horizontal, as shown in the diagram below.</p> <p>The block moves a distance Δx up the ramp, before it comes to rest.</p>  <p>4.1) Draw a free-body diagram to show all the forces acting on the block in a direction parallel to the incline, whilst the block is sliding up the ramp.</p> <p>4.2) Show by calculation that the speed of the block at the bottom of the ramp is $3\text{m}\cdot\text{s}^{-1}$</p> <p>_____</p> <p>_____</p> <p>_____</p> <p>_____</p> <p>_____</p> <p>_____ (5)</p> <p>4.3) Calculate the distance, Δx, the block slides up the ramp.</p> <p>_____</p> <p>_____</p> <p>_____</p> <p>_____</p> <p>_____</p> <p>_____ (5)</p> | <p>As before, you will need to do the following</p> <p>Search for meaning, interpret examples given, analyze and synthesis concepts, evaluate scientific significance of examples given and solve the problems</p> <p>Use Scientific calculator and other stationeries needed to solve the given problems</p> <p>Employ free-body-diagram</p>  | <p>25 mins</p> |

QUESTION 5 (PROBLEM & SOLUTION)

A sphere of mass 2kg is dropped from a height of 60m above the ground. **Calculate its:**

(5.1) Kinetic energy E_K

(5.2) Potential energy E_P , after it has been falling for 3s.

Ignore air resistance.

SOLUTION (5.1)**Data**

Before the sphere is dropped, the speed $v = 0\text{m}\cdot\text{s}^{-1}$

$m = 2\text{kg}$, $h = 60\text{m}$, $E_K = ?$, $E_P = ?$, $t = 3\text{s}$

$g = 10\text{m}\cdot\text{s}^{-2}$

$$(3.1) E_K \text{ at B} = \frac{1}{2}mv^2$$

$$= (0,5 \times 2 \times 0) = \mathbf{0J}$$

$$E_K \text{ at H} = \frac{1}{2}mv^2$$

$$= (0,5 \times 2 \times (2 \times 10 \times 60))$$

$$= \mathbf{1200J}$$

SOLUTION (5.2)

First we need to find the height h which the sphere has fallen for 3s.

$$\Delta x = 0 \times 3 + (0,5 \times 10)(3)^2$$

$$\Delta x = 45\text{m}$$

$$\therefore 60 - 45 = \mathbf{15m}$$

$$E_P = mgh$$

$$= 2 \times 10 \times 15$$

$$= \mathbf{300J}$$

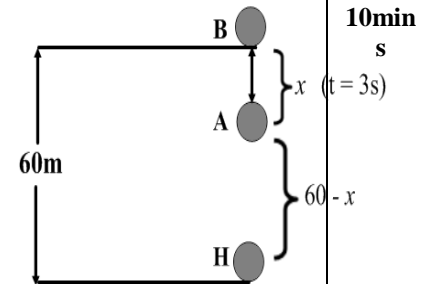
Question6: Student Activity

A pendulum bob of mass 2kg is lifted through a vertical height of 400m before being released.

Calculate:

(6.1) its kinetic energy when it passes through the lowest point.

(6.2) its velocity when it passes through the lowest Point

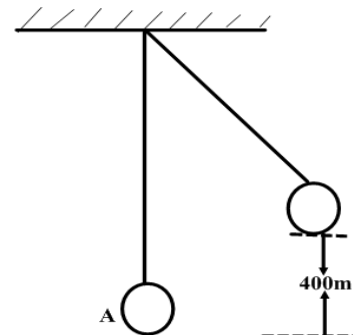


10min
s

Use equation of motion

$$\Delta x = v_i \Delta t + \frac{1}{2} a \Delta t^2$$

15
mins



To: HOD (Faculty of Education and Social Science)
Institution: Cape Peninsula University of Technology (CPUT)

From: IWUANYANWU, PAUL
E-mail: eng.pins@yahoo.com
Date: 20 November 2012

Dear Mr. F. Marlie,

**Re: Request for permission to carry out my research with 2nd and 3rd year
B.ED Physical science students (2012/2013)**

This letter seeks your permission to allow me carry out my research with the CPUT, 2nd and 3rd year B.ED physical science students. I am registered for masters in science education (student number 3216726) with the University of the Western Cape (UWC) in the School of Mathematics and Science Education. I am due for data collection during the first semester 2013. My research title is:

“Pre-service science teachers’ conceptual difficulties in solving mathematical problems in physical science.”

