

**The role of practical work in the teaching and learning of
Physical Sciences in the context of high-stakes examinations**

by

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ABSTRACT

Practical work implementation continues unchanged despite a lack of empirical evidence on its value. Enduring ideas about the role of practical work are used to justify exorbitant outlays on equipment, despite anecdotal observations to the contrary. To date, studies have mostly focused on resources, objectives achieved and teacher perceptions. Gaps in South African studies include how practical work is conceptualised in the curriculum, perceptions of its purpose, and implementation in the context of high-stakes examinations.

To answer the focus question on the role of practical work, three research questions were used to explore the i) rationale ii) characteristics and iii) why practical work was done in particular ways. Using a qualitative research design, 24 teachers and four subject advisors were interviewed, the Physical Sciences CAPS curriculum document was analysed, and nine practical work lessons were observed. The first finding was that assessment determined practical work implementation. This was achieved by the influence of the role players at different curriculum implementation levels. Secondly, the respondents' claims that doing practical work helps learn content, develop skills, and is an assessment requirement were also reflected in the CAPS document. However, it was found that the learning of content and not skills was prioritised. Thirdly, in the teacher-directed lessons, theory was revised, phenomena illustrated, basic skills practised, and data collected for the report write-up. Fourthly, the respondents held some commonly held misconceptions about practical work. These included doing practical work motivated learners, mirrored how scientists work, and the manipulative skills learnt were essential for learners' success with tertiary studies and science careers. However, the activities appeared to only generate situational interest amongst the learners. Fifthly, not all abstract concepts could be illustrated through the concrete activities, and some

phenomena were difficult to generate. In summary, the role of practical work in the teaching and learning of Physical Sciences in the context of high-stakes examinations was found to support the learning of theory and for assessment. Contributing to the literature, an adapted Lesson Observation Framework to determine the nature and effectiveness of the tasks and a revised classification system appropriate for resource-constrained contexts are proposed.

Keywords

practical work; laboratory; experiments; scientific investigations; Physical Sciences; CAPS; verification; skills; assessment; manipulative skills; process skills; science practices; inquiry

DECLARATION

I, Krishnaveni Naidoo declare that:

- (i) The research reported in this thesis, except where otherwise indicated, is my original work;
- (ii) This thesis has not been submitted for any degree or examination at any other university;
- (iii) This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons;
- (iv) This thesis does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:
 - a) their words have been re-written but the general information attributed to them has been acknowledged; and
 - b) where their exact words have been used, their writing has been placed within quotation marks, and referenced.
- (v) The work described in this thesis was carried out in the School of Education, University of KwaZulu-Natal, from January 2012 to December 2021 under the supervision of Prof. P.A. Hobden (Supervisor); and
- (vi) Ethical clearance No. HSS/0206/012D was granted prior to undertaking the fieldwork.

Signed:



Date: 17/02/2022

As the candidate's supervisor, I, Prof. P.A. Hobden, agree to the submission of this thesis.

Signed:



Date: 18/02/2022

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DEDICATION

This thesis is dedicated to all the teachers who teach practical work with good intentions, passion and dedication, and who continue to inspire our learners despite the challenges they experience. I also dedicate this work to my faithful, loving, and constant companions, Bella and Cody.

GLOSSARY OF ACRONYMS AND ABBREVIATIONS

CAPS	Curriculum and Assessment Policy
CASS	Continuous Assessment
C2005	Curriculum 2005
NatEd	National Education curriculum
NCS	National Curriculum Policy
RNCS	Revised National Curriculum Statement
SBA	School Based Assessment
Umalusi	The Council for Quality Assurance

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CHAPTER 1

INTRODUCTION

Physical Sciences is an elective secondary school subject for Grades 10 to 12 learners as part of the South African Curriculum and Assessment Policy (CAPS). The aim of this study was to determine the role of practical work in the teaching and learning of Physical Sciences in the context of South African high-stakes examinations at the end of Grade 12. To achieve this, the rationale for including practical work in the Physical Sciences CAPS curriculum policy was established. In addition, teachers' and subject advisors' understandings of the role of practical work was explored. This was followed by analyses of the implementation of practical work in selected Physical Sciences classrooms to establish the characteristics of the practical work done. The rationale for having practical work as part of the curriculum, and the characteristics of the practical work done provided insight into why practical work was being done in particular ways. In this chapter, I present an overview of this study, including the rationale for conducting this study and possible implications of this study for science education contexts that are similar to the high-stakes examinations in South Africa. This is followed by a discussion of the aim of this study, which precedes a summary of the research approach used to answer the research questions. I conclude with an outline of the structure of this thesis.

1.1 Background

According to Carrim (2013), effective participation in the dominant “modernist and increasingly post-modernist” world order requires developing countries such as South Africa to possess “cultural capital” (p. 58). This entails acquiring the requisite knowledge and skills to fit into this modernist and post-modernist order. Further, globalisation typified by the growing interdependence of world economies, compel countries to be producers and not mere consumers of knowledge, innovations, and technologies. In South Africa, advances in science, technology, and innovation are considered critical for stimulating a knowledge-based economy (Department of Science and Technology, 2015). A strong economy and a

technologically skilled workforce will equip South Africans for the Fourth Industrial Revolution (Department of Science and Technology, 2019). Equally valued is the idea that through understanding science and innovation, an informed scientifically literate society will be able to participate in local policy-making and contribute to improving the lives of all. South Africa, like many other countries, value and aspire to have a scientifically literate society who possess the knowledge and skills to be able to navigate life in the 21st century (Lelliott, 2014). Referred to as 21st Century skills, these skills include critical thinking, creativity, collaboration, and communication skills. Scientific inquiry is believed to be both a 21st Century skill and a means to develop other 21st Century skills (Tsakeni, Vandeyar, & Potgieter, 2019). In the South African White Paper on Science, Technology and Innovation (Department of Science and Technology, 2019), school science and mathematics are highlighted as being both critical foundations as well as pipelines for a scientifically literate society, and for advanced technology and innovation outputs through nurturing future scientists. Thus, the gravity of producing scientists who will contribute to and be in the forefront of scientific knowledge generation, technology, and innovation, and the need to develop a scientifically literate and skilled society weighs heavily on the foundations provided by the school science and mathematics curricula.(2011; Minner, Levy, & Century, 2010)

One of the stated aims of the South African National Curriculum Statement for Grades R to 12 is to equip learners with knowledge and skills that are meaningful to their own lives while being globally relevant (Department of Basic Education, 2011). Specifically, in the Physical Sciences Curriculum Assessment Policy (CAPS) document, it is stated that the purpose of the Physical Sciences school subject is to equip learners with skills such as investigating, problem solving, scientific, and technological skills for economic growth and preparing learners for careers in science (Department of Basic Education, 2011). eIn this document, practical work is defined as “practical demonstrations, experiments or projects used to strengthen the concepts being taught” (p. 9). Additionally, it is stipulated that “practical investigations and experiments should focus on the practical aspects and the process skills required for scientific inquiry and problem solving” (p. 144). Skills, such as scientific inquiry and problem solving skills that are stated as outcomes of practical work in the Physical Sciences CAPS document, have also been identified as important for developing a scientifically literate society, a robust economy, and producing innovations that will enable South Africa to be globally competitive (Department of Science and Technology, 2019). The

importance associated with acquiring these skills necessitates a closer examination of practical work in the Physical Sciences CAPS curriculum. Specifically, there is a need to determine the role of practical work in the teaching and learning of Physical Sciences in the context of South African high-stakes examinations.

1.2 Rationale for this Study

South African studies thus far have mainly focused on specific aspects of practical work such as the implementation of inquiry-based practical work (Akuma & Callaghan, 2018; Gudyanga & Jita, 2019; Ramnarain & Hobden, 2015; Ramnarain & Schuster, 2014; Sitole, 2016; Tsakeni, 2016; Tsakeni, et al., 2019). This study can provide insight into how practical work is being conducted and whether the intended curriculum objectives are achieved, contributing to understandings of why teachers do practical work in particular ways. At a curriculum policy level, there is a need to establish whether the practical work aligns with our definitions of science education and whether its implementation captures the essence of science as a discipline.

The problem is that despite several studies on practical work over the years, the role of practical work in the teaching and learning of the sciences remains unclear (Babalola, Lambourne, & Swithenby, 2019; Dillon, 2008). Lazarowitz and Tamir (1994) concluded that no other area in science education has attracted as much attention as practical work and proposed that the reasons are that while practical work is distinctive and unique, there are insufficient convincing data on its effectiveness. They explained that this is due to the complexity of factors affecting practical work implementation. One of these factors is the issue of contexts because practical work is implemented unchanged across different school and classroom contexts. It was found that several research findings on the role of practical work have been confusing and mostly inconclusive (Hodson, 1990, 1993; Jenkins, 1999; Lazarowitz & Tamir, 1994). Lunetta (1998) described how the laboratory has become a space for manipulating equipment but not ideas where learners follow recipes. Practical work was described as being ineffective in getting learners to understand concepts and theories of science (Woolnough, 1998). Hodson (1992) described practical work implementation as being “ill-conceived, muddled and lacking in educational value” (p. 65). Abrahams and Millar

(2008) commented on the unconfirmed prevalent view that increasing the amount of practical work would improve science education. Hodson (1998a, 1998b), Osborne (2015), and Wellington (1998), were amongst those who called for a reappraisal of the role of practical work in science education, yet practical work implementation has persisted with little changes (Gudyanga & Jita, 2019; Tobin, Tippins, & Gallard, 1994).

Despite the lack of clarity on the role of practical work in teaching and learning, in South Africa, practical work features prominently in curriculum policies. There have been three successive curriculum changes (the outcomes-based National Curriculum Statement, the revised National Curriculum Statement, and the current Curriculum and Assessment Policy Statement) within a relatively short period of about 20 years, from around 1992 to 2012. Each of these curriculum reforms although underpinned by different ideologies, introduced science curricula that specified practical work. The previous National Curriculum Statement Grades 10 - 12 (Department of Education, 2004) encouraged practical work but did not list it as compulsory but it is compulsory in the amended replacement Curriculum and Assessment Policy Statement (CAPS) for Physical Sciences Grades 10 - 12 (Department of Basic Education, 2011). Practical work in the Physical Sciences subject had to be included in formal assessment from 2012, as the first year of implementation. In my experiences of practical work implementation in the South African context, I have found that teachers often cite the lack of resources to do practical work as the main reason for poor learner achievement in Physical Sciences. However, in schools where practical work is being done, anecdotal reports indicate that there seems to be little difference in learner achievement in schools not doing practical work and schools where practical work is routinely being done.

Most South African research studies on school science practical work during each of the three curriculum reform periods focused on the context of practical work implementation, the teachers, and the type of practical work conducted. Meiring (1995) established whether teachers have inductivist or constructivist views of science practical work. Mudau (2007) investigated how a Grade 10 teacher conducted practical work as part of the National Curriculum Statement Grades 10 - 12, while Ngema (2011) explored teacher's conceptions of practical work. Teacher perspectives and practices have been the focus of some studies (Gudyanga & Jita, 2019) including a study that was specific to the Limpopo province (Kibirige, Osodo, & Mgiba, 2014). Other studies focused on the challenges of inquiry-based

practical work (Mokiwa, 2014), pedagogical orientations of teachers towards inquiry (Akuma & Callaghan, 2018; Ramnarain, Nampota, & Schuster, 2016; Ramnarain & Schuster, 2014); teachers' decisions on the practice of inquiry (Tsakeni, 2016, 2017); inquiry opportunities in practical work (Tsakeni, et al., 2019) as well as the implementation of scientific investigations (Ramnarain, 2007). There were studies that focused on the factors influencing practical work implementation (Hattingh, Aldous, & Rogan, 2007) and in specific contexts such as rural schools (Motlhabane, 2013); time allocation for practical work (Sibam, 2018); and practical work implementation in Grade 10 classrooms (Singh, 2014). Although the range of studies on practical work in South Africa is diverse and comprehensive, there are still gaps in our broad understanding of the role of practical work in teaching and learning. One of these gaps is the insufficient empirical evidence on the role of practical work in an examination-driven system, specifically how practical work is conceptualised in the Physical Sciences CAPS curriculum, the rationale for doing practical work, and the characteristics of the practical work implemented in the context of high-stakes examinations.

1.3 Aim of this Research Study

A content-focused academic curriculum typically promotes abstract and theoretical knowledge for the purposes of examinations (Green & Naidoo, 2006). In the Physical Sciences CAPS curriculum the content to be studied is closely coupled with assessment requirements (Grussendorff, Booyse, & Burroughs, 2014). In addition, the learning of skills, mostly associated with practical work, is listed but without explicit guidance on how to assess these skills. The problem is that in an examination-driven system that is distinctly paper and pencil-based, Physical Sciences practical work although made compulsory, may not be a priority.

Practical work is listed in the Physical Sciences CAPS curriculum as part of the assessment requirements. Making practical work compulsory for assessment has led to a renewed impetus to provide science equipment and professional development in KwaZulu-Natal (KwaZulu-Natal Department of Education, 2010). The KwaZulu-Natal Department of Education has prioritised the provision of laboratories and science equipment to schools where large amounts of funding have been allocated to resourcing (KwaZulu-Natal

Department of Education, 2010). One of the pillars of the National Strategy for Mathematics, Science and Technology (2019-2030) being finalised by the Department of Basic Education is the provision of resources for improving the teaching and learning of science. If the value of science practical work is not clear, huge investments in science equipment may result in a waste of valuable teaching time if it is not contributing to the teaching and learning of science. A study of the role of practical work in the Physical Sciences curriculum and the implementation thereof could also inform the nature of resourcing.

In my work with schools in KwaZulu-Natal, as a Department of Education official, my observation was that practical work in most schools was not a regular feature of many science lessons. Teachers have cited the lack of resources as a reason for not doing science practical work. However, anecdotal reports from science subject advisors and my own observations indicated that very little practical work was done even after making huge investments in science equipment. This was also a finding in the study by Hattingh, Aldous and Rogan (2007) in schools in the Mpumalanga province where it was shown that there was no correlation between the availability of resources and the amount of practical work done. Here, schools that were fully equipped still did little or no practical work. From my experience, in schools where practical work is regularly done, practical work activities are mostly prescriptive recipe following exercises. I have observed that often, the formulation of “correct conclusions” and “correct report writing” appeared to dominate the practical activities.

The overall aim of this study is to determine the role of practical work in the teaching and learning of Physical Sciences. Specifically, this study looks at the “why, when, what and how” of the practical work being done. The first aim of this study is to examine practical work as part of the Physical Sciences CAPS curriculum policy to establish the intended objectives for practical work. The second aim of this study is to understand teachers’ and subject advisors’ understandings of the role of practical work and their rationale for doing practical work. The third aim of this study is the focus on practical work implementation by examining the characteristics of the practical work done. Finally, having considered the evidence gathered, I have provided a number of reasons why teachers do practical work in particular ways and conclude on the role of practical work as a teaching and learning strategy in the study of Physical Sciences.

The significance of this study is that it will contribute to the debate on the role of practical work in the teaching and learning of Physical Sciences in South Africa as a developing country. This study could yield insights into whether international trends, such as those from industrialised countries apply to the South African context (Dempster, Mchunu, & Ramnarain, 2015; Kahn, 1990) and the African context (Babalola, et al., 2019). Further, a study on the role of practical work that highlights possibilities and limitations in the context of high-stakes examinations could be useful for decision-makers in four ways. Firstly, curriculum policymakers could make informed decisions about the inclusion of, the amount of, and the type of practical work to be included in the curriculum. This study could also point to statements of clearer learning objectives for practical work. Secondly, this study could inform the provision of costly laboratories and science equipment in a reality of competing priorities such as the premium placed on exit examinations. Thirdly, this study could clarify the objectives and content of teacher training on practical work. Fourthly, in light of practical work being typically time-consuming, the findings of this study could be important for school managers who may need to make decisions about staff allocations and timetabling.

In this thesis, it is argued that the primary role of practical work as implemented in the Physical Sciences CAPS curriculum is to support the learning of theoretical knowledge for the purpose of passing examinations. The main focus question is, “What role does practical work play in the teaching and learning of Physical Sciences in the context of high-stakes examinations?” The following research questions guided the study and provided evidence to answer this focus question:

- (1) Why is practical work part of the Physical Sciences CAPS curriculum?
- (2) What are the characteristics of the practical work done?
- (3) Why is practical work being done in particular ways?

Answers to these research questions provided evidence on the reasons for doing practical work and the nature of practical work done, which helped understand why practical work was done in particular ways.

1.4 The Research Approach

In this study, I used a qualitative research design within an interpretivist paradigm, to answer the research questions. A qualitative research design allows for open-ended research questions that allow multiple findings to emerge; field observations for first hand experiences of the phenomena; and interviews that permit in-depth probing of answers. An interpretivist paradigm allows for interpreting the findings to make inferences on the role of practical work in the teaching and learning of Physical Sciences. A qualitative research design and an interpretivist paradigm enable the study and interpretation of participants' unique contexts, their experiences, meaning-making and the multiple realities that exist (Hesse-Biber & Leavy, 2011). Hence, measures need to be taken to ensure validity and reliability of the findings because these could become potential weaknesses of this research design.

Practical work features as part of South African school science from Grade 4 to Grade 12. However, practical work is formalised as part of the assessment in the later years of schooling, such as in the Physical Sciences Grades 10 to 12, which made up the population of this study. There was no value in investigating classrooms where no practical was being done since the study focused on the role of practical work in the teaching and learning of Physical Sciences. In the Physical Sciences CAPS curriculum document, some practical work activities are listed as prescribed and compulsory for assessment, while recommended practical work activities are not required for assessment purposes. There are two prescribed practical work activities listed for Grades 10 and 11, to be completed in the first and second terms, and six activities are listed as recommended practical work. Three practical work activities are prescribed for Grade 12 to be completed in the first, second, and third terms of the year. In addition, three practical work activities are recommended for grade 12. The sample in this study was drawn from schools where the teachers indicated that Physical Sciences practical work was being done a minimum of two times a year for Grades 10 and 11, and a minimum of three times a year for Grade 12. The practical work activities in the Physical Sciences CAPS curriculum document are listed as experiments or investigations, except for two recommended practical work activities that are listed as practical demonstrations. Additionally, the sample was limited to laboratories and classrooms that had equipment and materials to do practical work. Permission was sought from the teachers, subject advisors, and learners to participate in the study. They were also informed of the steps to be taken to ensure

confidentiality of their participation. I was aware of the potential unequal power relations that may arise from me, the researcher, being an official in the Department of Education. This potential issue is discussed in more detail under the section on data collection (Chapter 3) and the section on the limitations of the study (Chapter 7). This study did not seek generalisations to other contexts but focused on the in-depth study of particular contexts. In South Africa, the different types of schools can be categorised according to the socio-economic status, historical groupings in terms of race and geographical location or as independent (private) or public (government controlled) schools. In this study, the schools were purposively selected to be representative of the range of schools in the afore-mentioned broad categories, while acknowledging that other combinations of school categories may exist. Data were collected from the sampled schools until data saturation occurred which is when no new data emerged.

To answer the first study question on the aims of practical work done, teachers and subject advisors were interviewed using semi-structured interview schedules. Semi-structured interview schedules are flexible, allowing for any adding or editing of questions if required. Recording of the interviews for revisiting later enabled the interviews to progress naturally. The interviews were then transcribed from the recordings and the transcripts were analysed using *NVivo* software. The transcripts were coded under pre-determined nodes found in the literature and the themes that emerged from the data were analysed. The Physical Sciences CAPS curriculum was also analysed to establish the rationale for including practical work as part of the curriculum. The second study question was concerned with the types of the practical work done and this required observing the lessons. In pre-practical telephonic interviews, the teachers indicated their intended objectives for their practical work lessons. A Lesson Observation Framework instrument was adapted and used to guide and record the observations made. The lessons were videotaped and the individual frames were later analysed. There was also a particular focus on the effectiveness of the lessons in terms of whether the teacher objectives were achieved. A sample of learners were interviewed after their practical work lessons to understand their experiences of the practical work. From the emerging themes and assertions, inferences were then made on why practical were being done in particular ways to answer the third study question on the reasons for doing practical work in particular ways.

1.5 Concepts used in this Thesis

The use of terminology and concepts is context-dependent that is depending on the context, these may take on different meanings. Leedy and Ormrod (1993) emphasised the importance of not only defining terms but doing so in the context it is used in the research study. In this section, I clarify some of the concepts that may be ambiguous, to avoid possible misinterpretations.

Practical work

Practical work is defined in terms of the type of activity as well as the role of the teacher and learners involved in the activity. In this study, science practical work is defined as one of the pedagogic strategies to achieve the goals of school science. Practical work involves learners observing or physically manipulating real objects and materials and engaging in related conceptual activities individually or in groups (Hofstein & Giddings, 1995) or learners engaging in hands-on and minds-on activities (Abrahams, 2011; Millar, 2004; Millar, Tiberghien, & Marechal, 2003). Teacher conducted practical work involves the teacher manipulating real objects and materials with learners observing and engaging in related minds-on activities, for example a teacher conducting an investigation. Such teacher-conducted practical work where the teacher is manipulating real objects and materials, is often referred to as a teacher demonstration, and is classified as practical work. However, a teacher demonstrating or illustrating a phenomenon, for example burning a strip of magnesium is not doing practical work. Further, science-related visits, surveys, presentations and role-plays, simulations and other virtual activities, modelling, and group discussions are not classified as practical work but as activities that may complement practical work. Hence, virtual activities such as computer simulations involving learners manipulating virtual objects, for example, moving electrons in a virtual model of an atom, or simulating an acid-base reaction are not classified as practical work but as complementary to practical work. SCORE (Science Community Representing Education) (2008) classified investigations, experiments, laboratory procedures and techniques, and fieldwork as core practical work activities. Practical work may be conducted in, but is not confined to laboratories.

Scientific inquiry

Minner, Levy, and Century (2010) described three distinct categories of scientific inquiry activities, “What scientists do (e.g. conducting investigations using scientific methods), how learners learn (e.g. actively inquiring through thinking and doing), and as a pedagogical approach (e.g. designing or using curricula for investigations)” (p. 476). In school science, inquiry refers to teacher and learner activities to develop knowledge, skills, and understandings of scientific ideas (Anderson, 2002). Inquiry is both an instructional approach (means) and a learning outcome (ends) (Abd-El-Khalick, et al., 2004) where the activities are guided by a research or inquiry question, may involve varying degrees of teacher guidance, and maybe open- or close-ended (Bell, Smetana, & Binns, 2005). In open-ended inquiry activities, the learners are given opportunities to identify the topic, inquiry question, and procedure, where the learner does not know the solution. In contrast, at the other end of the continuum, the teacher has more control over close-ended inquiry activities where the teacher provides the topic, inquiry question, and method, and the learners know the solution. There is a range of school science inquiry activities, including learners critically analysing secondary sources such as books and journals (National Research Council, 1996). Inquiry activities include scientific investigations, which are also a type of science practical work (Hume & Coll, 2008).

Investigations

An investigation is a type of practical work that is guided by an inquiry question where the steps of a scientific method are followed (Gott & Duggan, 1995). Here, learners may formulate questions; state hypotheses; make predictions; design methods; collect and interpret data; make conclusions; and communicate the results (National Research Council, 2012). Investigations involve varying degrees of teacher guidance and learner autonomy (Ramnarain & Hobden, 2015). Learners may practice manipulative and process skills as well as gain procedural understandings (Pekmez, Johnson, & Gott, 2005), and be given opportunities to do authentic inquiry, for example working with open-ended problems in real life contexts (Hume & Coll, 2010) and develop higher-order thinking skills (Dillon, 2008; Millar, Le Marechal, & Tiberghien, 1999; Minner, et al., 2010). Investigations centre around an inquiry question and may include experiments that are guided by an aim where standard methods are usually followed to test hypotheses and determine causal relationships between variables (Hume & Coll, 2008). Hence, in investigations the method to follow may be given to the learner.

Teachers may also conduct investigations while they engage with the learners. The term “science practices” is preferred to the terms practical work, experiments, and investigations. Science practices is an encompassing term that is used to refer to investigations, skills, science processes, and inquiry-type activities to highlight that both skills and knowledge are required when investigating the natural world (National Research Council, 2013).

1.6 Structure of the Thesis

This research study is presented in seven chapters. In this chapter, I provided the context, discussed the rationale, outlined the aims of this study, and provided an overview of the research approach used. In Chapter Two, I review literature related to practical work both internationally and in South Africa. Here, recent understandings of the domain of science and science education; common definitions of practical work; current research on the role of practical work in the teaching and learning of science; and a conceptual framework for understanding the implementation of practical work are discussed. A detailed explanation and justification for the research design, the sampling, the methods of data collection, and the techniques used for analyses are captured in Chapter Three. In Chapter Four, I attempt to answer the first research question, “Why is practical work part of the Physical Sciences curriculum?” by establishing the reasons for including practical work in the CAPS document. The rationale for doing practical work from the perspectives of the sampled teachers and subject advisors are also presented. In Chapter Five, the focus is on the characteristics of the implemented practical work and is guided by the second research question, “What are the characteristics of the practical work done?” I focus on the third research question in Chapter Six, “Why are practical work being done in particular ways?” This chapter is a synthesis of the findings of this study, which are the reasons for doing practical work and the characteristics of practical work done, to establish why practical work is being done in particular ways. In the final chapter, I summarise the role of practical work in the teaching and learning of Physical Sciences, present the conclusions of this study, and make recommendations for the implementation of practical work in the context of high-stakes examinations.