As I pointed out earlier, I intend to use 2nd and 3rd year students who are registered for physical science II and III. The nature of the study is based on mixed approaches which include quantitative and qualitative (questionnaires and interviews).

I intend to collect the data through the use of:

- 1) Instructional protocol that involves classroom arguments and discussions which can be beneficial to the students in developing/improving their conceptual understanding of the physical science phenomena in question.
- 2) Mathematical modelling that elucidate learning opportunities which I believe could help them find effective way to overcome the mathematical difficulties they tend to encounter when solving problems in physical science.
- 3) Student Learning Heuristics (questionnaires)

- 4) Mechanics (work, energy & power) data will be collected through the PSAT (Physical Science Achievement Test)
- 5) Interviews that focused on the emerging student learning heuristics and conceptual understanding.

All data collected will be treated with confidentiality and will be used solely for the purposes of the study. For the most important part, students' participation is a matter of choice and no one will be compelled to participate if s/he wishes not to take part.

Thank you kindly

Paul Iwuanyanwu



(CPUT): Faculty of Education and Social Sciences

17/11/2012

Dear B.ED physical sciences (II & III) students

I write seeking your permission to involve you in my research study. Currently I am pursuing master studies at the University of the Western Cape (UWC) and am about to collect data for my M.ED thesis. The study is meant to gather data on conceptual difficulties science students demonstrate in solving mathematical problems in physical science. The data will contribute towards the research findings for the thesis. It is hoped that the results will give indications/pointers of effective way to overcome the mathematical difficulties that students tend to encounter in solving problems in physical science.

I intend to collect the data through the use of:

- 1) Instructional protocol that involves classroom arguments and discussions which can be beneficial to you in developing/improving your conceptual understanding of the physical science phenomena in question.
- 2) Mathematical modeling that elucidate learning opportunities which I believe could help you find effective way to overcome the mathematical difficulties you tend to encounter when solving problems in physical science.
- 3) Student Learning Heuristics (questionnaires)
- 4) Mechanics (work, energy & power) data will be collected through the PSAT (Physical Science Achievement Test)
- 5) Interviews that focused on the emerging student learning heuristics and conceptual understanding.

You will be issued a learning module with multiple activities at the beginning of the study and are expected to complete them as instructed. And please feel free to write on a separate sheet and be careful to indicate and label question(s) number(s) correctly, if the space provided is not sufficient. The PSAT and interview will be held at the end of the semester. For all data collected, your confidentiality will be assured and in cases where your contributions may be used for future references or publication, your identities and interests will be protected. Thank you kindly for cooperation in advance.

Yours in Science Education

Paul Iwuanyanwu



To: Mr P. Iwuanyanwu
From: Mr M Marlie (Education Department)
Date: 21 November 2012

Re: Request for permission to carry out your research with 2nd and 3rd year BED Physical Sciences students at CPUT

Dear Mr Iwuanyanwu

I do not have a problem granting you permission to do your research (for Masters degree) with our students as spelled out in your letter.

I am however also forwarding your request to Prof. R. Chatty, Head of Research in our Faculty for his input regarding granting you permission.

Regards

A handwritten signature in black ink that reads "M F Marlie".