CHAPTER 2

LITERATURE REVIEW

In Chapter One, I gave an overview of this study and outlined the structure of the thesis. In this chapter, I locate this study within the relevant literature and introduce the frameworks that guided this study. I begin with differentiating between science and school science education, which is followed by definitions and common purposes for doing practical work, as well as teachers' views on the aims of practical work. Thereafter, I summarise how practical work has evolved over the years, with a particular focus on South Africa. The conceptual frameworks described in this chapter will provide the context and justification for selecting the research design outlined in Chapter 3 and the analyses done in subsequent chapters.

To locate this study on the role of practical work within existing research and to identify gaps in the literature, a wide range of literature had to be reviewed. This included exploring the different conceptions of science and goals of school science relevant to practical work. Reviewing trends in past and current studies, both internationally and in South Africa, enabled evaluations of the different types, purposes, aims, and definitions of practical work. Regarding the literature reviewed in this chapter, two issues require mention at the outset i) the nature of existing literature on practical work and ii) the reason for using dated references in this study. Firstly, in the literature reviewed there were instances where several definitions of the same term were found and often terms were used interchangeably and inconsistently. Furthermore, the authors did not always state their ideological positions, indicate the definitions adopted, or adequately describe the contexts of the study. Jenkins (1999) described the “voluminous literature on practical work” as a “multiplicity of sometimes conflicting claims and occasionally irreconcilable, even unattainable goals” (p. 21). Dillon (2008) added that confusions about the definition of practical work, especially when used without clarification make “discussions about the value of practical work difficult” (p. 5). Secondly, the bulk of the literature reviewed in this study originated internationally and several dated references were used. Rollnick's (2021) review of the book “School Science Practical work in Africa” included statements about the frequent referencing of international

authorities, particularly Millar; the lack of references to African studies; and the dated references on practical work. When reviewing the literature on practical work, I found several international studies relevant to this study, while the limited African studies focused mostly on resource constraints and curriculum changes. Rollnick (2021) described this as the “paucity” of available research in Africa on practical work (p. 1). Further, innovative, and influential research that changed the landscape of practical work is quoted in this study. Leach and Paulsen (1999) argued that innovative research that theorises and provides new insights on the aims and purposes for doing practical work, studies that question widely accepted ideas on the value of practical work, and studies offering new frameworks and analytical tools, have been critical in reshaping our ideas. Some of the seminal studies on practical work referenced in this study include those by Abrahams; Bybee; Hegarty-Hazel; Hodson; Hofstein; Jenkins; Kerr; Leach; Lunetta; Millar; Tamir; Wellington; and Woolnough. It was found that most of the pioneering work undertaken by these researchers was done in the years up to 2000. In light of the above, in this study, the literature referenced mostly originated internationally, several references appear frequently, and some are dated but are considered seminal and appropriate for the current study.

2.1 Science and the Goals of School Science

An overview of the concepts of science and science education will provide a context to understand the role of practical work in the teaching and learning of Physical Sciences. According to Hodson (1990), empirical studies on practical work framed by inaccurate and outmoded ideas about science and school science, contributed to myths about the role of practical work. The term “science” typically refers to a body of knowledge, a way of conducting inquiry and the pursuit of new knowledge (Millar, 2004). This body of knowledge is made up of ideas we have about the natural world (Osborne, 2015). Over the years, the dominant views on science included empiricism, positivism, logical positivism, falsification, and post-modernism. In the seventeenth and eighteenth centuries, the empiricists believed that knowledge is derived from experimentation. According to Chalmers (1999), from the 1920s positivism dominated and science was regarded as an accumulation of facts from infallible objective empirical testing. Logical positivism followed and saw a shift from verification to confirmation of facts through experiments (Losee, 2001). In the 1970s, Karl Popper

introduced falsification, where solving a problem required deducing a hypothesis from theory and testing it empirically (Schwartz, Lederman, & Crawford, 2004). Known as the deductive method, when the hypothesis was not supported by observations, the hypothesis was falsified and the theory rejected (Losee, 2001). Later, the postmodern view of science acknowledged science as a human endeavour, influenced by culture, and subject to change (Schwartz, et al., 2004). In contrast to empiricism, positivism, logical positivism, and falsification, in postmodernism there is no single scientific inquiry method and science is not value-free but a reflection of social and cultural traditions (McComas, Clough, & Almazroa, 2002). Our concept of science as a discipline influences our notions of school science (Hodson, 2014).

Hodson (2014) identified four goals of school science that are learning science, learning about science, doing science, and developing critical skills to address socio-scientific issues such as the “personal, social, economic, environmental and moral-ethical aspects” (p. 2537). While Hodson (2014) believed that in school science learners get to do science, Kirschner (1992) had earlier stated that school science is not about doing science but is about learning how to do science. Kirschner stated that scientists are concerned with doing science and cautioned against using the epistemology of the natural sciences as the pedagogical basis for teaching and learning school science. According to Kirschner, it is incorrect to assume that “the pedagogical content of the school learning experience is identical with the syntactical structure of the science” (p. 273). This includes, for example, the flawed notion that like the work of scientists, knowledge is discovered in school science. Unlike the four goals identified by Hodson, Bradley (2005) had earlier subscribed to one overarching goal of science education that is scientific literacy, which incorporated socio-scientific issues. Scientific literacy has been defined as the capacity to use knowledge and skills to understand and make responsible decisions about the natural world (DeBoer, 2000). According to DeBoer, scientific literacy is incorporated in the three goals of school science, which are learning science; practicing how to do science; and learning about science. Practical work has been identified as one of the pedagogic strategies to achieve the goals of school science (Abrahams, 2011; Hodson, 2014; Millar, 2004).

2.2 Definitions of Practical Work

To begin to understand the role of practical work in the teaching and learning of Physical Sciences, it is necessary to clarify what constitutes practical work. To date, there is less agreement about what practical work is despite claims on what can be achieved by doing practical work. In this section, I capture common definitions of practical work and provide the definition adopted in this study. Definitions of practical work can be grouped into those that specify where the activities are held, the type of activities, and the role of teacher and learners.

In the literature, there are contrasting views on which activities can be classified as science practical work. In the years preceding the 1900s, the term practical work referred to experiments conducted in laboratories (Bates, 1978). Hodson (1988, 1993, 1996) made the distinction between practical work, laboratory work and experiments. He explained that not all practical work is carried out in a laboratory and not all laboratory work is about experiments. There is agreement with Hodson's (1996) definition of practical work about where the activities are held but there is less agreement on whether learners observing practical work activities or participating in virtual activities are doing practical work (Abrahams, 2017). Hodson included laboratory work, computer assisted learning, teacher demonstrations, videos supported by worksheet activities, case studies, role playing, writing tasks, and making posters, as practical work. Bradley (2005) later adopted Hodson's definition but specified that the aim of the activities are to develop scientific literacy. Laboratory activities have been defined as "contrived learning experiences, in which students interact with materials to observe phenomena" (Hofstein, 1988, p. 190). These planned experiences are specified by the teacher and may have the phases of planning, design, analysis, interpretation, and application. Hofstein's definition excluded large group teacher demonstrations and field trips. Donnelly (1998) adopted this definition where laboratory work is performed by learners individually or in groups and do not include teacher demonstrations. Hodson's inclusion of computer simulations and videos in the definition of practical work was adopted by Millar, Le Marechal and Tiberghien (1999) where practical work was any teaching or learning activity where learners observe or manipulate real objects and materials as well as "direct representations of these, in a simulation or video-recording" (p. 36). In this definition, both learner observations and virtual activities are included in the definition of practical work. Earlier, Lunetta and Hofstein (1991) explained that computer simulations can

supplement practical work but is not practical work. Abrahams (2011) and Abrahams, Reiss and Sharpe (2013) excluded virtual objects in their definition. In contrast, Akuma and Callaghan (2018) recently claimed that inquiry-based practical work “is a relatively new strategy” where “learners collaboratively manipulate a combination of hands-on and/or computer-based science education equipment and materials or existing data sets ... as they engage in scientific practices through structured, directed or open inquiry” (p. 65). In addition to the nature of the activity, definitions of practical work have been confounded by different views on the roles of the teachers and learners when doing practical work. Analyses of the aforementioned definitions over the years have led to two conclusions. Firstly, to date, there are disagreements on what constitutes practical work and when an activity can be classified as practical work. Secondly, this calls for a definition of practical work that is relevant to developing countries such as South Africa where there are diverse and disparate schooling contexts.

Practical work has been defined as a pedagogic strategy and as one of the ways to teach and learn science through hands-on and minds-on activities (Abrahams, 2011, 2017; Abrahams, Millar, Whitehouse, Reiss, & Amos, 2011; Babalola, et al., 2019; Capps, Shemwell, & Young, 2016; Millar, 2009). Here, practical work includes fieldwork, role-playing, making models, practicing skills, and laboratory work that are not confined to laboratories. Laboratory work includes, and is not limited to experiments and investigations. In a report on practical work in science, SCORE (Science Community Representing Education) (2008) in the United Kingdom identified two categories of practical work based on whether they are core or directly related activities. Practical work refers to those core activities such as investigations, experiments, laboratory procedures and techniques, and fieldwork. Also referred to as practical work but as directly related practical work activities are designing and planning investigations, data analyses, teacher demonstrations, and learners experiencing phenomena. Science-related visits, surveys, presentations and role-play, simulations, modelling, and group discussions are not classified as practical work but as activities that complement practical work. Following the categories presented in the SCORE report, practical work can be defined as those activities involving learners manipulating objects and materials, and observing teacher demonstrations but exclude complementary virtual activities.

Bradley (2005) defined teacher demonstrations as a type of practical activity where the teacher presents science phenomena, directs the learner's active learning, and discusses the results. According to Bradley, for meaningful learning from demonstrations, the learner has to assimilate and accommodate the material presented. The role of the teacher is to engage the learners through questioning and discussions. Babalola (2017) adopted a definition of practical work that includes learner activities and teacher demonstrations. Related to teacher demonstration of practical work, is learner observation. Learner observations are not just the physical act of seeing but involve cognitive processes that are framed by a theoretical perspective and are influenced by the learner's experiences (Johnstone & Al-Shuaili, 2001). The learner's prior knowledge and experiences determine what is observed and this may result in learners making observations that are inaccurate or incomplete (Hodson & Bencze, 1998). Hodson and Bencze have suggested that whether the learners make observations from their own activities or from teacher demonstrations, they require direction and guidance from the teacher.

Hodson (1990) pointed out that the indiscriminate use of terminology have contributed to much confusion about what practical work is and can achieve. Over thirty years later, Rollnick (2021) maintains that incorrect use of the terms practical work and inquiry have contributed to poorly defined practical work. This necessitates clarifying the difference between inquiry and school science inquiry in the context of practical work. Scientific inquiry refers to the diverse ways scientists study the natural world and based on the evidence they gather, they are able to propose explanations (Anderson, 2002). In school science, inquiry is defined as both an instructional approach (means) and a learning outcome (ends) (Abd-El-Khalick, et al., 2004). The teaching and learning outcomes include learners developing their knowledge and understanding of science concepts, and developing skills by themselves or with the guidance of a teacher (Bybee, 2006). Inquiry learning is an active process that distinctly involves learners answering research questions through data analysis (Abd-El-Khalick, et al., 2004; Anderson, 2002; Stender, Schwichow, Zimmerman, & Hartig, 2018). The teacher could supply the data, provided the learner answers the research question through analysing that data (Stender, et al., 2018). Inquiry activities involve testing explanations against current knowledge, and communicating solutions (National Research Council, 1996), as well as using evidence to evaluate given and alternative explanations (National Research Council, 2000).

School science inquiry is often incorrectly conflated with hands-on activities, implying that inquiry only refers to physical activities (Ramnarain & Schuster, 2014). Inquiry activities that are hands-on and/or minds-on, and are guided by a research question can be classified as practical work. Not all inquiry activities are practical work. Learners theoretically analysing information to answer a research question can be classified as inquiry but is not practical work (Bell, et al., 2005). On the other hand, practical work may include practising a skill such as using an instrument, usually in the context of science content but this does not count as inquiry. A scientific investigation is a type of inquiry activity (Gott & Duggan, 1995) that is also classified as practical work (Hume & Coll, 2008). A scientific investigation is described as a process, which takes place in stages and includes planning and conducting investigations, collecting and evaluating data, and communicating findings (Abd-El-Khalick, et al., 2004; Hodson, 1992). Gott and Duggan defined a scientific investigation as “a specific type of problem-solving defined as a task for which a pupil cannot immediately see an answer or recall a routine method for finding it” (p. 15). Scientific investigations have been found to involve varying degrees of learner autonomy where learners generating their own questions for an investigation are regarded as most autonomous, resulting in meaningful learning (Ramnarain & Hobden, 2015). In the *Next Generation Science Standards: For States, By States* (National Research Council, 2013), a shift from the use of terms such as investigations, inquiry, skills, and science processes to science practices was proposed. This shift was necessary to emphasise that investigating the natural world requires not only skills but also the knowledge that is specific to each practice. Eight science practices were identified by the National Research Council (2013), “Asking questions; developing and using models; planning and carrying out investigations; analysing and interpreting data; using mathematical and computational thinking; constructing explanations and designing solutions; arguments from evidence; and obtaining evaluating and communicating information” (p. 382). It appears that the concept of science practices leans more towards minds-on than hands-on activities.

The definition of practical work adopted in this study was the result of a review and synthesis of various definitions proposed in the literature over the years. The type of activity and the role of the teacher and learners in the activity were considered when defining practical work. In this study, science practical work is a pedagogic strategy and includes those teaching and learning activities where learners physically manipulate real objects and materials and engage in related conceptual activities individually or in groups (Hofstein & Giddings, 1995)

or learners engage in hands-on and/or minds-on activities (Abrahams, 2011; Millar, 2004; Millar, et al., 2003). Practical work includes learners observing and engaging with teachers who manipulate objects and materials, for example teachers conducting investigations are doing practical work. A teacher who is just demonstrating or illustrating a phenomenon and those science-related visits, surveys, presentations and role-plays, simulations and other virtual activities, modelling, and group discussions are not classified as practical work. Practical work includes experiments; investigations; cookbook exercises; fieldwork; and practicing of skills (SCORE, 2008). Practical work may be conducted in, but is not confined to laboratories.

2.3 The Rationale for doing Practical Work

To establish why we have practical work in the teaching and learning of Physical Sciences, the purposes for doing practical work require clarification. Johnstone and Al-Shuaili (2001) make the distinction between the purposes, aims and objectives of practical work. The purposes refer to the reasons for doing practical work, while the aims of practical work are statements about what, for example teachers intend to achieve, and the objectives are specific statements about what learners and teachers accomplish during a practical work activity (Johnstone & Al-Shuaili, 2001).

2.3.1 The purposes for doing practical work

In this section, common claims about the purposes for doing practical work are discussed. Discussions on the objectives of practical work are excluded due to being numerous and related to specific practical work activities. The four commonly stated reasons for doing practical work in the literature are to understand scientific knowledge, learn skills, learn about the nature of science, and to motivate learners (Hodson, 2014).

Practical work helps to learn theory

One of the most commonly stated goals of school science is acquiring the existing body of scientific knowledge (Beatty & Woolnough, 1982; Hofstein & Lunetta, 1982). Mundangepfupfu (1986) stated that we need to be realistic about what can be achieved through school science because school science is not taught to add to the body of scientific

knowledge, verify, prove or produce theories. Kirschner (1992) stressed that school science is not synonymous with science and cautioned against the common belief that scientific knowledge is best learnt through experiences that are based on the procedures of science. While there is some agreement that through school science learners could acquire the body of scientific knowledge, there is less agreement about acquiring this knowledge through practical work (Bennett, 2003a).

Over the years, contrasting findings have been reported on whether practical work helps learners understand the established body of scientific knowledge (Babalola, et al., 2019; Jenkins, 1999). Hewson and Hewson (1983) reported significant enhancement of learners' conceptual understanding in a group of South African learners who received primarily practical-based instruction. Lazarowitz and Tamir (1994) claimed that school science involves the learning of complex and abstract concepts and practical work can provide concrete opportunities to enhance the learning of these concepts and correct misconceptions, depending on how and when the practical work is done. This claim was later supported by Gopal, Kleinsmidt and Case's (2004) study where South African tertiary learners' misconceptions of evaporation, condensation and vapour pressure were identified and corrected using practical work activities. However, earlier studies reported contrasting findings on the learning of scientific knowledge through practical work. In a study of grade 11 chemistry learners in Zambia, Mulopo and Fowler (1987) reported no significant difference in the level of conceptual understanding between learners taught using practical and non-practical methods. They found that it was not the method of instruction but the level of intellectual development that influenced conceptual understanding. Jackman, Moellenberg and Brabson (1990) and later, Chang and Lederman (1994) also reported no improvement in conceptual understandings in their studies on the effectiveness of laboratory work. Watson, Prieto and Dillon (1995) found that the practical work had a marginal effect on English and Spanish learners' understanding of combustion, despite the large amount of practical work done by the English learners. In a subsequent study by Westbrook and Rogers (1996), learners experienced conceptual change when studying the effects of weight on flotation but no conceptual change was noted when learners studied shape and flotation. This was attributed to the incorrect interpretations learners made from inadequate experimentation on shape and flotation. In a study by Abrahams and Millar (2008) practical work was found to be effective

in getting learners to do what was intended with physical objects but less effective in being a cognitive challenge for learners.

Woolnough and Allsop (1985) cautioned that the close coupling of practical work and theory can have a detrimental effect on both the quality of practical work and the understanding of theory. Models have been used to explain how the demands of practical work may limit learning. Learners may experience a state of unstable overload when doing practical work when the working memory with a finite capacity becomes overloaded with incoming information, such as recalling theory, listening and reading instructions, identifying equipment, and learning new skills (Johnstone & Wham, 1982). As a result, learners resort to more comfortable or stable states such as following recipe-style instructions and using the practical work time as free time. Building on these findings, Tamir (1991) found that the simultaneous demands of applying intellectual and practical skills, and prior knowledge resulted in cognitive overload. To reduce the demands of practical work, an Information Processing Model was developed to successfully redesign an undergraduate chemistry programme that included improvements to written instructions, pre-laboratory work, and practising skills (Johnstone, Sleet, & Vianna, 1994). Building on previous work on cognition, Kirschner, Sweller, and Clark (2006) elaborated on how constructivist approaches including minimally guided inquiry practical work have failed because of the increased cognitive load on the working memory. Other models used to explain similar learning difficulties included that of Le Marechal (1999) where experimental observations belonging to the real world has to be translated into chemical equations and symbols in the reconstructed world. Modelling was also used by Schoster and von Aufschnaiter (1999) to explain complex cognitions where learners start at the level of objects and need sufficient time to construct new cognitions on higher complexity levels. Tiberghien (1999) observed that scientists have a very integrated knowledge of science whereas learners' scientific knowledge tend to be fragmented with no established relations between the different pieces of knowledge.

It has been argued that practical work, as a pedagogic strategy is less likely to facilitate knowledge acquisition (Hodson, 2014; Kang & Wallace, 2014; Toplis & Allen, 2012), unless for example learners develop specific reasoning skills (Stender, et al., 2018) and teachers use various levels of scaffolding to direct learning (van Uum, Verhoeff, & Peeters, 2017). On the other hand, it has been argued that learners need the requisite knowledge to benefit from

doing practical work, for example, observations cannot be made in a vacuum and require a theoretical frame (Hodson, 2014). Similarly, the appropriate theory is necessary to manipulate variables and enable reasoning from data (Kanari & Millar, 2004). Hodson claimed that it is the explanations of phenomena that could be facilitated through practical work, rather than learners acquiring new knowledge. Millar (2004) stated that it is unlikely that learners may learn concepts especially from a single practical activity but “practical work is nonetheless necessary for developing students’ understanding of scientific concepts and explanations” (p. 11). However, Haigh, France and Gounder (2012) found that Year 12 chemistry learners’ understanding of concepts did not improve through the practical work activity but the learners became more confused. Further, the learners were not able to make links between the observed phenomena with previously taught concepts on redox reactions. It can be concluded from the literature that the purpose of practical work for acquiring knowledge to achieve the goal of learning science, is complex and inconclusive.

Practical work helps develop learners’ skills

One of the reasons given for doing practical work is to develop skills (Abrahams, 2017; Abrahams & Reiss, 2012; Hodson, 2014; Toplis & Allen, 2012). Skills refer to the knowledge and ability required to do something, as opposed to knowing something (Kirschner, 1992). Gott and Duggan (1995) commented on common confusions between manipulative skills, process skills, and procedural understandings. Manipulative skills are those craft skills required for science careers (Hodson, 1990) and the motor skills required to handle equipment and materials for experimentation, such as arranging, fixing, pouring, weighing, and filtering (Fitzgerald, Danaia, & McKinnon, 2019). Padilla (1990) defined process skills “as a set of broadly transferable abilities, appropriate to many science disciplines and reflective of the behaviour of scientists” (p. 1). According to Padilla, process skills can be classified as either basic process skills that provide a foundation for learning or the more complex integrated process skills. Process skills include observations, stating hypotheses, analysing data, making inferences and drawing conclusions (Abrahams, 2011). Chigumbura (2016) used Padilla’s classification of process skills to study four teachers from two schools implementing CAPS Physical Sciences and found that the basic process skills were used more frequently than advanced process skills. While process skills refer to the processes involved in doing science, according to Gott and Duggan procedural understandings refer to the “thinking behind the doing” (p. 26). Gott and Duggan also clarified the difference between conceptual and

procedural understandings. Conceptual knowledge refers to the ideas or substantive body of knowledge such as facts, laws, and theories, while procedural understandings refer to knowing how to do science. The afore-mentioned terms can be illustrated using the example of measuring current strength. Setting up the circuit and operating the ammeter require manipulative skills. Measuring, that is taking correct readings; observing, controlling variables, and interpreting the data involve process skills. Procedural understandings refer to decisions made such as reasons for connecting the ammeter in series, the number of readings to take, and the most appropriate way to display the results graphically. Pekmez, Johnson, Gott (2005) building on Gott and Duggan's ideas proposed a "Performance Model" where they showed how substantive knowledge and procedural understandings are needed for developing higher order investigative skills. In their study of investigations, Pekmez, et al. found that the teachers' ideas mostly related to substantive ideas and not procedural understandings. Mudau (2007) used the afore-mentioned "Performance Model" to study two teachers' ideas about investigations during the implementation of the C2005 NCS curriculum and also found that the teachers focused on substantive ideas during practical work implementation even though their ideas about practical work were mostly about procedural understandings and process skills.

Several issues were raised around the claim that skills are acquired through practical work. Practical work often requires the collection of data through observation and measurement. Observations are based on our prior knowledge and beliefs, which determine what we choose to observe and what we actually observe, making observations subjective (Hodson & Bencze, 1998). According to Hodson and Bencze, learners may make observations that are inaccurate or incomplete because of their inexperience or the amount of time available for the activity. Jenkins (1999) claimed that for learners to be able to measure accurately they have to learn and practise the skill. Padilla (1990) stated that process skills reflect the behaviour of scientists. However, Wellington (1998) stated that there is little evidence to support the claim that skills such as observation, measurement, prediction and inference are transferable to other contexts, such as those in which scientists work. Scientists, according to Wellington, work in a social, political, and cultural context and have personal views, opinions and prejudices that influence the way they work and they do not rely solely on the skills that are promoted by school practical work. Regarding experiments, Mundangepfupfu (1986) stated that scientists use experimentation to test predictions and

make new discoveries, while school science experiments are not designed for discovering new knowledge. Also, there is a misconception that scientists only conduct experiments and follow the scientific method steps, and school science should replicate this (Jenkins, 1999; Kirschner, 1992). Osborne (2015) questioned the high status given to experimentation in science. He described science, as a set of ideas we have about the living and material world, and experimentation as one of six reasoning styles used to test and develop these scientific ideas. These six reasoning styles are mathematical deduction, experimentation, hypothetical modelling, classification and categorisation, statistical analyses, and historical evolutionary thinking. Osborne maintained that experiments are not the primary or defining attribute of science and school science should be about learning scientific ideas through theoretical discussions, representing science, reading science, writing science, talking about science, and doing science. According to Osborne there is “an overemphasis” of “nebulous and ill-defined skills” (p. 16) when doing practical work and often there is a “failure to make the links with scientific ideas” (p. 19) and suggested that practical work should be used to develop procedural understandings. Regarding investigations, Hume and Coll (2008) found that practical work activities resulted in learners acquiring a narrow view of scientific inquiry and a few low level skills. Their study involved observing 12 one-hour lessons and included six teacher and learner interviews. They found that the practical work investigations involved extensive teacher direction with strong emphases on scientific concepts. Learners could provide descriptive details of the practical work but were unable to provide scientific justifications and explanations. The learners perceived and experienced scientific investigations as linear and unproblematic.

Practical work teaches about the nature of science

Another stated goal of school science is to learn about the nature of science, which refers to the methods, values and assumptions when generating scientific knowledge, and the characteristics of scientific inquiry (Abd-El-Khalick, Bell, & Lederman, 1998). Leach and Paulsen (1999) stated that learners need an understanding of the nature of science in order to understand specific products of science, for example, laws, concepts, theories and methods. Understanding the nature of science includes developing scientific attitudes such as open-mindedness and objectivity. Leach (1999) mentioned that there are more than one set of scientific attitudes and ethical issues may arise from promoting one set of attitudes over another. It is also unclear whether teacher behaviour and the structure of school practical work

can help learners develop scientific attitudes and whether curiosity, objectivity, and critical thinking can be fostered (Hodson, 2014).