.....
M. F. Marlie

HoD: Education Department (FET): Bellville Campus

PO Box 1906 Bellville 7535 South Africa
086 123 2788

Table 3.5: Descriptions of PSAT pre-test analysis³

| <i>PT</i> | <i>C/E Group</i> | <i>g</i> | <i>n</i> (4) | <i>Section A</i> <i>Marks =10</i> | <i>Section B</i> <i>Marks =30</i> | <i>Minor</i> <i>D₁</i> | <i>Major</i> <i>D₂</i> | <i>Atypical</i> <i>D₃</i> | <i>Total</i> <i>marks</i> | <i>N</i> |
|-----------|------------------|----------|-----------------|--------------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|---|------------------------------|----------|
| | | | | Item 1 – 2.2 | Item 3.1 -3.5 | | | | | |
| A | C ₁ | m | 1 | 5 | 8 | 3s, 4u | 1z | 1s, 1u, 1z | 13 | 4 |
| B | C ₂ | m | 1 | 6 | 7 | 4s, 3u | 1z | 1s, 2u | 13 | 5 |
| C | C ₃ | f | 0 | 5 | 3 | 3s, 4z | 1z | 3z | 8 | 3 |
| D | C ₄ | m | 1 | 5 | 10 | 4s, 3u | 1u | 1s, 2z | 15 | 5 |
| E | C ₅ | f | 1 | 10 | 12 | 7s | 1u | 1s, 2u | 22 | 8 |
| F | C ₆ | m | 0 | 7 | 5 | 4s, 3u | 1z | 1u, 2z | 12 | 4 |
| G | C ₇ | m | 0 | 4 | 3 | 3s, 4u | 1z | 1u, 2z | 7 | 3 |
| H | C ₈ | m | 1 | 5 | 6 | 3s, 4u | 1u | 1s, 2u | 11 | 4 |
| I | C ₉ | m | 1 | 6 | 6 | 4s, 3u | 1u | 1s, 2u | 12 | 5 |
| J | E ₁ | m | 1 | 4 | 8 | 4s, 3u | 1z | 1s, 1u, 1z | 12 | 5 |
| K | E ₂ | m | 1 | 5 | 7 | 3s, 4u | 1u | 1s, 2u | 12 | 4 |
| L | E ₃ | m | 0 | 3 | 1 | 2s, 5u | 1z | 1u, 2z | 4 | 2 |
| M | E ₄ | m | 1 | 3 | 8 | 3s, 4u | 1u | 1s, 2u | 11 | 4 |
| N | E ₅ | m | 0 | 3 | 1 | 2s, 5u | 1z | 1u, 2z | 4 | 2 |
| O | E ₆ | m | 0 | 1 | 3 | 2s, 5u | 1z | 1u, 2z | 4 | 2 |
| P | E ₇ | m | 0 | 8 | 1 | 6s, 1u | 1z | 1u, 2z | 9 | 6 |

³For the three levels of difficulties D₁, D₂ and D₃, there are three code labels, *S*, *U* and *Z*. A satisfactory response is marked by *S*. A frequent but unsatisfactory response that is not correct is marked by *U*. While no responses is marked *Z*. **For example, 2u means 2unsatisfactory responses to the question level of difficulty.** The total number of correct responses is *N*.