One of the reasons given for doing practical work is that it illustrates how scientists work. Mundangepfupfu (1986) alerted us to a common misconception that scientists use solely experimentation and follow the sequential steps of a fixed singular scientific method. In a study by Wong and Hodson (2008) thirteen well established scientists from different parts of the world, working either in experimental or theoretical physics, provided descriptions of their practices that were in contrast to the image of science that is portrayed by school science curricula. Most of the scientists interviewed in this study stated that while they generated hypotheses in their work, they also used creativity, imagination, and argumentation rather than the routine procedures emphasised in school practical work. Scientists investigate the natural world in diverse ways and work with open-ended problems, sometimes with no data or established methods. The afore-mentioned discussions alert us to issues that may arise from equating school science, particularly practical work, with science as a discipline.

Practical work helps motivate learners

A less-articulated purpose for doing practical work in the literature is to motivate learners. The affective argument for doing science practical work is that it is exciting and encourages learners to become interested in science. Hodson (1990) claimed that one of the reasons teachers use practical work is “to motivate by stimulating interest and enjoyment” (p. 34). While most learners seem to enjoy science practical work, Bennet (2003a) questions what it is that learners enjoy about practical work and whether it motivates learners; and quotes research that indicate that learners enjoy science practical work where the purpose is clear, a challenge is provided and where learners have some control over what they have to do. Bennett adds that learners appear to enjoy the less constrained nature of practical work activities. While teachers often state that practical work motivates learners, Wellington (1998) asks what it is that practical work motivates learners to do.

In Wellington’s (2005) study, the junior learners stated that practical work was fun, different, and they enjoyed group work. Building on Wellington’s study, Abrahams (2009) study on the affective value of practical work involved senior learners from 25 schools in England where he found that practical work generated short-term interest in science.

Abrahams concluded that teachers used motivation as a “catch-all” term for “interest, fun, enjoyment, and engagement” (p. 2336). In addition, the teachers mentioned motivation when they were actually referring to learner interest and the learners stated that they liked practical work but when probed found that they preferred practical work to other methods of teaching. Palmer (2009) found that hands-on experimentation was the main source of situational interest amongst the learners studied and this was due to opportunities for social interactions, novel experiences, and a change from the monotony of theory lessons. Earlier, White (1996) described these experiences as memorable episodes that should be “one of the main outcomes of laboratory work” (p. 765). It was also believed that teachers can manipulate the conditions that increase a learner’s situational interest during these short-term encounters (Hidi, Renninger, & Krapp, 2004). Abrahams and Sharpe’s (2010) interview of 32 teachers revealed that what the teachers referred to as motivation was actually situational interest. They concluded that situational interest, which was interest in the practical work activity, was unlikely to endure beyond the lesson and it is also unlikely that doing more of the same activity will motivate learners to study science. Rotgans and Schmidt (2018) reported that in their study of 186 primary school and 71 secondary school learners, individual or personal interest was not a significant predictor of learner knowledge acquisition, but situational interest was. However, Bergin (1999) had earlier cautioned that although “most teachers aspire to increase the interest of their students, they should keep in mind the fact that interest enhancement does not necessarily lead to learning enhancement” (p. 96). Referring specifically to practical work, Wellington (2005) later questioned whether learner interest increased, and whether changes in the affective domain influenced the cognitive domain. A possible conclusion from these studies on practical work is that references to motivation was actually situational interest and that this interest may not have led to increased learning.

2.3.2 Teacher stated aims of practical work

Over the years, teachers’ views about the aims of practical work, although stated and grouped differently, have remained largely unchanged despite evolving ideas of science, science education, and practical work. In 1963, Kerr conducted a study to establish teacher ideas on the purpose of doing practical work. Kerr surveyed 700 science teachers from 150 schools. The teachers ranked the 10 aims, starting with the most important aim, as follows:

1. Encourage accurate observation and careful recording
2. Promote simple, common sense, scientific methods of thought
3. Develop manipulative skills
4. Give training in problem solving

5. Fit the requirements of practical examination regulations
 6. Elucidate the theoretical work so as to aid comprehension
 7. Verify facts and principles already taught
 8. Be an integral part of the process of finding facts by investigation and arriving at principles
 9. Arouse and maintain interest in the subject
 10. Make biological, chemical, and physical phenomena more real through actual experience.
- (Kerr, 1963, p. 21)

The teachers selected “accurate observation and careful recording” as the most important aim of practical work; and making phenomena more real was regarded as least important. According to these aims, one of the purposes of practical work was to understand the established body of scientific knowledge. This was illustrated by Aims Six, Seven and Ten. Aims One, Three and Four refer to developing skills. Practising the scientific method as a purpose of practical work is achieved by the second and eighth aims. According to Kerr (1963), the ninth aim referred to motivation and the fifth aim was to fulfil the prerequisites of assessment. While Kerr’s tabulation of the aims of practical work referred to learning science, learning about science and doing science, what is not clear is the specific aim to develop scientific attitudes such as objectivity, being critical and open-minded about scientific knowledge. Beatty and Woolnough (1982) asked teachers to rank 20 aims of practical work. Their list of 20 aims included the ten aims used in Kerr’s 1963 study. From the list of 20 aims, the teachers in Beatty and Woolnough’s study, ranked the following five aims as being most important: to encourage accurate observation; to arouse and maintain interest; to promote logical reasoning; and to comprehend and carry instructions.

Swain, Monk, and Johnson (1999) surveyed teachers from Egypt, Korea, and the United Kingdom, on the aims of practical work. They found that while there were several differences in rankings of the aims from the three different countries, the four most popular aims of practical work in all three countries were to encourage accurate observation; make phenomena more real; arouse and maintain interest; and promote logical methods of thought. They found that the aims of practical work proposed by the teachers were mostly unchanged for over 35 years. Wilkinson and Ward (1997a) surveyed and compared the aims of practical work proposed by Australian teachers and found that the highest ranking aims proposed were, to make science more enjoyable through actual experience; to promote scientific thinking; as well as to discover and verify facts. Pekmez, Johnson, and Gott (2005) interviewed English teachers on the nature and purposes of practical work, with specific reference to scientific investigations. The aims of practical work, according to 20 teachers in the study, were that

practical work reinforces learning by making it more tangible. A further seven teachers proposed procedural aims such as the learning of manipulative and process skills. Ten teachers claimed that the aim of practical work is to motivate learners, and two teachers stated that practical work helped enhance learners' communication. Abrahams and Saglam (2010) reported on a study of teachers' aims of practical work from England and Wales and compared their aims to those proposed by teachers in Kerr's 1963 study. They found that the aims of practical work proposed were unchanged for the teachers of 11 to 14 year old learners, but there were substantive changes to the importance of the aims for 15 – 18 year old learners. Assessment as an aim of practical work was found to have increased importance compared to the aims ranked in Kerr's study. Abrahams and Saglam attributed the substantial changes to the aims of practical work by teachers of senior classes to the introduction of scientific investigations, changes to assessment criteria, and attempts by policy-makers to improve the image of science. In a survey of 152 South Korean secondary school science teachers, Shim, Moon, Kil, and Kim (2014) found that secondary school teachers had positive views about teaching scientific inquiry and rated this highly. They also found that teachers viewed school experiments as being confirmatory where learners knew the results beforehand. Other stated aims of practical work are for learners to verify and learn theory and see how scientists discover knowledge (Wei & Li, 2017).

Babalola et al. (2019) studied the aims of practical work in four sub-Saharan African countries with resource challenges that are South Africa, Ghana, Tanzania, and Nigeria. They reported that the aims of practical work in these countries were similar to those reported in other western countries but with differing priorities. The most important aim of practical work identified was the learning of theory and content knowledge. This was followed by developing skills such as manipulative skills, observations, report writing, creative thinking, and designing experiments, as well as to motivate learners. It was found that most of the aims selected were pragmatic in nature where it was thought that practical work contributed to the skills required for economic and social development. In the afore-mentioned studies, the objective was for teachers to rank given aims and not to determine what the teachers actually aimed to achieve from doing practical work. Comparative studies on teacher rankings of aims were viewed as being problematic because the aims were based on different curricula and contexts (Wilkinson & Ward, 1997b).

2.4 Practical Work: International Trends

Historically, successive trends in school science in the United Kingdom and United States influenced the purposes for doing practical work and the types of practical work conducted. Hodson (1993) proposed that these trends were influenced by socio-economic factors, shifting views of science, and a growing body of research on practical work. Bennett (2003a) described practical work trends over the years as “a pendulum swinging between approaches which emphasised the facts about science to approaches which emphasised the methods of science” (p. 75). Reflecting on years of practical work implementation, Abrahams (2017) stated that “research has consistently found that it is no more successful in achieving most generic aims than other non-practical methods of teaching” (p. 404) and earlier, Osborne (2015) claimed that practical work in school science was “overemphasised and misunderstood” (p. 16) because practical work is “based on an erroneous conception of science” (p. 23). Toplis and Allen’s (2012) study of the role of practical work in the United Kingdom illustrated the importance of tracking the evolution of practical work. Their review of changes to practical work over forty years provided a context to evaluate the then prevalent beliefs about practical work. In this section, I provide an overview of each practical work trend to provide a context to evaluate current practical work implementation in South Africa.

2.4.1 Practical work from the 1800s to 1990

In the early 1800s, practical work was dominated by teacher demonstrations to verify facts and theories taught (Bennett, 2003a). In the latter part of the 1800s, practical work was influenced by H.E. Armstrong who promoted the heuristic approach emphasising the scientific method and discovery (Gott & Duggan, 1995). During this period it was believed learners conducted experiments to support theory (Losee, 2001). The Thompson Report of 1918 criticised the heuristic approach of this period, stating that the time spent in the laboratory cannot justify the results obtained (Kerr, 1963, p. 10). Individual experimentation for “discovery” was seen as a waste of time and resources (Bennett, 2003a). A focus on learning factual knowledge for examinations and the prevalent socio-economic circumstances resulted in a shift away from individual “discovery” experiments to illustrative cookbook type practical work that was believed to verify and confirm theory (Bennett, 2003a). This approach started in the 1920s and lasted for almost half a century.

During the 1960s and 1970s, heurism was once again favoured and this was known as the discovery-learning era. The purposes of practical work were to guide learners to “discover” theory and concepts, develop reasoning skills, encourage observation, and provide direct contact with the real world (Hodson, 1993). This view of practical work formed the basis of the British Nuffield Science courses that emphasised the teaching of the scientific method where learners performed experiments and were presented with information in a form that required them to “discover” underlying theories by themselves (Gott & Duggan, 1995). Learners had to “see the point of experimental work” where chemicals and the apparatus were the tools to answer questions (The Nuffield Foundation, 1966, p. 4). Gott and Duggan stated that the critics of discovery learning questioned the value of the artificial and restricted nature of the practical work activities that led to pre-determined answers and argued that formulated, tightly controlled experiments left little room for discovery and the answers to be “discovered” already existed in the accepted theories and principles. It was also pointed out that the conceptual demands of the courses were beyond the abilities of the average learners and the experiments had no relevance to the learners’ lives (Kreitler & Kreitler, 1974). These criticisms pointed to a need for change.

In the late 1970s Karl Popper’s falsification trended where solving a problem required deducing a hypothesis from theory and testing it empirically, and when the hypothesis is not supported by observations, it is falsified (Schwartz, et al., 2004). In the single deductive method, the assumption was that observations made in empirical testing are always reliable and infallible (Losee, 2001). The process movement of the 1980s emphasised the methodology of science as practised by scientists and this was regarded as being more valuable to learners than learning science content (Bennett, 2003a). The emphasis was on what scientists do and how they think rather than the facts and principles of science. Practical work involved the teaching of manipulative skills as well as process skills such as observing, predicting, classifying, and interpreting data, controlling variables and formulating hypotheses. Hence, in addition to the practical skills, the associated cognitive processes were also important. In light of this, the Nuffield Science courses were reviewed to emphasise the processes rather than the products of experimentation (Gott & Duggan, 1995). The problem identified with emphasising processes was that even though inquiry was emphasised, certain assumptions were made about how scientists work (Bennett, 2003a). Over-simplification of

scientific inquiry to the following of a series of steps of a scientific method to collect and analyse data was based on misconceptions on how scientists work (Wong & Hodson, 2008). The process movement was also criticised for giving prominence to processes at the expense of scientific content knowledge. Hodson (1990) claimed that practical work implementation was “ill-conceived, confused and unproductive” and the claims made about achievements were attributed to decades of “powerful myth-making rhetoric” (p. 33). Jenkins (1999) described these myths as “sterile, reflecting beliefs and assumptions rather than careful evaluation of evidence” (p. 21).

2.4.2 Practical work from 1990 to date

Throughout most of the 1990s to recently, inquiry-based approaches to school science consisted of a range of activities mirroring the authentic way scientists work (National Research Council, 2000). Inquiry activities are centred around a research question and are classified according to the openness of the tasks that are, Confirmation Inquiry; Structured Inquiry; Guided Inquiry; and Open Inquiry (Bell, et al., 2005). One type of inquiry activity that is classified as practical work is investigations that aimed to develop concepts, practical skills, and cognitive process skills. The heuristic approach once again returned but this time higher-level cognitive skills were included. This more holistic approach to practical work, included elements of all the major movements of the past: acquiring practical skills; relating real objects to scientific ideas, concepts and laws; and acquiring cognitive process skills (Gott & Duggan, 1995). When doing investigations, the emphasis was on thinking and not just doing practical work because the learners are given problems that require them to use higher order investigative skills (Pekmez, et al., 2005). Pekmez et al. (2005) proposed the Performance Model to explain investigations. In this Model, problems are solved through using substantive understanding (facts, laws and theories) operating alongside a procedural understanding (skills and conceptual understanding of skills e.g. an understanding of averages will influence how many measurements are taken) (Pekmez, et al., 2005). Bennett questioned whether practical work is the most effective way to achieve the goals of school science, given the costly resources required. Bennett asked, “Does the end justify the means?” and “What exactly are the ends and means of practical work in school science?” (Bennett, 2003a, p. 74).

In yet another trend known as science practices, the “ends” of practical work became the focus and the term laboratory work was favoured over practical work. In the *Next*

Generation Science Standards: For States, By States (National Research Council, 2013), science practices are made up of three dimensions: science and engineering practices, crosscutting concepts, and core ideas in science. Disillusioned with cookbook and confirmatory practical work where learners struggle to make the link between science content and processes, science practices aim to prepare learners for future careers in science and engineering where new knowledge and innovation are prized. Science practices focus on integrating content with authentic science and engineering practices. Laboratory work involves science practices such as asking questions; developing models; planning and carrying out investigations; analysing and interpreting data; constructing explanations and designing solutions; evidence-based arguments; and obtaining, evaluating, communicating information (Bybee, 2011; Osborne, 2014). The vision of science practices was explained, “A new vision for science education is grounded in the idea that science is both a body of knowledge and a set of linked practices for developing knowledge” (Penuel, Harris, & DeBarger, 2015, p. 45). Practical work is still inquiry-based and involves investigations but the focus is on integrating practical work with content and engaging learners in authentic practices like that of scientists and engineers rather than traditional cookbook exercises. Here, the repurposing of practical work has resulted in reshaping the nature of the activities.

2.4.3 Practical Work in Africa

In the recent past, there has been a marked increase in inquiry-based curriculum reforms in Africa. It is reported that despite this, the policy-practice gap remains. In a recent compilation of practical work studies from nine countries in Africa, “*School science practical work in Africa: Experiences and Challenges*” Ramnarain (2020) noted that there is much in common across African countries regarding the implementation of practical work, including the challenges faced by teachers. Research from South Africa; Namibia; Zimbabwe; Nigeria; Malawi; Kenya; Uganda; Zambia and Tanzania reported in this book described progressive inquiry-based curriculum reforms. However, the implementation of practical work did not reflect inquiry-based practices and were mostly influenced by contextual challenges and teacher preparedness. Studies reporting on the policy-practice gap included that by Mavuru and Dudu (2020) who described the Zimbabwean inquiry-based curriculum and the challenges of teacher preparedness, assessment, and resources that have persisted. Upahi and Oyelekan (2020) described similar challenges and practical work implementation that was characterised by cookbook recipe following. Using a narrative inquiry approach to analyse

practical work implementation in Kenyan secondary schools, Miheso (2020) found poorly planned and executed practical work with similar challenges such as limited resources. Similarly, Kibirige (2020) found that practical work implementation in Ugandan schools were characteristically highly structured with little opportunity for learners to plan and design their own investigations. Chabalengula and Mumba (2020) reported that the curriculum materials in Zambia emphasised low level inquiry skills such as manipulative skills rather than designing, planning, and interpreting data. In addition, the learners conducted practical work in a “vacuum” without making sense of their actions. The teachers in their study held narrow conceptions of science inquiry. Other practical work studies that focused on teachers included those done in Tanzania, Namibia, and South Africa. In a study of practical work in Tanzanian schools, the teachers were found to lack a mastery of science subject content, struggled to integrate practical work in their science teaching, lacked the impetus to engage learners, and were not adequately prepared to teach practical work (Semali, 2020). Asheela, Ngcoza and Sewry (2020) noted the lack of hands-on practical work in rural Namibian schools and reported that the reason most often cited by teachers was the lack of resources. They studied 21 in-service teachers from mostly rural schools in Namibia studying a post-graduate degree part-time at a South African university. Their finding was that in order for teachers to use resources to carry out hands-on and minds-on practical activities, they needed both knowledge and practice on how to use the resources. When the teachers became familiar with easily accessible resources, it increased their motivation, knowledge, and skills, highlighting the importance of teacher professional development. Ramnarain (2020) reported that in most South African classrooms (to be elaborated in the next section), prescriptive practical work cookbook exercises involve the teaching of basic process skills in challenging contexts and are often taught by teachers who lack content knowledge. Earlier, in a study of Ethiopian secondary schools, it was found that effective teaching of chemistry practical work was influenced by poor teacher knowledge of practical work, teacher absenteeism, and low teacher expectations of their learners, as well as insufficient time and resources to do practical work (Anza, Bibiso, Mohammed, & Kuma, 2016).

2.5 Practical Work in South Africa

In South Africa, practical work was part of changing curricula that paralleled political changes in the country. Practical work trends and the related research studies will be discussed over three periods of curriculum change: the pre-1994 period; the post-1994 period up to 2011; and the period from 2011 to present. Research studies on science practical work have focused on interrogating institutional beliefs and looking deeper into the challenges and potentials of implementation, with the aim of improving practice.

2.5.1 Practical work in the pre-1994 period

The South African education system prior to 1994 was divided into different departments for different race groups marked by racially-differentiated access to science and mathematics education (Reddy, 2006). In the 1970s, the Physical Science syllabus for whites-only schools contained general aims for practical work such as to facilitate learning, give opportunities for learners to make simple discoveries, to experience measuring techniques and to practice observing, recording and drawing conclusions. In 1973, the Joint Matriculation Board listed a set of minimum practical work to be done and justified this list by stating that Physical Science was an experimental subject and hence experiments should form an integral part of lessons (Lynch, 1976). Practical work in the Indian-only schools was compulsory and the aims were for learners to set up the apparatus for particular experiments, observe, collect data, and draw conclusions. Practical work was examined at the grade 12 level where learners had to explain the steps of the experiment, how and why the data were collected and answer theory related questions. According to Lynch, only the then Natal and Free State provincial departments examined grade 12 learners' practical work. Rogan (2004) stated that the pre-1994 curriculum emphasised rote memorisation of content from a prescribed syllabus and the assessment thereof. Practical work during this period involved mostly practicing basic skills through the sequential steps of cookbook-type experiments, while internationally in the 1970s and 1980s practical work was dominated by the process and constructivist learning approaches.

During the period of racially segregated schools, a selection of white teachers was asked to rank the aims of practical work. Most of these teachers strongly believed that practical

work was an important means of facilitating learning and understanding (Colussi, 1975). In a study of practical work in selected white high schools, Lynch (1976) found the following:

- Teachers ranked the following as the most important aims of practical work: to make the subject more real and interesting, to encourage accurate observation, to clarify theory and to promote scientific inquiry.
- The science syllabus did not contain specific objectives for practical work.
- The implementation of practical work in the various racially segregated departments of education differed considerably.
- The amount and type of practical work in the various provinces differed. More practical work was done in the Natal and Free State provinces where practical work was assessed.
- There was no evidence to suggest that the amount and type of practical work done affected learners' grade 12 examination results.
- There was no evidence to suggest that science practical work motivated learners to pursue science-related careers. (Lynch, 1976)

In the same study, but focusing on practical work in Indian high schools, the teachers raised several issues that influenced the implementation of practical work. An overly theoretical and lengthy syllabus; the restrictions of prescriptive practical work; insufficient resources; inadequate time to do experiments; large classes; and lack of laboratory assistants were quoted by teachers as some of the hindrances to successful practical work implementation (Lynch, 1976). In addition, it was found that teachers and learners viewed the aims of practical work differently. While both the teachers and learners believed that practical work made the subject more real and interesting, the learners considered the aims of encouraging problem solving and motivating them to study science further, as the least important aims of practical work. A decade later Hobden's (1986) study of practical work in Indian high schools reiterated the mismatch between the stated aims of teachers and the aims as perceived by learners with a significant number of learners not understanding the purpose for which the experiments were being conducted. Moreover, both the teachers and learners agreed that learner practical skills were limited and they lacked high order skills needed to complete the experiments.

The pedagogical value of the different types of practical work implemented in developing countries was questioned in light of the high cost of science equipment and laboratories. Mundangepfupfu (1986) argued that several misconceptions about science and science education have driven the need for investing large amounts of capital on laboratories. These misconceptions related to the nature of science, how scientists work, the purpose of science teaching and its pedagogy. Mundangepfupfu maintained that science teaching needed to be more realistic regarding what it can achieve, for example, the aims of school science are

not to make discoveries or produce theories. Misconceptions about pedagogy included the belief that learning by doing is more superior to other forms of learning and experiential learning can only be achieved in the laboratory. In addition, the measuring and quantifying done by scientists can be learnt anywhere and not just in a laboratory and experimentation is only a small part of what scientists do. Mundangepfupfu added that school science practical work was not designed for discovery, the outcomes are known, and a single scientific investigative method was being taught. A few years later, Kahn (1990) questioned whether research on practical work from industrialised countries could be applicable to developing countries and cautioned against the “slavish adoption by developing countries” (p. 127).

2.5.2 Practical work in the outcomes-based curriculum (1994 to 2010)

In 1994, the new democratic government recognised mathematics and science as part of the human development strategy for all South Africans. In 1997, Curriculum 2005 (C2005) with an outcomes-based education approach was launched. C2005 was heavily criticised for not specifying content adequately and for the lack of structured resource materials (Reddy, 2006). Practical work was largely unspecified with an emphasis on learner-centred project work. A review of the C2005 curriculum policy found that there was poor alignment between the curriculum and how it was assessed; teachers were not adequately trained; there was a lack of resource materials and laboratory equipment; and there was evidence of a policy overload (Department of Education, 2000). A revised version of C2005, the Revised National Curriculum Statement (RNCS), with greater structure for teachers was implemented (Sayed & Kanjee, 2013). In 2003, the National Curriculum Statement curriculum policy (NCS) was implemented (Department of Basic Education, 2003). In the NCS curriculum, a specific Learning Outcome (LO1) focused on scientific inquiry and problem solving skills where learners were expected to conduct an investigation, interpret data to draw conclusions, solve problems, and communicate information. The post-1994 outcomes-based curricula (C2005, RNCS, and NCS) leaned towards learner centred discovery learning where practical work centred around conducting scientific investigations. Internationally, during this period practical work no longer focused on discovery learning but focussed on the acquisition of process skills through investigations.

Post-democracy (1994) research studies up to 2010 in South Africa have focused on the material conditions and impact of the outcomes-based curriculum policy on practical work

implementation. In Meiring's (1995) study, the majority of teachers were found to hold an inductivist view of science, however those teachers who held constructivist views were strongly inductivist in their practice and assessment of laboratory work. In years to follow, the theoretical framework proposed by Rogan and Grayson (2003) were used by several researchers to study curriculum implementation in South Africa. Case studies of C2005 curriculum implementation in science classrooms revealed that little practical work was being done and when practical work was done, the learners practiced low levels of skills such as observing and recording results (Rogan, 2004). Rogan and later Stoffels (2005) found that despite having equipment, some teachers still did not teach practical work. The reasons suggested for this finding were that teachers lacked practical work skills and had insufficient understandings of science concepts. Hattingh, Aldous and Rogan (2007) used the theory of curriculum implementation proposed by Rogan and Grayson to study the factors that influence practical work in a sample of schools in the Mpumalanga province. They found that school capacity factors such as the ethos and functionality of the schools influenced the implementation of practical work. The availability of physical resources, such as science equipment, was not a predictor of whether practical work would be done. In addition, they found that teacher perceptions of their learners' academic ability and learner motivation to study influenced the complexity of practical work implemented.

Studies that highlighted teacher challenges when implementing practical work included those by Stoffels (2005), Mudau (2007), and Kriek and Basson (2008). Mudau's (2007) study of NCS curriculum practical work revealed that the two grade 10 Physical Sciences teachers' ideas of practical work did not shape how they implemented it. Both teachers understood practical work in terms of scientific investigations but emphasised content learning during practical work. The teachers in Kriek and Basson's study preferred prescribed, structured practical work and believed that learners learn better, when they do guided practical work. In Stoffels' study, the teachers persisted with a mechanical traditional teacher-centred approach to practical work. These teachers emphasised the systematic following of procedures and writing correct answers. Stoffels termed this defensive teaching aimed at maintaining control over the learners.

While most of the research studies during this period focused on teachers' perceptions and the pedagogy used, a study of learner experiences in the *Science Education Project*

revealed that practical work in the NCS curriculum was found to have many positive attributes but failed to enhance learners' understandings of the nature of science (Ntombela, 1999). Some of the reasons for the lack of success were teachers' own understandings of practical work as well as the rigidity of curriculum materials that claimed to introduce learners to hands-on practical work. A study that examined Grade 9 learners' process skills revealed that very few learners displayed a satisfactory understanding of how to collect data and communicate their findings (Conana, 2009). The study by Villanueva and Webb (2008) concluded that the documenting of activities and observations by learners during investigations enhanced their inquiry skills. In Ramnarain's 2017 study of scientific investigations in Grade 9 Natural Sciences classes, he concluded that the learners showed varying degrees of autonomy throughout the different stages of the investigations (Ramnarain, 2010; Ramnarain & Hobden, 2015). A two-phase curriculum change model was used to illustrate a lack of congruency between the inquiry-based NCS intended curriculum that focused on skills and the content-based NCS examined curriculum (Nakedi, Taylor, Mundalamo, Rollnick, & Mokeleche, 2012). In 2009, a Ministerial Task Team concluded that the NCS curriculum needed further streamlining with more emphasis on content (Dada, et al., 2009). This led to the implementation of the current Curriculum and Assessment Policy Statement (CAPS) (Department of Basic Education, 2011).

2.5.3 Practical work in the CAPS curriculum (2011 to present)

In the CAPS (Department of Basic Education, 2011) document it is stated that the aims of the Grade 10 to 12 Physical Sciences subject are to equip learners with knowledge, inquiry and problem solving skills; and an understanding of the nature of science and its relationship with technology, society and the environment. The stated purposes for studying the Physical Sciences are to prepare learners for future learning, specialist learning, employment, citizenship, holistic development, socio-economic development, and environmental management. It is also stated that practical work must be integrated with theory to strengthen the concepts taught and to develop inquiry skills that are essential for developing and preparing learners who will contribute to the country's scientific endeavours and goals.

According to Grussendorff, Booyse, and Burroughs (2014), while the previous NCS curriculum was learner centred and activity-based, the CAPS curriculum is more structured and prescriptive with regards to practical work. The number of prescribed and recommended

practical activities is summarised in Table 2.1. Further, there is an emphasis on experimentation and skills, for example, 88 experimental skills are referred to 182 times in the FET Grades 10 – 12 CAPS document. Regarding the implementation of practical work, in the “Overview of practical work” it is stated that practical work “may take the form of simple practical demonstrations or even an experiment or practical investigation” (Department of Basic Education, 2011, p. 11). However, with the exception of two recommended practical work activities, “Use a ripple tank to demonstrate constructive and destructive interference of two pulses” and “Practical Demonstration (Physics) Investigate the relationship between normal force and maximum static friction” (p. 12) it is not specified whether the other 24 practical work activities are to be taught as learner activities or teacher demonstrations. In the content section of the CAPS document, demonstrations are mentioned 15 times with reference to other practical activities that are neither prescribed nor recommended. An example of this is, “Practical demonstration: Generate a longitudinal wave in a spring” (p. 27). “Demonstrate” is mentioned 17 times, for example, “Demonstrate how to measure emf and terminal potential difference” (Department of Basic Education, 2011, p. 42).

Table 2.1 Number of practical work activities listed in Physical Sciences CAPS curriculum

	Grade 10	Grade 11	Grade 12	Total
Prescribed Practical Activities	2	2	3	7
Recommended Practical Activities	6	7	6	19

Earlier studies on CAPS practical work implementation reported on challenges with resources and learning contexts. In a 2013 study of 30 secondary schools in rural areas, Motlhabane (2013) reported that teachers in rural areas were not doing practical work because of a lack of science equipment. Motlhabane suggested that learners not doing practical work was one of the reasons for poor performance in Physical Sciences examinations. Singh’s (2014) study focused on the contextual challenges faced by two grade 10 teachers conducting practical work. Ramnarain and Schuster (2014) investigated the pedagogical orientations of in-service Physical Science teachers at disadvantaged township schools and privileged suburban schools. They found that the teachers at the township schools had strong direct teaching orientations where the direct exposition of the science was followed by confirmatory practical work. However, the teachers at the suburban schools, showed orientations towards guided inquiry with a guided exploration phase. The contributing contextual factors that

influenced the different teaching orientations were identified as class size, availability of resources, teacher competence and confidence, time constraints, learner ability, school culture, and parental involvement. Ramnarain and Mamutse (2016) explored the use of improvised physical resources in the absence of conventional laboratory resources in inquiry-based classrooms.

Other studies on CAPS practical work focused on the relationships between teacher perceptions and their practice. Four teachers were found to have a limited understanding of inquiry and used mostly teacher-centred approaches (Mokiwa, 2014). Using a six-item questionnaire in a small-scale survey, Kibirige et al. (2014) studied ten Grade 7 Natural Science teachers' perceptions of practical work in schools from the Limpopo province. They reported that while the teachers' perceptions of practical work were adequate, their classroom implementation were not. The teachers in Ramatlapana and Makonye's (2012) study believed that the CAPS policy was too restrictive and at times this compromised teacher autonomy. However, in a later study of three Grade 11 teachers, the teachers perceived the prescription of practical work in the CAPS policy and the report write-ups provided by the Department of Education officials as positive even though such prescription resulted in reduced inquiry-based learning opportunities (Gudyanga & Jita, 2019). The school type and contexts were found to affect South African and Malawian teachers' pedagogy choices, influencing their inquiry teaching approach (Ramnarain, et al., 2016). Teachers in Ramnarain and Hlatswayo's (2018) study had positive views on inquiry-based teaching but stated that they were less inclined to enact this in their teaching. From the afore-mentioned studies, it appears that there was no relationship between teachers' perceptions of inquiry-based strategies and their practical work implementation.

Gudyanga and Jita (2019) stated that it must be noted that some studies on practical work were conducted in purposively-selected inquiry classrooms. Akuma and Callaghan (2018) studied two resource-constrained schools using a three-level classification of inquiry that are Structured; Directed and Open Levels of inquiry. They found that the teaching practices of all eight teachers were at the Confirmation Level and concluded that the strategies were inconsistent with inquiry-based learning. Later, they also found gaps between inquiry-based practical work implementation and teacher competencies (Akuma & Callaghan, 2020). Specifically, the gaps were in the areas of teacher content knowledge, pedagogical

knowledge, technological knowledge, technological pedagogical knowledge, and some professional values. Tsakeni, Vandeyar, and Potgieter's (2019) study of four teachers conducting inquiry-based practical work concluded that the teachers used Structured Level Inquiry. The four teachers provided the procedures, of which one teacher also provided the question, and another teacher provided the solution. The practical work conducted was listed in the CAPS Physical Sciences document and the learners could have known the conclusions. However, the researchers believed that due to the inquiry opportunities of the practical work, and the teachers' scaffolding and questioning, the learners reached the conclusions from the data collected. It was found that learners' understandings of the nature of scientific inquiry had a positive influence on performance achievements in a standardised Physical Sciences test (Penn, Ramnarain, & Wu, 2019). The aforementioned challenges with inquiry-based practical work were summarised in a systematic review of research by Akuma and Callaghan (2019). They concluded that the challenges were due to four intrinsic issues that are teacher beliefs; design of practical work; implementation; and evaluation. These challenges were found to be linked to gaps in teacher knowledge, skills, and values. Ramnarain's (2020) overview of almost two decades of inquiry-based practical work in South Africa confirms that similar challenges have persisted over the years, which are teacher perceptions, pedagogical knowledge, and contextual factors when implementing inquiry-based practical work. In a study focused on improving pedagogical practices, teachers shifted their practices to inquiry-based teaching after empowerment evaluation professional development (Ramnarain & Rudzirai, 2020).

Studies have reported practical work implementation challenges during the three successive curriculum reform periods in South Africa that are the pre-1994; the outcomes-based C2005; and the CAPS curriculum periods. In the pre-1994 period, studies focused on the state of resources and contextual factors (Lynch, 1976) and the aims of practical work (Hobden, 1986). In the outcomes-based C2005 period, studies focused on resources; contextual factors; implementation of investigations; teacher perceptions; and pedagogy. In the CAPS curriculum period, studies focused on resources, contextual factors, teacher perceptions of practical work, and the implementation of inquiry-based practical work. Gaps identified in the research on practical work included the purposes for doing practical work; the implementation; and learner experiences of practical work, in the context of high-stakes examinations. Firstly, at the curricular level, the ideas about science, goals of science

education, and the underpinning ideologies of the curriculum need to be analysed. A study conducted on the Life Sciences C2005 curriculum found that the curriculum was mostly academic and student-centred (Mnguni, 2013). Secondly, the conceptual demand of practical work, specifically the knowledge and skills needs to be identified. Green and Naidoo (2006) analysed the knowledge contents of the NCS C2005 Physical Sciences curriculum and found that it contained complex cognitive and meta-cognitive competences. Thirdly, teacher understandings of the purposes and aims of practical work and the alignment with the intended curriculum will contribute to understanding the role of practical work. Phaeton and Stears (2017) found misalignments between the intended and implemented Zimbabwean A-level Biology practical work due to teachers misinterpreting the intended curriculum. Mpungose's (2021) study showed that teachers theorising about the CAPS curriculum were mostly informed by the prescribed content needed for addressing the formal curriculum. Fourthly, whether or how specific teacher objectives for the practical work lessons are aligned with the aims of the intended curriculum will contribute to understandings on how the intended curriculum is interpreted and implemented by teachers. Fifthly, the nature of practical work done and understanding why practical work is being done in particular ways, will provide insights into the role of practical work. In summary, establishing the role of practical work in the teaching and learning of Physical Sciences requires a comprehensive study of practical work at the intended, implemented, and attained levels.

2.6 Conceptual Framework

To guide this study on the role of practical work in the context of high-stakes examinations, a conceptual framework was constructed from social constructivist and social cognitive theories, as well as several relevant concepts. These concepts are the levels of curriculum representation, the types of practical work, the skills developed through practical work, and the levels of effectiveness of practical work activities. The result was a conceptual framework that guided the analyses and interpretation of the findings in this study.

2.6.1 Social constructivism and learning

Constructivism arose out of a dissatisfaction with behaviourist theories of learning where learning is viewed as a system of behavioural responses to physical stimuli and where

predetermined knowledge is broken down into content areas and skills (Fosnot & Perry, 2005). According to Fosnot, and Perry, assumptions made in behaviourist theories of learning included “observation, listening to explanations from teachers, or engaging in experiences, activities, or practice sessions with feedback will result in learning”; learners need external motivation; and assessment involves measuring observable outcomes (p. 9). Behaviourist theories of learning do not provide explanations on the cognitive changes that occur when understanding concepts as proposed by constructivist theories (von Glasersfeld, 2005). Constructivist theories are useful to understand how we learn and can inform the methods we use to teach (Dougiamas, 1998; Tobin, et al., 1994). Of relevance to this study, in social constructivism, learning is viewed as the social process of making sense of the world through interacting with objects and events (Tobin, et al., 1994).

Social constructivists believe that there is no truth out there to be discovered and subjective reality can only be personally constructed through social interaction (McRobbie & Tobin, 1997). Learners in a social constructivist classroom are autonomous and responsible for their own learning through interactions with others (Lederman, et al., 2014). When learners actively construct meaning through personal and social discourses, new knowledge is integrated into their existing knowledge (Bodner, 1986). An association is then made with existing knowledge and beliefs resulting in conceptual change (Bodner, 1986; Duit & Treagust, 2003; Hewson, 1996). According to Bodner, if a learner does not accept the new conception then there is conceptual conflict. Bodner calls this a state of disequilibrium. To restore equilibrium, pre-existing schemes have to be modified for equilibrium of conceptions (Gaigher, Rogan, & Braun, 2007). According to Gaigher, Rogan, and Braun, during conceptual change learners can develop new conceptions or modify existing conceptions. It was also found that conceptual change may result in learners developing alternative conceptions or learner misconceptions (Gopal, et al., 2004; Lazarowitz & Tamir, 1994).

According to Hewson (1996) the teacher is required to establish a context conducive for conceptual learning. One such context that provides varied multisensory experiences is school science practical work (Lorsbach & Tobin, 1997). The complexity of the scientific knowledge and the cognitive skills required for the practical work activity will determine the conceptual demand of the practical activity (Ferreira & Morais, 2015). Resta (2002) summarised the constructivist environment of science practical work lessons. Here, learners perform authentic

tasks; negotiate meanings and understandings; and undergo authentic assessment rather than traditional testing. According to Fosnot and Perry (2005), teachers need to allow learners to develop their own questions, test the hypotheses, and discuss their findings; and this does not involve “cookbook style teaching” because learning is an “interpretive, recursive, non-linear building process by active learners interacting with their surround - the physical and social world” (p. 34). Fosnot and Perry added that the visual and spatial aspects of practical work activities are important but for enhanced learning, these aspects must be accompanied by other forms of representations such as verbal, perception, and pattern recognition.

2.6.2 Social cognitive theory and motivation

A widely cited aim of practical work is to motivate learners and influence them to pursue science careers by capturing their interest (Bennett, 2003a). Motivation, interest, and self-belief, are interrelated concepts that can be explained through social cognitive theory. Social cognitive theorist Albert Bandura defined motivation as, “Activation to action. Level of motivation is reflected in choice of courses of action, and in the intensity and persistence of effort” (1994, p. 2). Bandura believed that motivation is cognitively generated and influenced by the beliefs people have about what they can achieve. To motivate learners, their self-efficacy beliefs must increase through accomplishments and successes, “Explicit, challenging goals enhance and sustain motivation” (p. 4). Motivation, in science learning refers to the enthusiasm for and curiosity about science that may influence learners’ belief systems (Abrahams, 2009). Bandura added that career choices are primarily related to motivation, which is influenced by self-belief that is formed through repetitive and sustained occurrences.

Interest according to Bergin (1999), which has been defined as preferences for objects and ideas, has been categorised as being personal or situational, referring to the enduring preferences people have for certain activities or liking something. Bergin added that factors such as relevance, competence, cultural value, social support, background, and emotions influence a learner’s personal interest; and these are not always within the direct influence of the teacher. Bergin stated that in contrast to personal interest, situational interest refers to the environment, activities, and content that could generate interest in the learner. Personal interest is likely to endure over time, while situational interest may change and is short lived (Hidi & Harackiewicz, 2000). During short-term encounters such as practical work, teachers can manipulate the conditions that increase the learner’s situational interest (Hidi, et al.,

2004). Practical work that stimulates situational interest may be useful for presenting an alternative image of science that is fun and enjoyable rather than difficult and boring (Abrahams, 2011). However, increasing a learner's situational interest may not increase their cognitive engagement or motivation (White, 1996).

2.6.3 The Interpretive Framework for analysing and interpreting practical work

Various concepts related to practical work were incorporated into an interpretive framework that was used in this study (*see Figure 2.1 on page 46*). The conceptual framework proposed by van den Akker (2010) on the three levels of curriculum representation was most useful to delineate the scope of this study and enable practical work implementation to be analysed at all levels. To determine the nature and effectiveness of the practical work conducted, various classification systems were reviewed. The classification of process skills proposed by Padilla (1990) was adopted and the framework to determine the effectiveness of practical work tasks proposed by Miller (2009) was adapted for this study.

The three levels of curriculum representation

The curriculum has been defined as the plan for teaching and learning, and different versions of the same curriculum can be described using the three levels of curriculum representation proposed by van den Akker (2010) (Figure 2.1). At each of these levels, Bernstein's (1996; 1999) pedagogic device can be used to determine how the role players influence the curriculum that is produced, transmitted, and acquired. According to van den Akker, at the first level (*macro level*) the system or government influences the intended curriculum. The curriculum writers and designers produce the published curriculum, which is made up of the ideal and the formal curriculum. The ideal curriculum reflects the ideology, vision, and rationale, while the formal curriculum is the syllabus. The recontextualisers (subject advisors and government officials) determine the rules of implementation and produce the illustrated curriculum such as lesson plans and the examined curriculum.

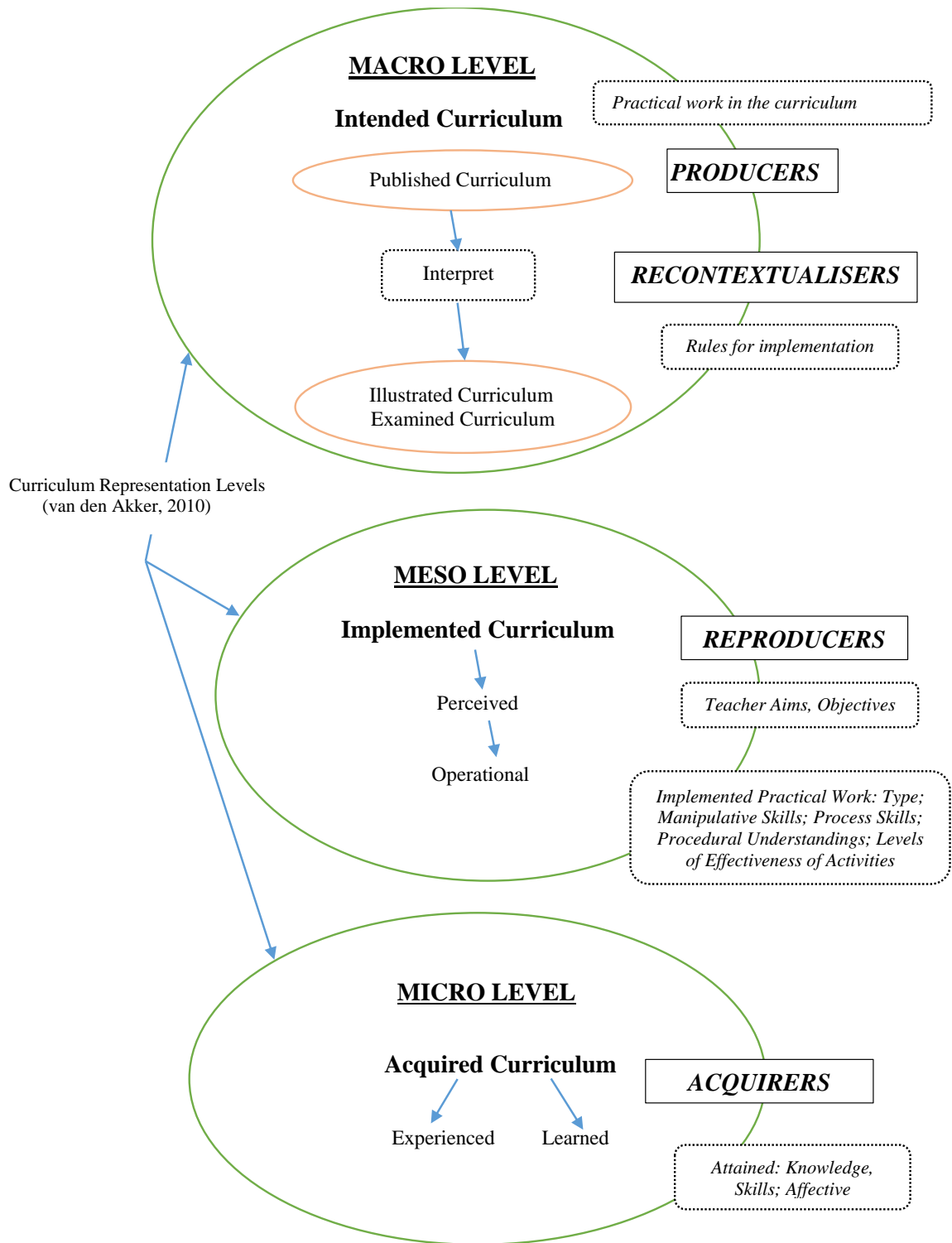


Figure 2.1 Interpretive Framework to determine the role of practical work

The second level of this Interpretive Framework (Figure 2.1) is the *meso level* where the role players are the reproducers (teachers). The teachers operationalise the illustrated curriculum, as they perceive it but within the rules set by the recontextualisers. The third level is the *micro level* where the learners experience and learn the acquired curriculum, which is assessed through the examined curriculum (*meso level*) as determined by the recontextualisers (Nakedi, et al., 2012). The framework proposed by van den Akker on the levels of curriculum representation was useful when establishing the role of practical work in the teaching and learning of Physical Sciences in the context of high-stakes examinations. To establish the rationale for doing practical work, the nature of the practical work implemented, and why practical work was done in particular ways, it was necessary to understand how practical work was conceptualised in the curriculum, implemented at the three levels, influenced by the various role players, and whether or how there was translation between the levels.

Nakedi et al. (2012) elaborated on the significance of examining the different levels of curriculum representations and the consequences of the role players' influences, in their study of the National Curriculum Statement Physical Sciences curriculum. They claimed that ideally the following levels should be aligned: the attained with the ideal curriculum levels; the operational with the perceived curriculum levels; and the examined with the published curriculum levels. They stated that in reality translations between the levels shift and may distort the curriculum. Other South African or African studies where van den Akker's (2010) framework to distinguish between the levels of curriculum representation were used included those by Khoza (2015); Phaeton and Stears (2017); Mpungose (2021); and Nakedi et al. (2012). Bernstein's (1996; 1999) pedagogic device framework to determine the influence of various role players at each of the curriculum levels were used in South African studies by Ferreira and Morais (2015); Green and Naidoo (2006); Khoza (2016); Nakedi et al. (2012), and Ramatlapanana and Makonye (2012).

Classifying the types of inquiry-based science practical work

For a practical work activity to be classified as inquiry, it must involve active hands-on and/or minds-on learning and the analysing of data to answer a question (Abd-El-Khalick, et al., 2004; Anderson, 2002; Bell, et al., 2005). Fitzgerald, Danaia, and McKinnon (2019) summarised the four levels of inquiry proposed by Herron (1971) based on the degrees of

learner autonomy and teacher direction. Progressing from Level 1 to Level 4, learner autonomy increases and the amount of teacher direction decreases.

These four levels of inquiry are:

- Level 1 *Confirmation Inquiry*: Learners are provided with the question and procedure. The teacher and learners know the solution in advance
- Level 2 *Structured Inquiry*: Learners are given the question and procedure. Learners provide the solution from the data collected, which may be known by the teacher and not the learners
- Level 3 *Guided Inquiry*: Learners are given the question and they design the procedure to answer the question
- Level 4 *Open Inquiry*: Learners formulate the question, design the study, conduct the investigation, and provide the solution. (Fitzgerald, et al., 2019)

The classification system proposed by Bradley (2005) was based on “the map of learning” developed by Ausubel. Practical work activities are located on a continuum between reception and discovery type activities, and between rote and meaningful learning activities. Bradley’s (2005) theoretical model describes the degree of involvement of the teachers and learners but not the different levels of inquiry, except for identifying open and guided inquiry. In addition, reception-learning activities where learners are not physically involved are classified as practical work. Further, this classification implies that discovery is the only way to achieve meaningful learning and according to Kirschner, et al. (2006), this is a misinterpretation of Ausubel’s ideas on the psychology of meaningful learning. Bell et al. (2005) stated that most practical work activities can easily be converted to fit into another level of inquiry by changing the way the teacher presents the activity.