Table 4.6 Representation of (PSAT) performance for each participant

| Pre-service teacher | Selected topic : Mechanics | Item № | Marks per unit items | Control Group | | Exp-Group | |
|---------------------|--|-------------|----------------------|---------------|-----------|-----------|-----------|
| | | | | Pre-test | Post-test | Pre-test | Post-test |
| 1 | Conception of work done | (1.0 - 2.2) | 10 | 5 | 6 | 4 | 5 |
| | Conception of work-energy theorem | 3.1.1 | 3 | 1 | 1 | 2 | 2 |
| | | 3.2 | 7 | 6 | 6 | 6 | 5 |
| | | 3.3 | 7 | 0 | 6 | 0 | 0 |
| | | 3.4 | 7 | 1 | 5 | 0 | 3 |
| | | 3.5 | 6 | 0 | 4 | 0 | 3 |
| 2 | Conception of work done | (1.0 - 2.2) | 10 | 6 | 6 | 8 | 8 |
| | Conception of work-energy theorem | 3.1.1 | 3 | 1 | 1 | 1 | 3 |
| | | 3.2 | 7 | 4 | 6 | 0 | 5 |
| | | 3.3 | 7 | 1 | 1 | 0 | 5 |
| | | 3.4 | 7 | 1 | 1 | 0 | 1 |
| | | 3.5 | 6 | 0 | 1 | 0 | 3 |
| 3 | Conception of work done | (1.0 - 2.2) | 10 | 5 | 6 | 3 | 5 |
| | Conception of work-energy theorem | 3.1.1 | 3 | 3 | 3 | 0 | 1 |
| | | 3.2 | 7 | 0 | 7 | 1 | 3 |
| | | 3.3 | 7 | 0 | 2 | 0 | 0 |
| | | 3.4 | 7 | 0 | 0 | 0 | 0 |
| | | 3.5 | 6 | 0 | 0 | 0 | 0 |
| 4 | Conception of work done | (1.0 - 2.2) | 10 | 5 | 8 | 1 | 1 |
| | Conception of work-energy theorem | 3.1.1 | 3 | 3 | 3 | 3 | 3 |
| | | 3.2 | 7 | 7 | 6 | 0 | 1 |
| | | 3.3 | 7 | 0 | 1 | 0 | 0 |
| | | 3.4 | 7 | 0 | 4 | 0 | 0 |
| | | 3.5 | 6 | 0 | 0 | 0 | 0 |
| 5 | Conception of work done | (1.0 - 2.2) | 10 | 10 | 10 | 3 | 5 |
| | Conception of work-energy theorem | 3.1.1 | 3 | 3 | 3 | 1 | 3 |
| | | 3.2 | 7 | 7 | 6 | 0 | 1 |
| | | 3.3 | 7 | 1 | 3 | 0 | 0 |
| | | 3.4 | 7 | 1 | 1 | 0 | 0 |
| | | 3.5 | 6 | 0 | 1 | 0 | 0 |

APPENDIX I

| | | | | | | | |
|----------|--|-------------|----|---|----|------------------------|----|
| 6 | Conception of work done | (1.0 - 2.2) | 10 | 7 | 5 | 3 | 6 |
| | Conception of work-energy theorem | 3.1.1 | 3 | 2 | 3 | 1 | 2 |
| | | 3.2 | 7 | 3 | 5 | 6 | 7 |
| | | 3.3 | 7 | 0 | 1 | 0 | 4 |
| | | 3.4 | 7 | 0 | 0 | 1 | 4 |
| | | 3.5 | 6 | 0 | 0 | 0 | 1 |
| 7 | Conception of work done | (1.0 - 2.2) | 10 | 4 | 9 | 5 | 10 |
| | Conception of work-energy theorem | 3.1.1 | 3 | 2 | 3 | 2 | 3 |
| | | 3.2 | 7 | 1 | 5 | 5 | 5 |
| | | 3.3 | 7 | 0 | 4 | 0 | 5 |
| | | 3.4 | 7 | 0 | 3 | 0 | 4 |
| | | 3.5 | 6 | 0 | 3 | 0 | 3 |
| 8 | Conception of work done | (1.0 - 2.2) | 10 | 5 | 8 | No participants | |
| | Conception of work-energy theorem | 3.1.1 | 3 | 2 | 3 | | |
| | | 3.2 | 7 | 2 | 5 | | |
| | | 3.3 | 7 | 0 | 5 | | |
| | | 3.4 | 7 | 1 | 3 | | |
| | | 3.5 | 6 | 1 | 3 | | |
| 9 | Conception of work done | (1.0 - 2.2) | 10 | 6 | 10 | No Participants | |
| | Conception of work-energy theorem | 3.1.1 | 3 | 1 | 2 | | |
| | | 3.2 | 7 | 3 | 2 | | |
| | | 3.3 | 7 | 0 | 2 | | |
| | | 3.4 | 7 | 2 | 1 | | |
| | | 3.5 | 6 | 0 | 1 | | |