South African studies where teaching and learning in inquiry-based classrooms were examined included those by Rogan and Grayson (2003), Ramnarain and Hobden (2015) Akuma and Callaghan (2018); and Tsakeni (2019). Rogan and Grayson proposed a theory for curriculum implementation in developing countries such as South Africa. The theory took into account, amongst other things, the diversity of schools, the range in the knowledge and skills of mathematics and science teachers, and the lack of or inadequate resources for individual learners. They based the theory on three constructs, “Profile of Implementation”; “Capacity to Support Innovation”; and “Support from Outside Agencies” (p. 1180). One of the dimensions of the “Profile of Implementation” is the implementation of practical work, which was described in terms of four levels. These levels range from teacher-centred demonstrations (Level 1) to open-ended learner-centred investigations (Level 4). Teacher demonstrations and learner conducted cookbook-type practical work are both classified as

Level 2, implying that both activities involve the same level of complexity (Hattingh, et al., 2007). In this framework, teacher demonstrations and learners' procedural understandings such as reflecting on data collected are included. However, not all types of inquiry-based practical work activities are represented. Hattingh, et al., stated that this framework was developed to classify practical work done during the implementation of the outcomes-based learner-centred C2005 curriculum, which emphasised scientific investigations. The aforementioned four levels of practical work implementation described by Rogan and Grayson are:

- Level 1: The teacher uses demonstrations to develop concepts in a teacher-centred lesson. The learners are attentive and engaged
- Level 2: The teacher uses demonstrations to promote a limited form of inquiry and engages with learners to encourage deeper thinking. Some learners assist in planning and performing demonstrations. The learners are engaged in groups to conduct cookbook-type practical work and communicate data using graphs and tables
- Level 3: The teacher designed practical work is used to encourage learner "discovery" of information. The learners perform guided hands-on "discovery" type practical work in small groups. Learners complete a report write-up where conclusions are based on data collected
- Level 4: Learners design and conduct their own open-ended investigations. The teacher facilitates and assists learners. Learners write a scientific report in which they use the data collected to justify their conclusions. Rogan and Grayson, (2003)

In the following subsection, I describe the frameworks developed and used to classify inquiry-based practical work in the South African context. A framework for classifying specifically investigations was proposed by Ramnarain (2010). Investigations are a type inquiry activity that is used to answer an inquiry question, involves the testing of hypotheses, manipulating variables, takes place in stages. According to Ramnarain, investigations can be classified according to the openness or closeness of the activity. This classification framework for investigations was based on learner autonomy and teacher control at each stage of the investigation. A structured investigation offers the least autonomy for the learner where the teacher identifies the topic, formulates the question and plans the investigation, while the learner collects the data and draws the conclusion. In a guided investigation, the teacher selects the topic and formulates the question, and the learner has the autonomy to plan and conduct the investigation. In an open investigation, the learner has the most autonomy. Here, the teacher identifies the topic and the learner formulates the question, plans the investigation, collects the data, and states the conclusion. The teachers used a number of strategies to support learners depending on the stage of the investigation (Ramnarain & Hobden, 2015). This classification of investigations was developed during the implementation of the C2005

curriculum when investigations dominated practical work for the Natural Sciences subject (Grades 7 to 9). Akuma and Callaghan (2018) studied inquiry-based teaching practices in resource-constrained schools. Using the 5E Instructional Model (Bybee, et al., 2006), they studied the five phases of inquiry-based teaching practices, which are the “Engagement”; “Exploration”; “Explanation”; “Elaboration”; and “Evaluation” phases. They found that in the initiation, planning, and classroom implementation phases the teaching practices were inconsistent with inquiry-based teaching. In Akuma and Callaghan’s classification of practical work, they excluded Level 1 Confirmation Inquiry, claiming that it is teacher-driven and worksheet based. They claimed that the learning resulting from following a given method where the outcomes are known is superficial. Tsakeni, et al. (2019) adopted the four-level classification of inquiry in their study of practical work and expanded on Structured Inquiry to accommodate various combinations of teacher and learner roles. Other variations to the levels of inquiry included levels from Level 0 to Level 3 with similar descriptions as those outlined by Herron (Dudu & Vhurumuku, 2012).

Manipulative skills, process skills, and procedural understandings

Identifying the manipulative skills, process skills, and opportunities provided for procedural understandings in practical work lessons contribute to our understandings of the nature of the practical work. Manipulative skills relate to physical activities in the psychomotor domain, for example, learners handle and control equipment and materials, assemble apparatus, rectify instrument errors, and practice safety (Jenkins, 1999). In contrast to manipulative skills, process skills and procedural understandings are cognitive processes. Process skills reflect the methods of science and are those broadly transferable abilities that are either basic or complex integrated process skills (Padilla, 1990). Padilla listed basic process skills as observing, inferring, measuring, communicating, classifying, and predicting. Integrated process skills are controlling variables, defining operationally (stating how to measure a variable), formulating a hypothesis, interpreting data, designing an experiment, and formulating models. Padilla included experimenting as an integrated process skill. In this study, what Padilla referred to as experimenting was listed as “designing experiments” since experimenting is also a physical activity and that would make it a manipulative skill. Process skills can be taught and mastering complex process skills require learners practising them in different contexts (Millar, 2009). According to Gott and Duggan (1995), procedural understandings or procedural knowledge refer to the epistemological

“thinking behind the doing” or questioning decisions made (p. 26). Gott and Duggan differentiated between conceptual and procedural understandings. Conceptual understandings refer to understanding the ideas or substantive body of knowledge such as facts, laws, and theories. Procedural and conceptual understandings together make up the cognitive processes necessary for conducting practical work and are related but distinct processes (Roberts, Gott, & Glaesser, 2010). Gott and Duggan coined the phrase “concepts of evidence” to describe the following categories of procedural understandings: task design; measurement; data handling and evaluation of the task.

Framework to analyse the effectiveness of practical work activities

Practical work is any teaching or learning activity where learners at some point manipulate or observe real objects or materials. For practical work to be meaningful, learners must engage in the related conceptual activities that is the thinking behind the doing. Practical work helps learners learn substantial knowledge and content (learn science); skills (learn how to do science); and the nature of science (about science). Examining what learners do, think, or learn during a practical work activity will illustrate the characteristics of the practical work. The effectiveness of the practical tasks can be established by comparing the achievements of the learners with the teacher intended objectives. Miller (2009) argued that it is more useful to determine the effectiveness of specific tasks rather than the entire practical work activity.

The framework proposed by Millar et al. (1999) and elaborated in Millar’s map of practical work in the “Practical Activity Analysis Inventory” can be used to establish the effectiveness of each practical work task. Miller maintained that to establish the effectiveness, various aspects of the practical work task have to be examined, for example, whether the intended objectives for the tasks were achieved. The teacher intended objectives for the tasks are examined at two levels: what learners are intended to do during the tasks (Effectiveness Level 1) and what learners are intended to learn from the tasks (Effectiveness Level 2) (Figure 2.2) (Millar & Abrahams, 2009). The learners may not do or learn what the teacher intended. Thus, there is a need to establish what the learners actually did (relationship between box B and C) and learnt (relationship between box A and D) (Figure 2.2) during the practical work activity. Miller (2009) asserted that there may be various reasons for the learners not doing what the teacher intended such as they might not be able to understand the task; execute the procedure as intended; or the apparatus may be inadequate or faulty. Further, the learners

might not engage mentally with the task and hence not learn from it, as intended. To establish whether a task is effective, it is insufficient to determine only what learners do and learn from objects and observables but the cognitive activities associated with the doing that is the thinking needs to be established. Tiberghien (1999) described this as the linking of the domain of objects and observables with the domain of ideas.

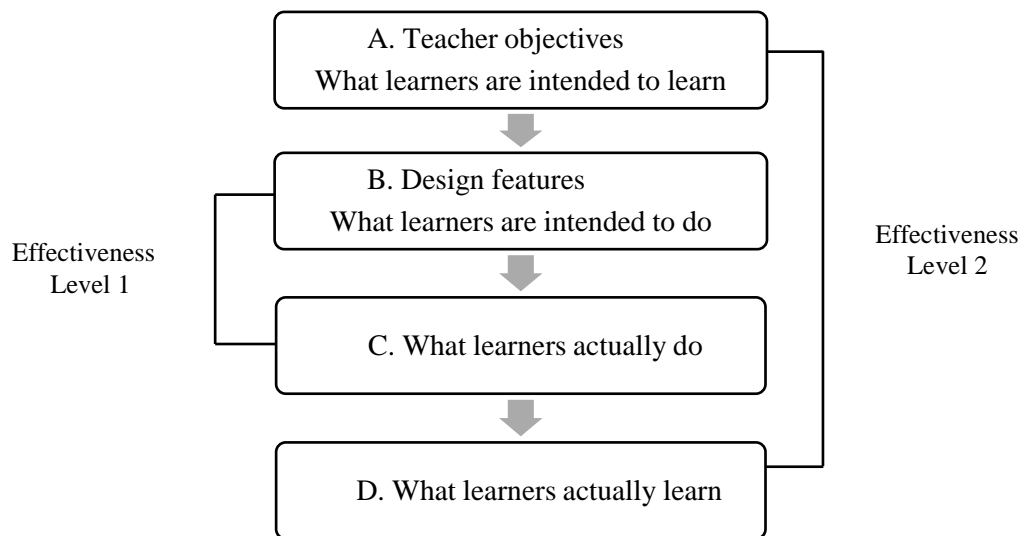


Figure 2.2 Levels of effectiveness of practical work tasks (Millar & Abrahams, 2009)

To establish the effectiveness of the practical work task, the Levels of Effectiveness (Figure 2.2) have to be considered in terms of the domains of objects and observables, and ideas (Table 2.2).

Table 2.2 Levels of Effectiveness of practical work tasks (Miller, 2009)

Practical activity is:	in the domain of objects and observables, when:	in the domain of ideas, when:
effective at Level 1	learners do what was intended with objects and materials, and observe as intended	learners think about what they are doing and observing
effective at Level 2	learners later recall and describe what they did and observed	learners discuss ideas on what they did and observed e.g. show understanding and application to other contexts

Miller (2009) concluded that the main purpose of practical work is to help learners make the links between two domains: “the domain of objects and observables (things we can see and handle) and the domain of ideas (which we cannot observe directly)” (p. 4). Miller’s map of practical work activities is comprehensive and considers the three identified purposes for practical work that are developing knowledge, learning skills, and learning about the nature of science. However, there is no mention of a fourth purpose for doing practical work that is motivation or interest, which has been reported by, for example, Hodson (1990).

2.7 Conclusion

In this chapter, I presented definitions and commonly articulated purposes for doing practical work to illustrate that there are still disagreements in the literature. The review of practical work implementation during three major international trends and during three curriculum policy periods in South Africa showed that there were differing findings on practical work implementation. Studies on CAPS practical work implementation have focused on specific aspects such as teacher perceptions, inquiry-based activities, and lack of resources. From the literature review, it was established that a definition of practical work that is relevant to the South African, is needed. In addition, teachers’ and subject advisors’ views on practical work and an understanding of how practical work is implemented in the context of high-stakes examinations is required. The conceptual frameworks making up the Interpretive Framework that guided this study were also presented. In the next chapter, I describe and justify the research design used in this study.

CHAPTER 3

THE RESEARCH STUDY

In Chapter 2, I provided the conceptual framework used and reviewed relevant literature to contextualise this study. The aim of this study was to determine the role of practical work in the teaching and learning of Physical Sciences in the context of high-stakes examinations. To achieve this, firstly the rationale for including practical work as part of the Physical Sciences CAPS curriculum had to be established. This required analysing the Physical Sciences CAPS policy document and ascertaining the teachers' and subject advisors' reasons for doing practical work. Secondly, the practical work lessons had to be observed and analysed to establish the nature of the practical work done. A qualitative research design was found to be most appropriate for the collection and analyses of the data in this study. In this chapter, I describe the research design, and methods used in this study. This includes descriptions and justifications for the selection of the research approach, the sample, data collection methods, data analyses, and the ethics considered.

3.1 The Research Design

Henning, van Rensburg, and Smit (2004), stated that it is the purpose of a study that should determine the nature of the inquiry. The purpose of this study was to establish the role of practical work in the teaching and learning of Physical Sciences in the context of high-stakes examinations. To answer the main focus research question, "What role does practical work play in the teaching and learning of Physical Sciences in the context of high-stakes examinations?" three focus areas were studied, namely the rationale for doing practical work, the nature of the practical work conducted, and why the practical work was done in particular ways.

The study of these focus areas was guided by the following three research questions:

- (1) Why is practical work part of the Physical Sciences CAPS curriculum?
- (2) What are the characteristics of the practical work done?
- (3) Why is practical work being done in particular ways?

Answering the above-mentioned research questions required analysing the Physical Sciences CAPS document, interviewing the participants, and observing the practical work conducted in Physical Sciences classrooms. Through an interpretivist paradigm, the participants, their interactions and socially constructed realities, as well as the phenomena peculiar to those classrooms could be studied and interpreted. One of the roles of research is “to make sense of (or interpret) the meanings others have of the world” (Cresswell, 2009, p. 8). In this study, answering the focus research question on the role of practical work required interpreting participants’ views on practical work and their experiences of doing practical work. In interpretivism, intentional individual behaviour has meaning and research tries to understand how these individuals interpret the world around them (Cohen, Manion, & Morrison, 2018). According to Cohen, et al., and Cresswell, through an interpretivist paradigm, inquiry is not value-free and the researcher’s values may influence the research. This meant that I had to be aware of my own biases, especially when interpreting the data analysed. There are assumptions inherent in an interpretivist research paradigm and these had to be considered in the selection of the research design. Further, through an interpretivist paradigm, observation as a human construct is fallible and open to error and all theory is revisable (Gallagher & Tobin, 1991; Henning, et al., 2004). Hence, the research design of this study had to include multiple methods of data collection for triangulation of the data.

In an interpretivist paradigm where reality is socially constructed and the way the participants make meaning needs to be understood, a qualitative research design is most appropriate because it enables the use of research questions to explore, interpret, and understand the social context (Henning, et al., 2004). In addition, through a qualitative research design, multiple sources of data such as documents, interviews, and observations can be used to provide insights into the multiple realities and meanings constructed (Leedy & Ormrod, 1993). According to Henning, et al., another strength of a qualitative research design was that patterns, categories, and themes are able to emerge from the data rather than being imposed on the data collected. To determine the teachers’ and subject advisors’ views on the

aims practical work and reasons for including it in the curriculum, qualitative research methods such as interviews allowed in-depth inquiry. Establishing the characteristics of the practical work done required direct observations of phenomena in the natural context of the classroom could be done. Observing social phenomena in natural settings such as classrooms was possible because in qualitative research, the contexts and how it influences the participants' making of meaning, is a focus (Henning, et al., 2004). From a constructivist perspective people construct meaning in multiple ways in different contexts (Cresswell, 2009). Learning in social constructivism is the social process of making sense of the world through interacting with objects and events such as those found in practical work lessons (Tobin, et al., 1994). In this study, the learners were interviewed to understand the meanings they constructed from their experiences with practical work. One of the strengths of a constructivist framework is that it can be used to analyse the learning potential of a lesson (Tobin, et al., 1994). The learning potential of a lesson however, is multifaceted where the visual representations provided by, for example practical work is just one aspect of the complex processes involved in learning. Establishing the conceptual change that is associated with learning is complex and was beyond the scope of this study. Although not the primary focus of this study, using social cognitive theory an attempt was made to understand whether or how practical work motivated learners.

3.2 The Sample

In this section, I explain how the schools were selected, describe the teachers, subject advisors, and the learners interviewed, describe the lessons observed, and discuss the representativeness of the sample.

3.2.1 Selection of the schools

Qualitative research is concerned with the in-depth understanding of smaller samples that are purposively selected (Hesse-Biber & Leavy, 2011). Cresswell (2009) stated that qualitative researchers often purposively select their participants and sites in a way that best helps to understand the problem and seek answers to the research questions, which in this study was to establish the role or practical work in the teaching and learning of Physical Sciences in the context of high-stakes examinations. Operationally defining the population

under investigation on the outset is essential for ensuring that the sample is representative of the population and that the appropriate participants for the research inquiry are selected (Drew, Hardman, & Hosp, 2008). In addition, without clearly defining the characteristics of the population, it will be unclear whether or to whom the results could be generalised. Drew, Hardman, and Hosp defined a population as “all constituents of any clearly described group of people, events, or objects who are the focus of an investigation” (p. 83). They stress that the population must relate to the topic of the study. This study was concerned with practical work implementation in schools that had the minimum required resources. Hence, resource constrained schools were excluded from the study population. Drew, Hardman, and Hosp refer to such exclusions as the restrictions in the defined population. In this study, the population consisted of secondary schools from the Pinetown and Umlazi Education Districts in Durban, in the KwaZulu-Natal province of South Africa that had the opportunity to conduct Grades 10 to 12 Physical Sciences practical work because they had science equipment and/or science laboratory space, and a Physical Sciences teacher.

While the population is the entire group that the researcher wants to draw conclusions about, the sample is a sub-set of the population from which the researcher will collect the data (Leedy & Ormrod, 1993). Purposive sampling can be used to select the sample, which has characteristics of the population, and for an exploratory study allows for studying a specific context (Neuman, 1991). The sample consisted of schools where, according to the teachers, Physical Sciences practical work was routinely conducted, that is a minimum of three times a year in Grade 12 and a minimum of two times a year in each of Grades 10 and 11, according to the requirements outlined in the Physical Sciences CAPS curriculum (Department of Basic Education, 2011). Hence, the sample was representative of schools that do practical work and not of all schools. Other sampling criteria included schools within travelling distance; familiarity with the school geographical location; and schools where the teachers were willing to participate in the study. In addition, both public and independent schools were included in the sample. Forty-two schools within travelling distance that had science equipment and where the teachers claimed to do practical work as prescribed in the Physical Sciences CAPS curriculum were initially identified. These schools were located in the Durban area in the KwaZulu-Natal province, specifically the Pinetown and Umlazi Districts. The Pinetown and Umlazi Districts are predominantly urban and semi-urban in nature (KwaZulu-Natal Provincial Treasury, 2010). The forty-two schools within travelling distance were either

public or independent schools, and located in either urban or semi-urban areas of the Pinetown and Umlazi Districts. According to the KwaZulu-Natal Provincial Treasury, the afore-mentioned urban and semi-urban areas in this study are typical of other areas in KwaZulu-Natal and South Africa. As a result, a restriction in the sample was the exclusion of schools from rural areas. According to Gardiner (2008) there are several definitions of rural areas making the identification of rural schools complicated. In the Rural Education Draft Policy (2017), rural areas are defined as farms and traditional areas characterised by low population densities and low levels of economic activity and infrastructure. Schools are often referred to in terms of the Quintile index that is the poverty rating of its geographical location. A Quintile one school may be located in the poorest area but this area may not be rural as defined in the Rural Education Draft Policy. Given this ambiguity, I opted to continue with the sample of schools that were from areas classified as cities, towns, or townships.

Permission was sought from the Department of Education: KwaZulu-Natal to conduct research in schools from the Pinetown and Umlazi Districts (Appendix A). A letter was sent to the Principals seeking permission to conduct the research at their schools (Appendix B). This letter explained the nature and significance of the research study, expectations of the teachers, and a commitment to not disrupt teaching and learning at the school. Of the 42 identified schools, Physical Science teachers and/or Principals from 15 schools agreed to participate in the study (Appendix C). The 15 sampled schools consisted of previously racially segregated public schools as follows: four (ex-White) schools from urban residential and city areas; three (ex-African) schools located in semi-urban residential township areas; and seven (ex-Indian) schools located in urban residential and city areas, as well as one independent school from an urban residential area. The rationale for selecting schools from previously racially segregated schools was that given the history of unequal funding for schools, the levels of resourcing usually differed. Including schools from all previously racially segregated schools ensured a representative sample with a good cross section of schools ranging from those that were well resourced to those schools that had the required minimum resources to conduct Physical Sciences practical work. In summary, the final sample of 15 schools studied was located in urban or semi-urban areas in the Pinetown and Umlazi Districts in the Durban area of KwaZulu-Natal and were representative of previously racially segregated schools. In addition, the sample of 15 schools had the minimum required

resources to conduct practical work routinely, according to the requirements outlined in the Physical Sciences CAPS curriculum document.

3.2.2 The teachers, subject advisors and learners interviewed

From the sample of 15 schools, 24 teachers who indicated they used practical work to teach Physical Sciences routinely, agreed to be interviewed (Appendix C). Additional interviews were not sought because data saturation was reached with the 24 interviews that is no new data were forthcoming from additional interviews and the teacher responses became similar. Their teaching experiences were as follows: eight teachers with less than 10 years, 15 teachers ranging from 11 to 29 years, and one teacher had 30 years of teaching experience. A laboratory assistant with 35 year's work experience also agreed to be interviewed. Teaching experience was not a sampling criterion but was noted to observe if any patterns emerged between teaching experience and teachers' views on practical work or the characteristics of the practical work conducted. Of the four subject advisors who agreed to be interviewed, two worked with schools from the Pinetown and Umlazi Districts and the other two worked in other Districts. Of the 24 teachers interviewed, over a two-year period, nine teachers agreed for me to observe their lessons. Three of these teachers had less than 10 years' experience with one teacher each from an ex-African township school, an ex-White urban school, and an ex-Indian urban school. One teacher had 12 years of experience and taught at an ex-Indian urban school. Five teachers had between 21 and 25 years' experience and taught at ex-Indian and ex-White urban schools. The nine lessons were observed until data saturation was reached. The lesson observations were followed by interviews of 15 randomly selected learners to determine their experiences of the nine practical work lessons (Appendix C). I actively tried to generate more opportunities to interview additional learners but was frustrated by constraints of not disturbing other lessons and the after school schedules of the learners. The learners had to attend other lessons or after school extra-curricular activities, or had to travel home using public transport. It was also for this reason that the learner interviews were not lengthy but lasted a maximum of 15 minutes.

Getting teachers to participate in the interviews and gaining access to observe the Physical Sciences practical work lessons were difficult. It appeared that most teachers, who did not respond to several emails, telephone calls, and messages appealing to them to participate in the study, were reluctant to participate in the study. A few of the teachers who

finally agreed to participate in the study did so when appeals were made to their Principals. The teachers also determined which practical work lessons were to be observed. Teachers who refused to participate in the study were questioned about their reasons. The two common reasons provided by the teachers were that they were not doing any practical work or they had already done the prescribed practical work for the term. Some of the teachers mentioned that they had forgotten to invite me to their practical work lessons and a few teachers mentioned that they had changed the dates and forgot to inform me. Two Grade 12 teachers mentioned that they were focusing on completing the syllabus and not on the practical work. Two curriculum writers were approached to be interviewed about their reasons for including practical work in the Physical Sciences CAPS curriculum. Both curriculum writers declined to participate in the study. Their reasons for non-participation included being too busy, being conflicted about being a government employee discussing a government document, and not remembering what their contributions were when writing the curriculum document. The study findings would have been enhanced if they had provided more context to the curriculum. Overall, it was difficult to get teachers to participate in the study and even more difficult to gain access to observe practical work lessons. Some possible reasons for this reluctance could be an indication that teachers were not comfortable with their practical work lessons being observed or they feared that their teaching would be judged or they were not confident about how they were conducting practical work, or they did not conduct practical work according to the curriculum requirements. However, I was satisfied that although the sampling was purposive, the schools in the study were representative of a cross section of the population of urban and semi-urban schools in KwaZulu-Natal and similar schools in South Africa, that have the opportunity and means to do practical work, have a Physical Sciences teacher, and follow the same curriculum.

3.2.3 The lessons observed

In this study, practical work is defined as those hands-on and minds-on activities where learners are actively engaged, manipulating real objects or observing teacher demonstrations, and does not include virtual activities. Practical work activities in the Physical Sciences CAPS curriculum document are listed as experiments, investigations, or demonstrations. To avoid influencing teachers' definitions of practical work and beliefs about the aims of practical work, they were requested to invite me to their practical work lessons without me specifying the type of activity. Of the nine practical work lessons observed, the teacher demonstrated

four practical work lessons with varying degrees of learner involvement. Initially, I aimed to observe only prescribed practical work because it was compulsory for assessment purposes. There are seven prescribed practical work activities and 21 recommended practical work activities listed for Grades 10 to 12 in the Physical Sciences CAPS document (Appendix D). I observed the following nine practical work lessons over a two-year period: three prescribed and one recommended Grade 10; three prescribed and one recommended Grade 11 practical work; and one Grade 12 prescribed practical work lesson. A summary of the practical work lessons observed is provided in Table 3.1 and details of the schools, practical work lessons, teachers, and learners interviewed are provided in Appendix C. Grade 12 lessons were mostly avoided because of the typical pressures teachers and learners experience with the final year of schooling. Requesting to observe prescribed practical work activities limited the number of practical work lessons that could be studied. Teachers following the same Department of Education provincial work plan resulted in the practical work activities being conducted at similar times, reducing the number of lessons that could be observed by myself. The refusal by most teachers for me to observe their practical work lessons, observing mostly prescribed practical work lessons, and lessons being taught around the same time, compelled me to complete the lesson observations over two years.

Table 3.1 The practical work lessons observed

School	Teacher	Title of Practical	Prescribed or Recommended	Grade
School C	Vish	Titration: To investigate how to use an acid-base reaction to determine the concentration of a solution	Prescribed	11
School D	Bongi	Verify Boyle's Law	Recommended	11
School F	Eric	Electrical Circuits: division of potential across series resistors and parallel resistors	Prescribed	10
School F	John	Effect of Intermolecular Forces on Evaporation	Prescribed	11
School G	Sarah	Evaporation, Solubility, Capillarity	Prescribed	11
School G	Jen	Series and Parallel Circuits	Prescribed	10
School I	Betty	Precipitates	Recommended	10
School L	Lenny	Law of Conservation of Linear Momentum	Prescribed	12
School N	Jiten	The Heating and Cooling Curve of Water	Prescribed	10

3.2.4 Representativeness of the sample and generalisations made

In this study, the population consisted of secondary schools from the Pinetown and Umlazi Education Districts in Durban, in the KwaZulu-Natal province of South Africa that had the opportunity to do practical work because they had the minimum resources and a Physical Sciences teacher. The criteria for selecting the sample were schools where practical work was routinely done as per requirements in the Physical Sciences CAPS document; schools with teachers that were willing to participate in the study; and schools that were within travelling distance and were in a familiar geographical location. This sample was not representative of the larger population of schools in KwaZulu-Natal or South Africa and I did not seek to make generalisations about the teaching and learning of practical work. Creswell (2009, p. 193) states that particularity rather than generalisability is the hallmark of qualitative research where the value of such research lies in specific descriptions and themes emerging from specific sites and contexts. Small non-representative samples that are typical of qualitative research do not allow for statistical generalisations but rather for analytical generalisations where the scale is sacrificed for depth (Hesse-Biber & Leavy, 2011). However, while the primary focus of this study was not to make generalisations, attempts were made to find points of generalisability that may be applicable to other identifiable, similar settings of practical work implementation in similar types of schools in KwaZulu-Natal and South Africa.

3.3 Data Collection Methods and Instruments

In studies located in an interpretivist paradigm, a qualitative research design is most appropriate to understand social contexts (Henning, et al., 2004) through multiple data collection methods such as document analyses, interviews, and observations to enable insights into multiple realities and meanings constructed (Leedy & Ormrod, 1993). In this study, the multiple data collection methods were interviews, observations, and document analyses. To answer the first research question on the aims of practical work, the data were collected through in-person teacher and subject advisor interviews and analyses of the Physical Sciences CAPS document. The data collection methods to answer the second research question on the characteristics and types of practical work done were observations of practical work, analyses of learner worksheets, and learner interviews. Prior to the lesson observations,

the teachers were interviewed telephonically to establish their intended objectives for the lessons. A synthesis of the data obtained from the first and second research questions were used to answer the third research question on why practical work was conducted in particular ways. The data collection instruments were semi-structured interview schedules and analytical frameworks. In Table 3.2, a summary of the data collection methods and instruments used to answer each of the research questions is provided.

Table 3.2 Research Questions, Methods, and Instruments

Research Question	Focus	Method	Research Instrument
1. Why is practical work part of the Physical Sciences curriculum?	‘Why’ practical work is done. Nature, purposes and aims of practical work	Teacher and subject advisor interviews Analysis of CAPS policy document	Semi-structured interview schedules Document analysis: Instruments to identify procedural understanding; process skills
2. What are the characteristics of the practical work done?	The ‘what and how’ of the practical work: The nature and effectiveness of practical work done	Pre-practical and post-practical work teacher and learner interviews Lesson observations	Semi-structured interview schedules Instruments to identify type of practical work; procedural understanding; process skills Lesson Observation Framework
3. Why is practical work done in particular ways?	The ‘why’: Reasons practical work done in particular ways	Synthesis of first two research questions	Interpretation by Researcher

I attempted to include multiple sources of data that are interviews, observations, and document analyses to establish the rationale for including practical work in the Physical Sciences CAPS curriculum and to determine the characteristics of the practical work done.

3.3.1 Refining the data collection instruments

Two teachers (Grade 10 and 11) were interviewed in the pilot study. The pilot interviews were audiotaped, transcribed, and then analysed. It was found that the interview questions did not follow a logical order and as a result, the interviews did not flow well. The questions were then grouped into six focal areas that are general questions about the teacher; the aims and purposes for doing practical work; examinations; benefits of practical work; how practical work was being done; and how practical work should be done. Some questions were found to be too lengthy, for example, an excerpt from the CAPS document on the aims of

practical work was read, and teachers and subject advisors were asked if they achieved these aims in their lessons. This excerpt was excluded from the original interview schedule and the teachers were asked about the aims of the practical work they conducted, and thereafter about the aims of practical work as indicated the CAPS document. There were a few irrelevant questions such as how practical work is generally taught at their schools. The teachers tended to provide lengthy answers on how other teachers conducted or failed to teach practical work rather than reflecting on their own practice. Additional direct questions needed to be added, for example, when asked about their beliefs about the aims of practical work, a follow-up question on where they read or heard about this was added. The interview questions were also checked to see if they were open-ended and not suggestive of answers, for example, the question, “It is commonly believed that practical work helps learners perform better in examinations ...” had to be changed to, “Does practical work influence learner performance in examinations? Why do you think so?” The testing of the semi-structured interview schedules gave me a sense of the interviewing process, how to manage the interviews, and the importance of listening during an interview. Gillham (2000) explained that the piloting process will highlight redundant questions and those that need reviewing. In the pilot study, I was also able to refine the questions in the interview schedules to ensure that the first research question on the rationale for doing practical work was being addressed, specifically the teachers’ and subject advisors’ views on the aims and purposes for doing practical work.

In the pilot study, two practical work lessons were observed. The practical work activity “Measuring potential difference” was taught as a teacher demonstration and learners in groups conducted the practical on the “Relationship between force and acceleration”. The notes from the lesson observations were crosschecked with the videotape recordings for accuracy. It was noted that there were aspects of the lessons that needed to be observed more closely. These were the nature of the learner engagement and teacher questioning during the teacher demonstrations; learner interactions during data collection in the group; and how the teachers incorporated theory in the practical work lessons. The pilot of the observation schedule revealed that it did not include items on the context of the lessons such as the setting or type of practical work and items on motivation and assessment, which were mentioned during the teacher and subject advisor interviews. The section on the relationships between objects, observations, and ideas were not clear and needed to be reworded. Several items in each of the sections needed to be regrouped for ease of reference, and the format made user friendly.

Initially, the teachers' voices captured in the video recordings were not audible because the videotape recorder was placed at the back of the laboratory. A cellular phone was then placed on the teachers' desk to record the teacher's voice. The pilot study was valuable because I could become familiar with the data collection methods and refine the instruments.

3.3.2 The interviews and the interview schedules

A qualitative research design enabled me to use interviews to understand the perspectives and experiences of the participants. The data collection began with teacher and subject advisor interviews to establish their definitions of and reasons for doing practical work. According to Gillham (2000) an interview is a conversation between two or more people where the interviewer seeks responses for a particular purpose from the interviewees. Kvale (2009) expanded on this, stating that powerful knowledge is constructed during this conversation. In qualitative research, unequal power relations may arise from the data collection itself, for example from observations and interviews (Henning, et al., 2004). I was aware of the potential unequal power relations that may arise from me, the researcher, being an official in the Department of Education. The teachers and subject advisors were informed that the research study was not an evaluation of them or their work and the data collected would be used solely for the purposes of this study. Regarding the observations, I tried to remain inconspicuous and unobtrusive. However, this was not always possible because I had to interact with the learners during the lessons. Interviewing, on the other hand, is by its very nature a process that takes place between people who are unequal in power. Henning et al. stated that "a planned interview is not a free, naturally occurring conversation" but is a "contrived social interaction" (p. 66). My awareness of the inherent unequal power relations in interviews prompted me to revisit the questions and opt for a semi-structured interview. The semi-structured interview enabled me to have a dialogue in a conversation and allowed the interviewees to express themselves freely rather than me rigidly sticking to a script. Understandings of how the interviewer's control and authority may influence the outcomes of the interviews made me more self-aware of my questioning style. I began the interviews with informal questions in a friendly conversational tone so that interviewees could share their thoughts and opinions without much inhibition. Also, the interviewees selected the locations for the interviews. During the interviews, I intervened strategically to ensure that the interviewees answered the questions and did not provide the "right" answers. In interviews it is not only what the interviewees say but how they say it and what they omit that is important

(Henning, et al., 2004). Hence, some of the interview questions were designed to be deliberately indirect, for example, “Why do teachers do practical work?” followed by, “What do you think is the reason for doing practical work?” and “Is it important to do practical work and if yes, why?” Tuckman in Cohen et al. (2005) stated that indirect questions are more likely to produce frank responses. The flexibility of the open-ended questions in the semi-structured interview schedules enabled the rephrasing of questions to check for accuracy and consistency in the answers (Cohen, et al., 2005; Harding, 2013). Through follow-up questions, the interviewees could justify their responses. The closure of the interviews included a summary of the responses to validate whether I understood the responses correctly; thanking the interviewees; and appealing to the teachers to permit me to observe their next practical work lesson.

Kvale (2009) described translation as the process where the academic research questions give rise to groups of thematic interview questions that are structured in everyday conversation language. The teacher interview questions (Appendix E1) were grouped into focus areas, for example, introductions, general questions, definitions, aims, benefit, purposes, frequency and type of practical work taught, and challenges experienced. The questions in the subject advisor interview schedule (Appendix E2) were similar to those in the teacher interview schedule, except for the last section that focused on the frequency, type, and the way practical work was being done in schools with science equipment, how practical work was assessed, and challenges experienced. Prior to the lesson observations, the teachers were contacted telephonically to confirm the date, time, title of the practical work, and the objectives of their lesson. The teachers and learners were interviewed after the lessons were observed (Appendix E3). The learner interviews focused on their experiences, the importance of practical work, questions on their understandings of the activity, and their preferences for learning practical work. I questioned teachers on whether their objectives were achieved; why they conducted the practical work in particular ways; possible learner benefits; and how the practical work would be assessed. All in-person teacher, subject advisor, and learner interviews were audiotaped, except for one teacher interview. Apart from stating that she was not comfortable with the interview being audiotaped, no other reasons were forthcoming. I wrote brief notes during the interviews, particularly critical statements made by the interviewees. Using a structured approach, I was confident that the interviews yielded consistent and useful data.

3.3.3 The lessons observed and the observation schedules

Observations, according to Cohen, Manion, and Morrison (2018) enable the researcher to gather data on the research setting, interactions between participants, and critical incidents. Cohen et al. refer to critical incidents as being non-routine but very revealing, offering the researcher insights that otherwise would not be available routinely. Critical incidents observed were noted. Lesson observations were the primary source of data to answer the second research question on the characteristics of practical work done. From the sample of 15 schools in this study (Appendix C), teachers from seven schools granted me access to observe nine one-hour practical work lessons (Table 3.1). Permission was obtained from the teachers to videotape the lessons. Harding (2013) cautioned against solely using observations to collect data, citing an example where the participants may change their behaviour in the presence of an observer and recommended the use of additional data collection methods such as interviews. In this study, issues that arose from the lessons observed were clarified with the teachers and the learners in the post-practical interviews (Appendix E3). Data on the characteristics of the practical work observed were collected using four instruments that are the instruments to classify the type of practical work observed; to identify opportunities for learners to develop procedural understandings; to identify process skills; and a framework to determine the effectiveness of the practical work tasks observed.

The first lesson observation instrument was developed to classify the types of practical work observed (Appendix F). The classification system for identifying the types of practical work was synthesised from various classification frameworks found in the literature, my own experiences of observing practical work lessons, and from teachers' and colleagues' anecdotal reports of practical work implementation. The intention was to produce a classification that was simple, practical, and relevant for South African classrooms. The classification frameworks reviewed from the literature were those proposed by Rogan and Grayson (2003) for developing countries; the classification of investigations by Fitzgerald, et al. (2019) based on the classification proposed by Herron; and the classification of investigations by Ramnarain and Hobden (2015). In the afore-mentioned classification frameworks, various levels of inquiry-type activities including investigations were accommodated, based on the openness of the activities and the range of learner autonomy. However, most of these classification frameworks did not account for two types of practical work found to be

prominent in South African classrooms which are teacher-conducted investigations (Rogan & Grayson, 2003) and learners conducting cookbook type exercises (Hattingh, et al., 2007).

To classify the types of practical work, I considered the theory of curriculum implementation for developing countries developed by Rogan and Grayson (2003). Based on this theory and my own experiences, I opted for a framework that included investigations, teacher-centred practical work and cookbook-type practical work, which was not limited to inquiry-type practical work (Table 3.3). In teacher conducted practical work, the teacher completes all activities and the learners observe. Learners conducting cookbook exercises follow the steps of a given method to collect data and obtain expected results. Unlike investigations, cookbook type exercises do not include an investigative question or involve manipulating variables. In addition, four types of investigations based on the teacher and learners' roles during each of the six commonly found stages of investigations, were included. These stages are determining the topic; formulating the question; collecting and analysing data; and proposing a solution. The learner autonomy increases from Confirmation to Learner-initiated investigations and at each stage, specific aspects of the investigation may be unknown to the learner. A description of each type of investigation is provided below and the instrument to identify the different types of practical work is summarised in Table 3.3.

Four types of investigation-type practical work were included in the classification system adopted:

<i>Confirmation investigation:</i>	The teacher provides the question and method. The learners collect and analyse the data (learner hands-on and minds-on). Solution is known and provided by the teacher and/or learner
<i>Structured investigation:</i>	The teacher provides the question and method. The learners collect and analyse the data (learner hands-on and minds-on). Solution is unknown to the learner and is provided by the learner from the data collected
<i>Guided investigation:</i>	The teacher provides the question. Learners devise procedure; collect and analyse the data (learner hands-on and minds-on). Solution is unknown to the learner and provided by the learner from the data collected
<i>Learner-initiated investigation:</i>	Learners are responsible for all stages of the investigation from selecting the topic to finalising the conclusion (learner hands-on and minds-on). Solution is unknown to the learner and provided by the learner from the data collected

In Table 3.3 the roles of the teachers and learners at each stage of the activity are indicated, although in practice there may be variations. It is also indicated whether the activities are hands-on and/or minds-on for both the teachers and the learners.

Table 3.3 Classifying the type of practical work

		Role of Teacher and Learners at each stage of activity					
		Topic	Question	Method	Collect data	Analyse data	Solution / Conclusion
Type of Practical Work: Investigations							
Confirmation Investigation	L hands-on L minds-on	T	T	T	L	L	Known to L
Structured Investigation	L hands-on L minds-on	T	T	T	L	L	Unknown to L
Guided Investigation	L hands-on L minds-on	T	T	L	L	L	Unknown to L
Learner-initiated Investigation	L hands-on L minds-on	L	L	L	L	L	Unknown to L
Type of Practical Work: Teacher conducted activity							
	T hands-on T minds-on	T	T	T	T	T	Known or unknown to L
Type of Practical Work: Cookbook exercises							
	L hands-on	T		T	L	L	Known to L

T: Teacher L: Learner

The second lesson observation instrument (Appendix G) to identify the opportunities provided for learners to develop procedural understandings in the CAPS curriculum document and the lessons observed, was the classification provided by Gott and Duggan (1995). The procedural understandings were grouped into those associated with the design (variables, fair test, sample size), the measurement (scale, range intervals, choice of instruments, repeatability, accuracy), data handling (choice of tables, graphs, patterns), and evaluation (reliability, validity) of the practical activity. The third lesson observation instrument (Appendix H), to identify the process skills mentioned in the CAPS document and in the lessons observed, was the classification of process skills provided by Padilla (1990). Padilla distinguished between basic and integrated process skills. Basic process skills are: observing (using the senses to gather information); inferring (making a guess about an object or event

based on previous information); describing measurements (describing the dimensions of an object using measurements); and communicating (using words or graphics to describe an action, object or event).

The fourth lesson observation instrument was the Lesson Observation Framework (Appendix H) and this was used to collect data on the teacher intended objectives and what was actually achieved by the learners, in terms of objects, observables, and ideas. The Lesson Observation Framework instrument (Appendix H) contained pre-determined items based on the “map” of practical work tasks proposed by Miller (2009). Given that the time allocated for practical work lessons was limited to one hour, a structured observation instrument with predetermined categories and items was required. The “map” proposed by Miller was simplified and additional items were added to collect data on the teacher aims for the lesson; learner involvement and interactions; learner assessment; and observations on learner motivation. An item on teacher demonstrations was added and this was based on the finding by Rogan and Grayson (2003) that in countries such as South Africa demonstrations were prevalent. The item added was, “Describe/explain observations made from the teacher/learner manipulating objects & materials”. Using the instrument, the intended versus actual achieved for the following three parts of the lessons could be captured:

- Section A: Teacher aims and objectives for the lesson
- Section B: What learners did with objects, observables, and ideas
- Section C: Degree of openness and closeness. Learner involvement and interactions.
Motivation and other observations

In Section A, the teachers’ aims and objectives are captured before the lesson commences. This section captures what the teachers intended for learners to do with objects, observables, and ideas and what was actually achieved in the lessons. An excerpt of Section B of the Lesson Observation Framework instrument is illustrated in Figure 3.1. Section B captures what the teachers intended for learners to do with objects, observables, and ideas and what was actually achieved in the lessons. In Section C, teacher and learner involvement and interactions are captured. Due to limited space, in Figure 3.1 only two practical work lessons are shown. If the learners did with objects, observables, and ideas, as intended by the teacher then the teacher was successful at Effectiveness Level 1 (Figure 2.2). According to Millar and Abrahams (2009), determining achievements at Effectiveness Level 2 that is learning from the objects, observables, and ideas as intended by the teacher is complex, “often involving unobservable entities” (p. 60). Moreover, this required repeated observations, which meant

further disruptions to teaching and learning. Additionally, assessments of the learning had to be conducted after lengthy periods to establish if, for example learners could recall and apply what was learnt during the practical activity. Attempts to establish learning at Effectiveness Level 2 was difficult and time-consuming and it was for these reasons that I confined the study to establishing if learners did as intended with objects, observables, and ideas at Effectiveness Level 1.

SECTION B: Intended vs actual objectives: What learners did with objects, observables, and ideas

B1: OBJECTS / OBSERVABLES		Heating & Cooling Curve		Titration	
<i>Did learners do with and/or observe objects and materials as was intended?</i>		I	A	I	A
Use instrument/device/apparatus/equipment to measure/collect data					
Follow a method or procedure					
Make an event occur					
Make/present an object/material					
Observe material, event, or quantity from manipulating objects & materials					
Observe material, event, or quantity from the teacher manipulating objects & materials					
Manipulate objects					
B2: IDEAS		Heating & Cooling Curve		Titration	
<i>Did learners think/discuss/explain what they were doing and observing?</i>		I	A	I	A
Describe/explain observations made from manipulating objects & materials					
Describe/explain observations made from the teacher manipulating objects & materials					
Design a procedure or method					
Make a prediction from a Guess/Hypothesis or Law/Theory					
Test a prediction					
Explore relations between objects					
Explore relationships between variables					
Explore relations between objects and variables					
Identify a pattern					
Determine a value which is not measured directly					
Account for an observation/finding using given/known explanation					
Account for an observation/finding by proposing a new explanation					
Report on Observations made					
I = Intended		A = Actual			

Figure 3.1 Section B: Lesson Observation Framework instrument (excerpt)

Miller, Le Marechal and Tiberghien (1999) asserted that the learners should not only have to be successful at doing and learning with objects, observables, and ideas as intended by the teacher but they have to make the links between objects and observables, and ideas. By establishing links between the domain of objects and observables with the domain of ideas it can be determined whether the learners were thinking about what they were doing and learning (Table 2.2). As indicated in the previous paragraphs, given the complexity associated

with establishing any learnings from specific practical work tasks, I studied the links made between the domain of objects and observables, and the domain of ideas; only in terms of what learners did and not what they learnt.

3.3.4 Document analyses

The nature of practical work in the Physical Sciences CAPS curriculum policy document were determined using instruments discussed in the Section 3.3.3 The lessons observed and the observation schedules. Using instruments identified in the literature, the CAPS document was analysed to establish mentions of procedural understandings (Appendix G) and process skills (Appendix H). Learner worksheets used in the lessons were also analysed. The purpose, structure, and content of the learner worksheets (Appendices 5.1.1 to 5.1.8) were analysed to establish the nature of the information given to learners.

3.4 Data Transformation and Analyses

Data collected from the interviews and lesson observations were transcribed to look for trends, patterns, and themes. Once the data showed recurring patterns and no new themes emerged, the data collection ended because data saturation was reached. This was referred to by Neuman (1991) as adequacy where data saturation occurs when there is no new information and adequate data has been collected. After each lesson observed, the data collected were transcribed and analysed before observing the next lesson. This enabled me to focus on particular aspects and gaps in the lessons that followed and to check for data saturation. This, together with the limited number of prescribed practical work lessons available to observe and difficulties with gaining access to the lessons, resulted in the lesson observations taking place over two years.

The audiotapes of the interviews were transcribed after each interview session. This gave me an opportunity to start thinking about the data, look for gaps, and note critical incidents. Cohen et al. (2005) cautioned against data loss, distortion of data, and fragmenting of data during the transcribing process. To prevent data loss and distortion of the data, the transcripts were read and the audio recordings were listened to several times to check for

accuracy and whether any social aspects of the interview were lost during the transcribing. To avoid fragmenting the data that may distort the holistic essence of the interview, each interview transcript was read in totality and a short description was made of the salient issues that arose during the interview. Similarly, the narratives emerging from the lessons observed and critical incidents were noted. Themes, patterns, and outliers from the interview transcripts and observations made were recorded in tables and texts. An excerpt of notes made on motivation and assessment from initial readings of the transcripts is given in Appendix J. The analyses of the data were the most time-consuming and intense part of the data gathering exercise. The data analyses required several periods of “stepping away” from the data and then to enter the analyses with a fresh perspective. According to Neuman (1991) a qualitative researcher analyses data by organising it into categories on the basis of themes. Gillham (2000) stated that these categories need to be exhaustive that is cover all the data, including redundant data without overlaps. Neuman noted that data analysis is not a “clerical data management task” but an important part of data interpretation (p. 460).

The transcribed interviews were organised and analysed using *NVivo* software. The transcribed texts were imported into *NVivo* and coded using nodes. This coding process involved the assigning of nodes to words or sentences or segments of text. This allowed for the condensing of data into analysable segments with the intention of generating themes (Hesse-Biber & Leavy, 2011). Specifically, Neuman’s (1991) three-step process to code data was used. Firstly, during open coding pre-determined nodes and themes from the literature and the research questions were used (Abrahams, 2011; Millar, 2004; Millar, et al., 1999). These initial nodes were assigned to the phrases in the transcripts imported into *NVivo*. The themes that emerged from these nodes were at a low level of abstraction because it was based on the research questions and the literature only. Thereafter, nodes that emerged from the data were included, for example, the type of learner (success of practical work done depends on the ability of learners). In the second stage of coding, termed axial coding by Neuman, I reviewed and corrected the initial nodes where there were duplicates and several child nodes had to be grouped into parent nodes (Appendix K). The third step, selective coding, was completed after the nodes were consolidated. This involved scanning all the data and identified nodes to look for outliers. The nodes were then clustered into themes such as “generates interest”. The interpretation of the data did not follow the transformation and analyses of the data sequentially but was an iterative process. In this study, given the varied

and numerous ways in which meaning could be constructed, during data analyses and interpretation, consideration was given to the complexities of, rather than the narrowing of meanings into a few predetermined categories of themes (Hesse-Biber & Leavy, 2011).

3.5 Achieving Validity and Reliability

“If a piece of research is invalid then it is worthless” (Cohen, et al., 2005, p. 105). According to Cohen, et al., validity is achieved through the depth, richness, scope of the data, and triangulation done. Validity, that is, the accuracy of the findings according to Cresswell (2009) requires the following to be applied to the data: triangulation; member checking; use of rich, thick descriptions; presentation of outlying data or discrepant information and peer debriefing. Triangulation of the data was done by using different sources of data that were interviews and observations. The findings were based on convergent themes from both these sources of data. Member checking entailed revisiting some of the teachers interviewed, through telephone conversations to seek further clarity on certain issues such as discrepancies that arose out of the interviews. An example of this was a teacher interviewed who stated that practical work was not prioritised at the school. However, this teacher later said that practical work was important for their learners’ continuous assessment. Cohen et al. stated that this is an important exercise and misperceptions by the interviewer must be minimised to ensure validity. Contradictory and outlying data were also reported to ensure that the data were correctly represented. An example of outlying data was one teacher reporting that practical work was demonstrated when parents visited the school during open days to attract learner admissions because they believed that doing practical work made the school appear prestigious and this would impress the parents. Additionally, the themes and findings were discussed with colleagues in science education who provided their perspectives, for example, why teachers who had sufficient resources chose not to teach hands-on learner conducted practical work.

Qualitative research reliability is a fit between what the researcher records as data with what actually occurs in the natural setting. Reliability also refers to dependability or consistency, as well as the precision and accuracy of the research done (Hesse-Biber & Leavy, 2011; Neuman, 1991). Creswell (2009) provided ways to make qualitative research

reliable and these were applied to the data collection and analyses. To begin with, the observation and interview schedules were planned, constructed, piloted, and refined. In addition, the transcription of the interviews and summaries of the observation schedules were checked for accuracy. The nodes were re-checked after each transcript was coded. To ensure that the data collected was reliable, the interviews were audiotaped, and the lessons observed were videotaped for repeated viewing later. The interview questions had to be carefully constructed and piloted. Leading or redundant questions were rephrased or removed.

3.6 Ethical Considerations

According to Cresswell (2009) researchers need to protect their research participants, develop a trust with them and promote the integrity of the research. A number of ethical issues can stem from the problem being investigated, the method used, the context of the research and what is done with the data (Cohen, et al., 2018). Ethical considerations in this research study included gaining access, informed consent, as well as adhering to anonymity and confidentiality.

Access to the schools was gained through obtaining permission to conduct research from the KwaZulu-Natal Department of Education (Appendix A). Teachers were then requested in writing, via the school principal, to participate in the study (Appendix B). This letter explained the aim of the research; what the research would entail; issues of confidentiality and anonymity; what was expected of the teacher and commitments to not disrupting the lessons. Informed consent and co-operation from the participants required explaining the purpose and nature of the research. Cohen et al. (2018) outlined four elements which informed consent must adhere to. These elements are competence, voluntarism, full information, and comprehension. The participants were reminded that they were volunteers and could withdraw from the study at any time. They were given full information about the rationale, scope, and significance of the study so that they could understand the nature of the research. Anonymity of the participants was maintained through deleting identifiers for the schools, teachers, subject advisors, and learners, and the use of pseudonyms. I also committed to ensuring confidentiality of the data through secure storage and being the only person to have sole access. Recordings of the interviews and observations using audio- and video-tapes

were also negotiated with the participants. Harding (2013) considered the worthiness and benefits of a research project as an ethical issue. The participants were explained the significance of the study that is contributing to understandings of the role of practical work in the teaching and learning of Physical Sciences in the context of high-stakes examinations in South Africa.

3.7 Conclusion

In this chapter, I outlined and justified the research approach, design of this study, the methods, and instruments used to collect the data. The data analyses techniques used and considerations of validity and reliability were also presented. In this chapter, I discussed four instruments that were used to observe the practical work lessons. These were the classification system to establish the type of practical work activity; the opportunities learners had to develop procedural understandings; to determine the process skills taught, and a modified Lesson Observation Framework to establish whether the teachers were effective with getting learners to do as intended. Finally, the data transformation process used and commitments to ethics were discussed. The focus of the next chapter is a discussion on the rationale for doing Physical Sciences practical work through analyses of the Physical Sciences CAPS curriculum document and discussions on the reasons given by the respondents for doing practical work. The evidence presented in Chapter 4 provides answers for the first research question on why we have practical work in the teaching and learning of Physical Sciences.

CHAPTER 4

THE RATIONALE FOR DOING PRACTICAL WORK

In Chapter 3, I introduced the research design, sample, research methods, and data collection instruments used in this study. In this chapter, I present teacher and subject advisor views on the rationale for doing practical work. Here, the responses from the interviews with 24 Physical Sciences teachers and four subject advisors are organised and described. In the interviews, the teachers, and subject advisors were asked, “Why do you think we have practical work in Physical Sciences?” and “Why do you do practical work?” as well as, “What do you think are the reasons for doing practical work?” The respondents’ rationale for doing practical work and its stated role in the CAPS curriculum are described in this chapter to answer the first research question, “Why is practical work part of the Physical Sciences CAPS curriculum?” In Chapter 5, I describe the characteristics of the practical work observed to understand why practical work is done in particular ways.

When the teachers and subject advisors were asked about their reasons for doing practical work, their responses included both the purposes and the aims of practical work. Hart, Mulhall, Berry, Loughran, and Gunstone (2000) explained the differences between the purposes and aims of practical work. They explained that the purposes refer to the “teacher’s pedagogical intentions – the teacher’s reasons for using a particular laboratory activity ... and how the activity is intended to result in planned student learning” (p. 656). The aim, on the other hand, refers to specific activities. Johnstone and Al-Shuaili (2001) added that the purposes refer to the reasons for doing practical work, while the aims are more specific and refer to what the teachers intend for learners to achieve from doing the practical work activity. They also explained that the objectives refer to the outcomes of specific tasks. An example to illustrate this would be the learning of skills as the purpose; the learning of process skills would be the aim, while one of the objectives of the activity would be to learn how to identify variables. In this study, the respondents mentioned several aims of practical work and these aims are grouped into four purposes that are the learning of content knowledge; gaining skills; learning about the nature of science and motivating learners.

4.1 Practical Work helps with Learning Content Knowledge

In this section, I present responses from teachers and subject advisors where they indicated that practical work helps with learning theory. The largest category (coded 273 times in the 28 interview transcripts) was supporting the learning of theory as the reason for doing practical work. In the sections below, the respondents' views are presented in categories that describe how, when and why practical work supports the learning of theory.

In the interviews with the teachers and subject advisors, their overwhelming response was that practical work helps learners with learning theory. Some of the words and phrases coded from the responses were “understanding concepts, grasp concepts, consolidate theory, consolidate theoretical understandings, understand the theory, conceptual understanding, clarify theory, understand work, understand difficult concepts, concepts made simpler, make concepts clear, correcting misunderstandings, abstract to concrete, reinforce theory, discover theory, verify concepts” (Appendix L). The extracts below provide evidence of the respondents' view that practical work helps to strengthen and learn concepts:

For me even if I have to do the same prac over and over again – for me to see the learner get that conceptual understanding once it is done, that is important ... conceptual understanding from the prac is most important. (Jay Interview, 19/01/2015)

A subject advisor, (Mr Thami) felt that “practical work is prescribed in order to strengthen the concepts that are being taught” and goes on to say that, “It has been proven that learners stand a better chance of understanding concepts if they can be demonstrated practically” (Mr Thami Interview, 18/01/2015). When asked where such written proof exists, he stated that it is a well-known fact. Another example was Lenny who stated that “you can actually see that once a learner does a prac then they grasp a concept a lot better because they gonna have that understanding” (Lenny Interview, 14/02/2015). The following respondents stated that by helping with the learning of theory, practical work helps learners with assessments. According to Jane:

You see theory they learn in class can be you know difficult. So when they see the prac even if I do it, they begin to understand - so I can see because they answer exam questions and you see they understand. So it really helps. (Jane Interview, 21/05/2013)

Raj had earlier stated that practical work helps with the learning of theory. He later he went on to say that, without practical work there would still be some understanding of concepts and this is sufficient for the purposes of assessment:

I must say that if practical work was totally taken away, you know, totally taken away, the child will to some extent still be able to create some kind of understanding of that particular concept but may not be as well rounded as with practicals but in the interest of a theoretical exams he may be able to get his full marks. (Raj Interview, 23/05/2013)

Four respondents claimed that doing practical work influences how learners think. Sizwe stated that practical work helps learners to “think out of the box” (Sizwe Interview, 07/05/2013). John stated that practical work helps learners “think on their feet” (John Interview, 13/04/2013). Raj believed that with verification practical work, there is thinking involved and that practical work makes learners think critically while Lenny stated that practical work “stimulates thinking” (Lenny Interview, 14/02/2015). Practical work was said to help with learning concepts because it “is an application of theory” (Mr Thami Interview, 18/01/2015) and it is “when the learners apply theory that is learnt” (Mr Sharm Interview, 08/05/2013). Explanations on how practical work helps learn theory included, it “plays a part in formulating the concept...it causes links to be made in the brain and this results in understanding” (Raj Interview, 23/05/2013) and making links between pieces of information:

I think that if you look at how learners learn – it is sometimes sort of isolated bits of information – so the more they engage it, the more they are about to put together information, gather that information and put together links that the practical work is a major part of that in that it can contribute to understanding. (Sharm Interview, 08/05/2013)

The following extract is an example of a claim that benefitting from practical work depends on the type of practical work activity. For Sarah, it is when “you physically verify what is taught” (Sarah Interview, 21/05/2013). Verification practical work is done to prove a theory:

Well if it's verification, generally we read the prac beforehand ... learning will come in terms of when you don't do too much of explaining where the child has to research and thinks, 'I need to draw this graph first then I need to draw another graph so I can show this'. There's discussion - why this happened? Even in your verification pracs there is definitely thinking involved.
(Raj interview, 23/05/2013)

From the extract above, it can be seen that to learn from verification practicals there has to be some decision-making and independent thinking by the learner; the teacher's role is to guide rather than provide all the information; and post-practical discussions are important. In addition, eight respondents stated that when the learners discover the concepts themselves, they would understand and remember it better (Appendix K). This can be seen from Neel's

statements: “Practical work is the learner discovering for himself” and “Where the child discovers something” (Neel Interview, 21/05/2013).

The teachers felt very strongly about how observations helped learners understand theory. Vish believed that by observing a practical, the learner’s thinking is stimulated, “With the practical work, now he is actually observing what is going on – he is actually making his own conclusions and stuff – you are stimulating thinking” (Vish Interview, 13/04/2013). Sarah stated that “it is important for them to see, to observe – like colour change, magnetic fields” (Sarah Interview, 21/05/2013) while Bongi stated that through observations learners can arrive at the conclusion of the practical. Vish stated, “You find that lots of things make sense when you actually see it. It is actually observing what is going on” (Vish Interview, 13/04/2013). Mr Sharm stated the importance of the visual experience, “I think the practical work adds another dimension to the way learners see what is happening – to the way they answer questions and to their understanding of theoretical constructs” (Sharm Interview, 08/05/2013). However, Eric believed that if learners understood a concept then there is no need to illustrate it:

A lot of the concepts that they have are wrong so when they expect something to happen and it doesn’t – so why not? You know, why didn’t it do what you expected it to and then you have to change their mindset but if you taught them what the correct concept is and then you illustrate – it’s mundane – it’s no point. (Eric Interview, 13/04/2013)

There was also reference to learners remembering what they see, “Yes like in chemistry you talk about visible results so it will be easier for the children to remember the theory part if they actually see it in the experiment” (Kanye Interview, 07/05/2013). Neel felt that “practical work helps in that the child remembers it better for a longer period of time by seeing it...because science is not an abstract subject - it is more like seeing something and believing” (Neel interview, 21/05/2013). While the teachers stated that practical work helps learn and remember theory, a learner from Betty’s lesson on “Precipitates” mentioned that it was the theory learnt that helped understand what they were observing. She stated, “We learnt quite a bit of that in class – the precipitates that will form and the test you perform ... we had to recall a lot of what we did in class and we had to remember” (Sue Learner Interview, 29/05/2013).

Most of the teachers and subject advisors (27 out of 28 respondents) in some way referred to practical work making abstract concepts more concrete for learners. For Mitch, “Seeing the

science makes it tangible, more real for them” (Mitch Interview, 22/05/2013). Raj stated that practical work provided a visual representation for abstract concepts, making it more understandable. He added that this was necessary because, “Physical Science is deemed one of the more difficult subjects, even from a society's point of view. When you try to bring the abstract to the more concrete you are seeing things” (Raj Interview, 23/05/2013). Raj used an example to illustrate his claim that learners learn through concrete experiences provided by practical work:

All learners learn through concrete examples ... if you take an atom which is so small it's impossible if you don't create that model and show them that model and get an idea of, you know what this model looks like, it will be so difficult for them to understand this because you talking about something that is so small and so abstract.
(Raj interview, 23/05/2013)

Sarah added that is particularly relevant to learning chemistry:

Chemistry mostly at that *micro level* is very abstract for the child. It is something that they have to imagine with the molecules reacting and doing things. We have been talking about the properties and evaporation and the kind of forces and how it affects the properties and how it affects the matter. (Sarah Interview, 21/05/2013)

Vish, Jiten, Shoba, Lungi, and Jay also made similar claims. Shoba was certain that practical work makes abstract concepts concrete, “Absolutely, without a doubt because concepts are abstract, for example EMF” (Shoba Interview, 14/02/2015). Vish stated that practical work results in learning “through making a visual impact on learners because they can see it because they got something concrete” (Vish Interview, 13/04/2013). Vish used an example to explain this:

Like for example let's say you tell grade 11 learners, you know what, all objects fall at the same acceleration 9,8 meters per second per second squared, but if you drop a page and a pen and obviously then to them, what is he talking about? If you actually do the experiment and take a 1kg and a 5kg object and drop that from a certain height and we get the ticker tape and get each of them to measure it and you calculate the acceleration and you get 9,8, that registers permanently. (Vish Interview, 13/04/2013)

Jiten explained, “If you are teaching off the chalkboard and you are not showing the kids the practical work it is very abstract” and that learners believe the theories when taught through practical work, “Seeing is believing” and “something clicks when you (learner) actually see it” (Jiten Interview, 22/02/2015). Lungi also used an example to illustrate her claim, “Like the experiment for the chemical change – after they did the experiment they were so happy that they did see the change because when they were learning about it they could only imagine it” (Lungi Interview, 19/01/2015). Jay also used the example of seeing a chemical change “where

they can see things like colour change and stuff like that and it becomes a little more concrete and makes it easier in terms of understanding and such” (Jay Interview, 19/01/2015). A subject advisor, Mr Thami claimed that practical work “stimulates learning through the senses” and “the aim of practical work is to reinforce the content taught in each grade and this is why the CAPS document outlines the concepts and practical work side by side” (Mr Thami Interview, 18/01/2015).

In the following quotes from those interviewed, it can be seen that there were two prevalent views based on the type of practical work. The respondents were divided on whether discovery- or verification-type activities help with learning theory. Three teachers, Pearl, Preggs, and John stated that doing discovery-type practical work helps learning theory. Pearl explained, “If they discover a relationship for themselves, it is likely to remember it better than just being told concepts” (Pearl Interview, 22/05/2013). Preggs stated that by doing the practical work before the theory, his learners “remember because they discover the knowledge” (Preggs Interview, 08/05/2013). John referred specifically to investigations:

The biggest thing is for them to put a practical investigation in place themselves – so we look at the next step will be: can you actually without the teacher intervening figure out exactly what is expected of you in the practical? And then the last part will be collecting the data, observing and once that part is over then it normally takes another lesson all together where they got to now interpret that data and discover the conclusions by themselves and that’s where they discover the concepts. (John Interview, 13/04/2013)

Vinay, Raj, and Lenny mentioned that verification-type practical work helps learn theory. According to Mr Vinay, “They may learn from verification experiments that may assist to remember some laws” (Vinay Interview, 23/11/2014). Raj explained how verification practical work done after learning a concept helps with learning theory:

You can’t do a prac absolutely totally in a vacuum. The child knows nothing about, you know, whatever and it’s so difficult because even a pre-prac discussion doesn’t cover everything. So more often than not teachers like to do it first and then the prac as a verification and then definitely the learning will follow because it’s easy, you know for them to understand why they doing what they doing. (Raj interview, 23/05/2013)

Lenny explained that if you did the practical before teaching the content it would be following a recipe as opposed to doing it at the end of a section as a verification exercise where it would enhance learning:

You teaching in a vacuum if you do the practical work first then it becomes a bit of, you know, recipe. They just follow the recipe and they do everything and there is some understanding but maybe not too much as when they already know the content now and they just verifying and everything becomes sense to them. (Lenny Interview, 14/02/2015)

Vish agreed, “You have to cover some basic concepts first and they need to know the aim and where they are heading and they can now benefit from it” (Vish Interview, 13/04/2013). The afore-mentioned quotes indicate that while some teachers thought that new concepts could be learnt from doing practical work, others felt that practical work enhanced learning only when the concepts were already learnt.

Five teachers expanded on the type of practical work to include the academic abilities of learners. Jake stated that verification practical work helped the academically weaker learners:

For a smarter child I think that it is better for them to do practical work where they actually come up with sort of conclusions from the practical work and I think with the weaker guys it is good for them to see it afterwards. So it is almost like proof so they can then internalise it.

(Jake Interview, 22/05/2013)

Mitch agreed with Jake:

I find that with my students that weaker boys are better off doing a prac after they have been taught rather than getting them to infer ... they are not going to be able to interpret data in quite the same way as the top end of the spectrum. Most of the classes here are of mixed ability ... so guys from the bottom half I would invariably do the prac after teaching them the stuff, more as verification. But for the top half I would do before-hand so that they can actually come to the conclusion themselves. (Mitch Interview, 22/05/2013)

Shoba felt that academically weaker learners benefitted from practical work, “Weak learners benefit from pracs and for bright learners it does not make a difference because they can figure it out” (Shoba Interview, 14/02/2015). Mr Sharm made similar claims about academically stronger learners, “A very bright child would almost sort of work things out theoretically without having to see an experiment ... but I think with the majority the benefit of engaging and being able to see that experiment” (Sharm Interview, 08/05/2013). Anne disagreed, stating that practical work benefits “academically strong learners” and for the rest of the learners it is “play time” (Anne Interview, 13/04/2013). Two teachers indicated in the interviews that the concepts learnt could be determined by assessing the report write-up of the practical work. Sarah explained that when the practical report write-up is assessed, the results and conclusions written by the learners indicated whether they understood the practical activity. Neel stated that learners’ understanding of the theory related to the practical work activity could be established from the questions in the report write-up. When prompted further, both Sarah and Neel indicated that it is the theory and not the learners’ practical skills that is being assessed.

4.2 Learners Develop Skills and Learn about the Nature of Science

The respondents at some stage of the interviews made reference to learners developing skills when doing practical work. The word “skills” and related words and phrases were coded 198 times in the 28 interview transcripts (Appendix K). All respondents mentioned manipulative skills (140 times), while some mentioned process skills (58 times). Statements about becoming proficient with handling equipment for tertiary studies and science careers featured prominently in the interviews.

At some point in the interviews, all respondents stated that the aim of practical work is to learn skills, specifically, manipulative and process skills. Some of the manipulative skills mentioned were the handling of equipment (John Interview, 13/04/2013); manipulating and using equipment (Raj Interview, 23/05/2013); practicing safety precautions (Shoba, Interview, 14/02/2015). Other reasons given were preparing learners for post-school studies and careers (Betty Interview, 29/05/2013; Jay Interview, 19/01/2015; Jiten Interview, 22/05/2015; Raj Interview, 23/05/2013, Shoba, Interview, 14/02/2015). In addition to manipulative skills, the respondents believed that learners develop process skills such as observation, measuring, identifying variables, inferring, and drawing conclusions when doing investigations. The excerpts below show that teachers and subject advisors, when discussing manipulative skills, made specific mention of learners becoming familiar and proficient with equipment. John mentioned becoming skilled from using equipment in general, “For me it is about learning skills in general. They are learning skills like how to use the apparatus” (John Interview, 13/04/2013), while Raj mentioned specific types of equipment:

Children are able to manipulate equipment ... use equipment. They learn how to use electrical equipment: voltmeters, ammeters ... read them. Holding a glass beaker. It's difficult to show on the board this is a burette and this is how we turn it and so forth - colour change, adding a certain volume of acid and it is an important skill. (Raj Interview, 23/05/2013)

The respondents were specific about why it was important for learners to become proficient with handling equipment. They discussed the skills necessary for learners' success at tertiary institutes. One of these respondents was Betty, “They get to use the equipment and when they go out to tertiary institutes they are accustomed to it” (Betty Interview, 29/05/2013). Jiten added that, “The problem arises when you reach university as a physics or chemistry student – you should be able to use the equipment” (Jiten Interview, 22/05/2015). Mr Sharm made a similar claim, “One of the things that universities complain about is that learners don't come

prepared. They are not sort of laboratory savvy because they have been denied experiences. We know that that happens in schools” (Sharm Interview, 08/05/2013). When probed further, Mr Sharm spoke of schools not having equipment or teachers not giving learners opportunities to handle equipment.

In addition, Lenny and Anne referred to the importance of becoming proficient with handling equipment for future careers in the sciences. Lenny mentioned that, “Maybe he wants to go into chemical engineering or electrical engineering or something. That skills application is going to help him” (Lenny Interview, 14/02/2015). Anne agreed, “They going to have the skills and the confidence to go and become engineers and doctors and teachers” (Anne Interview, 13/04/2013). Shoba agreed with the other respondents but added safety to the benefits of manipulating equipment, “Skills are developed through handling equipment, and for practicing safety in the lab, using equipment prepares them for university” (Shoba, Interview, 14/02/2015). Raj agreed:

Handling of equipment. You walk into university some of these guys say this child never saw a beaker before ... a child is going to Chemistry One doesn't know what a measuring cylinder looks like ... they just get a job as a chemical analyst assistant somewhere and he needs to manipulate the equipment. If you are a nurse you need to use a thermometer. (Raj Interview, 23/05/2013)

References to process skills were coded 58 times from transcripts of 14 respondents. Mr Sharm, Mr Thami and Mr Vinay made general claims about understanding the scientific method and developing investigative skills as benefits to doing practical work. Other respondents mentioned specific aspects of investigations such as collecting, analysing, interpreting, and representing data. The process skills mentioned included observing, communicating findings, and identifying, and controlling variables when doing practical work. One teacher, Mr Sihle specified the following skills, “Stating the hypothesis, finding the variables, collecting and interpreting data” (Sihle Interview, 21/01/2015). The following teachers stressed the importance of learners collecting and analysing data: Anne, Jiten, John, Kanye, Mitch, Pearl, Raj, and Sizwe. Jake, John, Lungi, Pearl, and Sarah spoke of learners getting experience with representing data such as drawing graphs. While all respondents mentioned manipulative and process skills only Pearl mentioned the related procedural understandings from doing practical work. She explained, “Understanding how to represent data. Why represent in a particular way is the best way like a table and not a graph is the advantage of doing practical work” (Pearl Interview, 22/05/2013). Other teachers mentioned

identifying and controlling variables but did not mention learners understanding how to control variables, determine which variables to control, or understanding the distinction between different types of variables such as categoric, discrete, continuous, and derived variables.

In the Physical Sciences CAPS document (Department of Basic Education, 2011), there are several references to practical skills in the Vision alongside the “content, concepts and skills” section for each term of the year, as well as in the Assessment Section (Grussendorf et al., 2014). In the study commissioned by the Council for Quality Assurance in General and Further Education and Training (Umalusi) to analyse the Physical Sciences CAPS curriculum, Grussendorff et al. (2014) identified the skills related to practical work in the document. Using Padilla’s (1990) system to classify process skills, it was found that process skills appear 267 times in the document (Table 4.1). Seven manipulative skills are mentioned 115 times; five basic and eight integrated process skills are mentioned 113 times; and there are 39 mentions of 10 procedural understandings. According to Grussendorff et al., there is a greater emphasis on gaining skills from doing practical work in the CAPS document compared to the previous outcomes-based curriculum.

The teachers and subject advisors in their interviews also mentioned the three categories of skills as stated in the Physical Sciences CAPS document that are manipulative and process skills, as well as procedural understandings. Additionally, similar to the CAPS document, there were fewer references to procedural understandings as the rationale for doing practical work. During the interviews, four out of the 24 teachers and two out of the four subject advisors mentioned that practical work was a way to learn about science and this appeared 13 times in the transcripts. One example is, “It shows the steps to take when you want to prove something” (Raj Interview, 23/03/2013). It also shows “the ways in which science happens” (Jake Interview, 22/05/2013). Jake added, “The learners get to write in the scientific way and see how theory is arrived at”. According to Neel, practical work is about how scientists work:

Practical work is close to how scientists work ... shows how discoveries were made by scientists. It is more discovery...like Einstein would have done practicals to have come up with his equation and the same with Newton – all of them”. (Neel Interview, 21/05/2013)

The subject advisors who defined practical work as a way to learn about the nature of science were Mr Sharm and Mr Vinay. Mr Sharm mentioned, “Practical work is when you get a glimpse of how scientists work” (Sharm Interview, 08/05/2013).

Table 4.1 Manipulative skills, process skills, procedural understandings in the CAPS document

Skill	Number of times mentioned in CAPS document
Manipulative Skills	
Manipulate and read equipment	32
Conduct/follow steps of an experiment	26
Measure	13
Record measurements / collect data	24
Conduct a practical investigation	8
Verify	3
Demonstrate	9
<i>Total</i>	<i>115</i>
Basic Process Skills	
Present information (Communication)	10
Make inferences	2
Predict	3
Classify	3
Observe	26
<i>Total</i>	<i>44</i>
Integrated Process Skills	
Control variables	8
Formulate a hypothesis	5
Analysis (qualitative)	2
Interpret results	25
Interpret given data	4
Evaluate an experiment	1
Draw conclusions	20
Design a practical investigation/project	4
<i>Total</i>	<i>69</i>
Understand experimental variables	15
Understand importance of scale; values	3
Selecting graphs, interval range and best fit curve	2
Selecting suitable instrument/technique	6
Importance of accuracy	3
Understand need for repeatability	1
Selecting appropriate tables and graphs	2
How to identify patterns	4
Understand implications of experimental design	2
Understand laboratory procedure	
<i>Total</i>	<i>39</i>
Total number of times practical work skills mentioned	267

4.3 Doing Practical Work Motivates Learners

In the CAPS document, there is no direct mention of doing Physical Sciences practical work to motivate learners. In contrast, all respondents except one teacher stated that practical work motivated learners and this was one of the reasons for doing practical work. They spoke of “interest, encouragement, enjoyment, enthusiasm, confidence, excitement, and fun” when asked how practical work motivated learners. From the responses, motivation and related terms were coded 72 times in the 27 interview transcripts (Appendix K).

John claimed that practical work motivated learners by giving them confidence but did not elaborate further (Appendix J). Jay stated that practical work “motivates learners when they start to enjoy it” (Jay Interview, 19/01/2015) and Sarah agreed, “I think that firstly it invokes an interest in the subject. I think like it makes them enthusiastic to learn. They enjoy the experience” (Sarah Interview, 21/05/2013). Jake spoke of interest as well as enjoyment, “You know I enjoy it and the boys enjoy it and that to me is maybe not real science but it is a lot closer to sort of what a real scientist does and they become interested” (Jake Interview, 22/05/2013). When asked how practical work motivated learners, Vish also mentioned interest but was the only respondent who suggested that practical work can be used to motivate academically weaker learners, “Even the weaker child gets interested” and “become more enthusiastic - the interest - they become more motivated” (Vish Interview, 13/04/2013). Sipho agreed, “The interest - for me it’s the interest. But more importantly what I have seen with practicals is that it does keep them excited about the subject” (Sipho Interview, 07/05/2013). Lungi shared how learners reacted about going to a laboratory, “Like when they know they are going to the lab – they all come, they get so excited, they all come” (Lungi Interview, 19/01/2015). Mr Vinay also spoke of interest and excitement, “Offsets monotony of theoretical lessons. Stimulates interest in learning and gets them excited about doing science” (Vinay Interview, 23/11/2014). While most teachers and subject advisors spoke of enjoyment, excitement, and interest, others spoke of practical work motivating learners because it is fun. Jane said, “Pracs are fun but they learn while having fun. It motivated them to learn” (Jane Interview, 21/05/2013). For Eric, learners enjoy practical work and it keeps them interested, “Uhm, in terms of science it’s just for peaking interest. They all thoroughly enjoying it - it is good fun. They enjoy it - it is fun but beyond that, there is nothing (Eric Interview, 13/04/2013). However, apart from being enjoyed by learners and keeping them

interested, Eric did not believe that practical work motivated the learners or had any value beyond enjoyment.

Raj firstly spoke of how he used practical work to motivate learners, “I do it first as a demo to encourage the pupils to motivate them to do science. The minute you do any practical work then immediately, those kids are motivated” (Raj Interview, 23/05/2013). He then went on to emphasise why he did practical work, “I do practical work mostly because it is important it offers motivation ... it is excellent as a motivational tool ... Definitely motivate them and gets them involved as well ... and they are interested” (Raj Interview, 23/05/2013). Raj was clear about the role of practical work in motivating learners, “I think it motivates. The minute you do any practical work then immediately those kids are motivated” (Raj Interview, 23/05/2013).

However, Anne stated that doing practical work did not result in learners being motivated. She mentioned that learners may have fun but not in terms of enjoying the practical work. It appears that her reasoning was based on the idea that when learners do not understand the practical work they may become disillusioned, lose interest, and consider the lesson as free time:

Ya I think that most of the learners I teach are pretty motivated in any case. I don't think it's a particular motivating factor within my context that I am teaching. In fact, it is probably seen as more of an ominous task than a motivational factor. I think they see it as a play lesson, in a sense, and because they not always able to relate the academics to the practical which they don't understand I don't think it serves as much as a motivation for them. The fun aspect is more that they see it as a free lesson - like talk with each other. (Anne Interview, 13/04/2013)

It appears that the learners in Anne's class are motivated to learn and this is not due to doing practical work. From Anne's response, it seems that when the learners do not see how the practical work activity is related to theory or do not understand the activity, they become disinterested in the lesson. She mentioned that learners saw practical work as being “an ominous task” suggesting that they consider practical work as a bother. Anne also mentioned that the learners see practical work lessons as play lessons, implying that the learners probably did not see the value of doing practical work or were disinterested.

4.4 Conclusion

To begin to understand the role of practical work in the teaching and learning of Physical Sciences, I described teachers' and subject advisors' responses on their rationale for doing practical work. Additionally, I organised, provided examples, and analysed their responses in terms of similarities, differing views, and outliers. The teachers and subject advisors interviewed generally agreed that the reasons for doing practical work were that it helps learners learn theory and gain skills, is a requirement of assessment and can be used to motivate learners. Some respondents disagreed with the afore-mentioned purposes for doing practical work. In total, out of 28 respondents, 27 stated that practical work helps with learning theory; 28 agreed that practical work helps learners gain skills; 28 proposed that assessment is a reason for doing practical work; and 27 respondents suggested that practical work could be used to motivate learners. The respondents' suggested purpose for doing practical work that was most mentioned was the learning of theory. This was followed by the gaining of skills; for assessment purposes; and for motivating learners. Analyses of the Physical Sciences CAPS document text revealed that there is mention of only two purposes for doing practical work and these are for supporting the learning of theory and the developing of skills. In Chapter 6, I will use the analyses described in this chapter to present evidence for assertions on the rationale for doing practical work, to answer the first research question. In the next Chapter, I provide descriptions and analyses of the characteristics of the practical work lessons observed.

CHAPTER 5

WHAT HAPPENS IN PRACTICAL WORK LESSONS?

In Chapter 4, I organised, analysed, and presented an analysis of the Physical Sciences CAPS policy document, as well as the teachers' and subject advisor' responses on rationale for doing practical work, in relation to the first research question. In addition definitions of and the rationale for doing practical work as stated in the CAPS policy document were discussed. In this chapter, I organise, analyse, and present the characteristics of the practical work lessons observed, in relation to the second research question on the characteristics of the practical work lessons observed. The analyses from this chapter as well as those analyses from Chapter 4 will be presented as assertions in Chapter 6.

5.1 Examples of Practical Work Lessons Observed

To answer the second research question on the characteristics of practical work lessons, I requested permission from the 24 teachers interviewed to observe their practical work lessons. Nine teachers granted me permission to observe nine practical work lessons ranging from grades ten to twelve (Appendix C). In the Physical Sciences CAPS document, these practical work activities were prescribed for formal assessment except for 'Verify Boyle's Law', which was recommended for informal assessment. In this section, I describe a sample of four selected lessons observed because of some common characteristics, as well as features that were unique to each lesson and relevant to this study. These four lessons described in this section were typical of the practical lessons observed, with the exception of the practical on "Boyle's Law", where the equipment malfunctioned. There were five general characteristics common to all four lessons. Firstly, the practical activity followed the theory taught in class. Secondly, the teachers began the lessons with a recap of the theory learnt, then stated the aim and question to be investigated. Thirdly, the teachers provided and discussed the method to be followed. Fourthly, the teacher and/or learners followed the method and collected or attempted to collect the data. Fifthly, the teachers discussed the contents of the report write-up that learners had to complete for assessment purposes. In the pre-practical

work interviews, Jiten who taught the lesson on the “Heating and cooling curve of water” and Vish who taught the lesson on “Titration” indicated that learners would conduct the practical activities after observing the teacher demonstrations. Eric (Division of potential across series resistors and parallel resistors) and Bongi (Verify Boyle’s Law) indicated that learners would conduct the practical work activities in groups. Features unique to each of the four practical activities will be discussed in the sections to follow.

5.1.1 Learners observe teacher-conducted investigation and the use of example

data: “The heating and cooling curve of water” taught by Jiten

In the CAPS document, this grade 10 practical activity is compulsory for formal assessment, to be completed in the first term of the year:

Prescribed experiment for formal assessment. Draw the heating curve of water. Start with ice in a glass beaker and use a thermometer to read the temperature every 1 minute when you determine the heating curve of water. Do the same with the cooling curve of water starting at the boiling point. Give your results on a graph. Materials: Burner, glass beaker, ice water and a thermometer. (Department of Basic Education, 2011, p. 19)

This lesson was included for discussion in this section because it was an example of a teacher-conducted investigation where some learners assisted with collecting data and other learners observed the activity. The learners were kept engaged through the teacher’s discussions and questioning. The learners followed steps of an investigation that are analysing and interpreting the data, and reaching a conclusion. This lesson was unique because the learners did not use the data collected from the demonstration but analysed example data provided by the teacher to reach the conclusion.

Jiten (with 12 years teaching experience), indicated in the pre-practical interview that he would begin with a demonstration and learners thereafter would conduct the practical work activity in groups. He also mentioned that this practical work activity followed theory lessons on the three phases of matter and the Kinetic Molecular Theory. Specifically, the learners were taught the concepts of freezing, melting point, boiling point, evaporation, and condensation, as well as intermolecular forces, phase change, and latent heat. While both the heating and cooling curve of water are prescribed in the CAPS document, only the activity on the heating curve of water was completed in the lesson observed. In a laboratory, Jiten lit the gas stove, placed a wire gauze over the flame, and placed a beaker of ice with a thermometer over the flame and added a little tap water to the ice. Jiten stated that the reason for adding

water to the ice was for the thermometer to be submerged in a liquid. Three learners had to then record the temperature readings. One learner held the thermometer and read out the temperature readings while another learner recorded the time, and a third learner wrote the temperature readings on the chalkboard every two minutes, using green chalk. Jiten wrote minus two as the first temperature reading at zero minutes in green chalk. He explained to the learners that they would have got this reading under ideal conditions but not from this activity because it was too warm in the laboratory. The three learners observed the melting of the ice and were told to stop collecting data at 91°C before the boiling point of the water was reached. While the three learners collected the data, Jiten discussed the structure of the practical report write-up, learner assessment for the practical, and concepts related to the practical. On the chalkboard, before the commencement of the lesson, Jiten had prepared two pre-populated tables using white chalk. These pre-populated tables are reported here as Table 5.1 for the cooling curve of water and Table 5.2 for the heating curve of water. Jiten stated that the results in these Tables were temperatures recorded by a previous class who conducted the practical in the morning when the air temperature was much cooler.

Table 5.1 Example data provided for the practical: Cooling curve of water

Temperature (°C)	100	100	90	80	70	60	50	40	30	20	10	0	0	-2
Time (minutes)	0	2	4	6	8	10	12	14	16	18	20	22	24	26

Table 5.2 Example data provided for the practical: Heating curve of water

Temperature (°C)	-2	0	0	10	20	20	40	50	60	70	80	90	100	100
Time (minutes)	0	2	4	6	8	10	12	14	16	18	20	22	24	26

Jiten mentioned to the learners that it was not feasible to demonstrate the cooling curve of water in the lesson because this required a large amount of time to complete the activity. He then explained the aim of the lesson, “So we going to do the practical on the heating curve of water today. What we have here now is the scientific method” (Jiten Lesson Observation, 22/02/2015). In the discussions during the first 20 minutes of the lesson, he focused on the

theory related to the practical activity. He mentioned the following precautions that should be taken when doing the practical task, which had to be mentioned in the report write-up: using the gas stove in a well-ventilated area, avoiding the error of parallax, and why the tip of the thermometer should not touch the bottom of the beaker. During this first 20 minutes of the lesson, Jiten also discussed the format of the report write-up and how it would be assessed, in detail:

So you have double sheet of paper but listen what I am telling you now. Alright? While we are waiting for the ice to melt, I will show you how I want the practical report. If you look at your practical report there is a Rubric there on the front telling you how you are going to get marked for your practical. Right just go right down to the bottom there, you can see: “Answer the questions below right at the end of the practical”. It’s out of 16 marks. But you going to get points according to your rubric. If you get between one and three points, you get one mark. Makes sense to you people? If you get between four and nine points, you get two marks according to your rubric. Pay attention to your rubric, it tells you what needs to be in your practical report ... When you handing in your practical report, this page here, the Rubric, that’s your cover page. Understand? On the front you will put your name, grade and register number. Where you gonna get your register number from? You can ask your teacher in second registration. So name, grade, register number. This can be stuck as a flap. So this must be a double page and it must be handed in to me like this. Is that clear? You can start with the practical on the first page here. So you put your investigative question, like I told you, the hypothesis, variables and so forth. The questions however, must be answered on the last page.
(Jiten Lesson Observation, 13/02/2015)

While the three learners continued to collect the data, Jiten discussed the investigative question, hypothesis, and variables for the activity:

For this investigation, you start with your investigative question. Right. This is the format, okay. You know what an investigative question is – it relates two variables. The answer can’t be yes or no – it can’t be yes or no. Hypothesis is your answer to your investigative question and then write down a list of the apparatus and watch carefully here – we write down a list of the apparatus that we are using not necessarily the apparatus you are using in your practical sheets, okay? So look at what we are using here. The variables – you have to write down an independent variable, a dependent variable and a constant variable. Whatever we change is our independent variable – in this case here we are using time as your independent variable – independent variable goes on your X axis. The dependent variable is temperature – temperature changes with the change of time, isn’t it, so that goes onto your Y axis. So everybody understands, temperature on your Y axis, time on your X axis. By the way what are we keeping constant here? We using a certain amount of ice and we keeping that the same, okay? You got your variables, the method is given to you on the sheet. Your results – your results will now be a Table of Results. *Jiten pointed to the Table on the board with example data.* So your results are going to be your Table of Results. You are going to plot your graph according to the results I put up here on the board not from the experiment. The best time to do this experiment was in the morning when it was still a bit cold, right? Now it’s a bit hot so we don’t expect our results to be exactly the same. The analysis – from this Table here you will draw your graph.
(Jiten Lesson Observation, 22/02/2015)

A worksheet, assessment rubric and a set of questions to be answered were given to the learners (Appendix M1). Jiten told the learners to list the apparatus from the actual practical

and not the apparatus listed in their worksheets in the report write-up. He used the example of the method in the worksheet requiring a Bunsen burner while in the actual practical a gas stove was used. I observed that the learners listened attentively to Jiten and made notes while he gave instructions on how to complete the report write-up and took a further 12 minutes of the lesson to discuss the assessment criteria, allocation of marks and due date for the report. Jiten's instruction to the learners was that they had to complete the report write-ups on both the heating and cooling curve of water using the example data on temperature provided by him on the chalkboard. Jiten reminded learners five times throughout the practical lesson that they should use the example data on temperature written with white chalk and not the results from the practical activity, which was being written with green chalk. Despite repeated instructions, on three separate occasions throughout the practical lesson, learners still asked for clarity on whether to take down the example data from the pre-populated table or the actual data obtained from doing the task. Table 5.3 shows the actual temperature results (in italics) that were recorded from the activity compared to the example data given by Jiten.

Table 5.3 Actual temperature recorded and example temperature readings given for 'Heating Curve of Water' practical

Temperature recorded (°C)	-2*	<i>10</i>	<i>14</i>	<i>15</i>	<i>16</i>	<i>25</i>	<i>31</i>	<i>48</i>	<i>56</i>	<i>65</i>	<i>71</i>	<i>77</i>	<i>81</i>	<i>91</i>
Example Temperature (°C)	-2	0	0	10	20	20	40	50	60	70	80	90	100	100
Time (minutes)	0	2	4	6	8	10	12	14	16	18	20	22	24	26

* The teacher inserted -2 °C for the temperature at zero minutes before the practical began in green chalk

Jiten discussed the example data, "So can anyone tell me, why does the temperature remain constant now at the melting point?" (Jiten Lesson Observation, 22/02/2015). The temperature readings being referred to were '0 °C' after two and four minutes of heating the ice. This temperature reading appeared twice in the example data given (Table 5.3). Jiten then continued to discuss the definitions of melting point, boiling point, heat, temperature, latent heat of fusion, and latent heat of vaporisation. The last 28 minutes of the lesson were used to discuss the results from both sets of the example data and other requirements for the report. He posed several questions to the learners and answered most of them himself when learners did not respond or appeared to have little understanding of the concepts.

In the extract below, Jiten questioned the learners on the definition of heat, kinetic energy, and concepts such as boiling point:

- T: Because when we heat the substance – what is the definition of heat? *Silence. No responses from the learners*
- T: Transfer of energy from hot to cold, isn't it? I told you all that before so when you heating something you transferring heat into those particles, isn't it? They will gain more kinetic energy and will move faster. Understand? If they moving faster then the temperature is a measure of the average kinetic energy. So if they moving faster then the average kinetic energy is increasing, isn't it? So the temperature increases. So tell me why the temperature will remain constant at the boiling point?
- L1: Because it's at room temperature. (Jiten Lesson Observation, 22/02/2015)

Jiten explained how he arrived at the example data for the Cooling Curve of Water:

- T: Okay you are going to take down the results that I got there. There's the Table of Results there. You have the heating curve here. Now we not going to actually in this lesson sit and watch the temperature decrease isn't it? It takes too long so what we have done now is that we have inverted our results for the cooling curve, right? So now you will see that time equals to zero, temperature zero. Temperature remains constant at the boiling point. Then you will notice that as the time progressed what had happened?
- Ls: *Some learners:* Decrease
- T: It starts to decrease because of the heat that is being removed because it is now cool, isn't it? Do you notice the melting point here the temperature remains constant? *Jiten pointed to 'Table of Results – Cooling Curve' on the Chalkboard.* So you are going to have your results – you are going to have two Tables – one Table of Results for the Heating Curve and one Table of Results for the Cooling Curve. Then you going to have two graphs – one for the Heating Curve and one for the Cooling Curve from the Table of Results.
(Jiten Lesson Observation, 22/02/2015)

In this lesson, Jiten set up the equipment and three learners recorded some temperature readings, while other learners observed. Learners were shown how to collect data, concepts learnt in theory lessons were revised, and he discussed the report write-up using the example data provided. This practical work lesson was dominated by teacher talk, and from the learner responses, it appeared that the learners did not fully understand the required concepts taught in the theory lessons. Jiten provided the aim, investigative question, and hypothesis. He also provided the results and discussed the contents of the report write-up. The learners appeared to be concerned with the details and correct answers for the report write-up and assessment thereof. Jiten did not use the opportunities from the practical work lesson to explain why the actual results obtained were not similar to those in the textbooks, which were obtained under ideal conditions. Abstract concepts such as latent heat were not made concrete by providing opportunities for learners to observe phenomena macroscopically.

5.1.2 Learner observation of teacher conducted investigation with limited learner hands-on: “Titration” taught by Vish

In the Physical Sciences CAPS document (Department of Basic Education, 2011) Titration is listed as a prescribed practical for Grade 12, “How do you use the titration of oxalic acid against sodium hydroxide to determine the concentration of the sodium hydroxide?” (p. 13). Thereafter, “Types of Reactions” is listed as one of the sub-sections of Chemical Change for Grade 11 together with the practical activity: “Experiment: (1) Titration (leave until grade 12 or do a simple qualitative titration here and a more ... quantitative titration in grade 12)” (p. 92). Vish explained that Grade 11 learners were being taught a Grade 12 prescribed practical because he had to demonstrate colour changes using indicators and teach balancing of equations in Grade 11, and in this way, he could accomplish this as well as complete a Grade 12 practical work activity for the following year. However, for this practical activity, Vish demonstrated how to use titration to determine the concentration of Hydrochloric Acid (HCl) using a Sodium Hydrogen Carbonate (NaHCO_3) solution. This lesson was selected for discussion in this section because it was an example of a teacher demonstration where the teacher collected the actual data and engaged the learners throughout the demonstration. The learners had to analyse the data and provide the conclusion. A discussion of this practical work activity will illustrate how investigations that require expensive or delicate equipment may need to be conducted by the teacher. In addition, the importance of teacher explanations and questioning during demonstrations will be shown.

In the pre-practical interview, Vish (with 21 years teaching experience) indicated that he would demonstrate the practical work activity. He also indicated that the objectives of the lesson were to motivate the learners, prepare them for examination related questions, and show them how to do titrations. Vish set up the apparatus and equipment in a lecture theatre occupied by thirty-eight learners. At the beginning, he mentioned to me that the reason for demonstrating the practical was there was insufficient equipment for all learners and that the burettes were delicate and expensive. Further, he stated that learners would be better able to observe the demonstration in a lecture theatre. The learners were told that they would be given the worksheet at the end of the lesson and they had to make notes during the activity. The worksheet listed the apparatus needed as well as the method to conduct the practical work activity (Appendix M2). On the front table of the lecture theatre, a burette was set up on a retort stand. Labelled conical flasks, pipettes, and beakers were also placed on the front table.

Vish began the lesson with a short recap on the difference between acids and bases. He then explained the aim of the practical activity, “So in this titration we are going to find the concentration of the HCl. The aim of the experiment by doing the titration we are going to determine the concentration of the HCl” (Vish Lesson Observation, 26/04/2013). Vish then wrote the following equation on the chalkboard: $HCl + NaHCO_3 = NaCl + H_2O + CO_2$. This was followed by an explanation of how the $NaHCO_3$ solution was prepared and how its concentration was determined. The concentration of the $NaHCO_3$ solution was then written as $c = 0,1 \text{ mol.dm}^{-3}$ on the chalkboard. Vish then discussed the importance of using clean, dry glassware and why it was essential for all glassware to be clearly labelled. He began by discussing why methyl orange was used as an indicator and illustrated what the colour changes would look like, before he conducted the demonstration:

So for this experiment because we got a strong acid and a weak base we going to use methyl orange. So before we start we need to know the colour change otherwise we wouldn't know it has been neutralised. Open the textbook it will tell you methyl orange in an acid it is pink and in a base it is yellow and when it is neutralised they tell you brown but actually it's more like petrol. *Vish showed a solution in a conical flask.* So when it reaches this colour it is now neutralised. What we need to do is that before we start we need to compare colours – agreed? So we can say which is the acid – which is the base just by looking at it. So what I'm gonna do is I'm going to take a little bit of each and put into a test tube and put the indicator in each one and you will see the colour. (Vish Lesson Observation, 26/04/2013)

Vish explained the procedure in detail as he demonstrated the titration:

What we going to do is we going to react these two. *Vish pointed to the HCl and NaHCO₃ solutions*). Remember yesterday's lesson we prepared this solution here (*points to the NaHCO₃ solution*). How we prepared it? We worked out the mass. What equation did we use? (*teacher writes $C = m/MV$ on the chalkboard*). I prepared a solution of Sodium Hydrogen Carbonate (*teacher shows learners a measuring cylinder with a solution*). I took the mass and made a solution. At the moment my Sodium Hydrogen Carbonate concentration is. *Vish wrote $c = 0,1 \text{ mol.dm}^{-3}$ on the chalkboard*). Now here I got concentrated HCl. I took 10ml and I made it one litre. Okay so the concentration of the Sodium Hydrogen Carbonate is 0,1 and the concentration of the HCl I don't know. So, in this titration we are going to find the concentration of the HCl. So the aim of the experiment by doing the titration we are going to determine the concentration of the HCl. (Vish Lesson Observation, 13/04/2013)

Vish discussed some of the precautions that had to be taken, for example, why the acid had to be poured slowly; why more than the required amount of acid is poured and then the excess discarded into a beaker; and why the burette tap had to be slowly opened and closed. He also explained how to read the gradations on the burette, taking into account the meniscus and avoiding the error of parallax. Vish then decanted 20cm³ of $NaHCO_3$ into three flasks and added a few drops of methyl orange indicator. Throughout the activity, he explained what he was doing and reasons for doing it in particular ways. He wrote 20cm³ as the known volume

of NaHCO_3 on the chalkboard. A volume of $18,8 \text{ cm}^3$ of HCl was used for the end-point to be reached. Vish wrote this on the chalkboard and indicated that the experiment had to be conducted three more times and the average volume of HCl would be used since, “The more times it is repeated, the more accurate it would be” (Vish Lesson Observation, 26/04/2013). Vish was well prepared for the lesson: he had set out the apparatus; labelled the glassware; and prepared the solutions before the lesson. Vish engaged the learners throughout the lesson with his dialogue and questioning. The learners were attentive throughout the lesson although not all learners could see the details of the demonstration when seated in the lecture theatre. Hence, Vish called several groups of four learners to the front of the lecture theatre to participate in the activity. Each time, he showed these learners how to open and close the tap; avoid the error of parallax; how to swirl the conical flask; and how to read measurements on the burette. It was observed that most learners struggled to open and close the tap, and to swirl the flask simultaneously without knocking the tip of the burette; and most learners overshot the end-point.

Throughout the practical work lesson, Vish emphasised the aspects required to complete the report write-up as well as how the practical will be assessed in the examinations. After working out the average volume of HCl used to reach the endpoint, Vish listed the values required to determine the concentration of HCl . In the worksheet given, the learners had to complete the table of values and answer the questions based on the activity. Learners then used the formula to work out the concentration of HCl to be $7,666 \text{ mol.dm}^{-3}$. Vish explained that for the grade 12 examination, learners would be expected to round off figures to two decimal places. In the last 15 minutes of the lesson, he discussed the completion of the report write-up, in detail:

The worksheet contains the entire process. Okay so when I see you on Wednesday you got questions one to five – you gonna add question six. Question six is: List two precautions you should take when doing the experiment. I gave you four precautions if you listened very carefully. Question six you are going to add to the last page. On this Table – *points to the Table in the worksheet* – you will find a Table at the back. It says volume of Sodium Hydrogen Carbonate. The volume is going to be? (Vish Lesson Observation, 26/04/2013)

He also mentioned how the titration will be tested in the forthcoming examinations and gave an example of an examination question:

Any questions? So we all 100% sure about a titration. A question like this will definitely come out in the June exam. Always comes out for about 10 – 12 marks. Choosing the right indicator – reason for choosing the right indicator. Most important thing is volume of acid for each one. Take down the Table. (Vish Lesson Observation, 26/04/2013)

Vish determined the following aspects of the activity: the aim; investigative question; equipment to use; procedure to follow; and how to complete the report write-up. The learners were shown how to calculate the concentration of HCl from the results obtained from the titration demonstrated by the teacher. Together with the learners, he analysed and interpreted the results. The one-hour lesson was adequate for Vish to demonstrate the titration, and give learners opportunities to practice using the equipment.

5.1.3 Learner hands-on investigation: “The Division of Potential” taught by Eric

This practical work activity is listed as a prescribed practical for formal assessment for grade 10 in Term Two under the section “Electric Circuits” as follows:

Prescribed experiment: Part 1 Resistors in series. Set up a circuit to show that series circuits are voltage dividers, while current remains constant.

Prescribed experiment: Part 2 Resistors in parallel. Set up a circuit to show that parallel circuits are current dividers, while potential difference remains constant.

(Department of Basic Education, 2011, pp. 44 - 45)

The reasons for including Eric’s practical work lesson in this section are as follows: the lesson was an example of a learner hands-on and minds-on practical work activity; learners followed the investigation method provided by the teacher; and the activity was an example of learners working in small groups. Through this discussion, the importance of structuring investigations so that learners can collect and analyse the data themselves, and reach their own conclusions from the data collected even when the outcomes are known, will be illustrated. Moreover, it will be shown that through questioning the teacher can provide opportunities for learners to think about the data collected even when the learners are aware of the relationships and patterns in the data.

Eric who had 24 years teaching experience taught this practical work lesson. In the pre-practical interview, Eric indicated that in preparation for this lesson, the learners practiced how to connect resistors in series and parallel in a circuit and use a multimeter. The following concepts were taught in the theory lessons before the practical: current strength, potential difference, and resistance. He also indicated that the lesson would be a practical activity with learners working in groups. According to Eric, the objectives of the lesson were for learners to learn skills, see relationships between quantities, and for assessment purposes.

In a large classroom, 24 grade 10 learners conducted the practical work activity in pairs. One learner from each group collected the equipment and for the first 17 minutes of the one-hour lesson, Eric gave instructions on how learners should set up the equipment. The written instructions (Appendix M3) were also projected on a screen at the front of the laboratory. Eric provided the research question and the learners had to state the hypothesis and variables for the investigation. The learners collected the data for the next 22 minutes. Throughout the lesson, Eric assisted some learners who were not getting any readings on the multimeter and showed the learners how to connect the multimeter, “Okay so as soon as you start let me have look at your connections to see what you have done. So what happens when you put it the wrong way? You get a negative sign” (Eric Lesson Observation, 14/05/2013). It was observed that some learners were aware of what readings they ought to get, “In this one they have to all add up to what you get here” (Learner Joey, Lesson Observation 13/04/2013). Several learners visited other groups to compare their voltage readings. One group of learners was observed trying various ways to reposition the multimeter and when asked for a reason for this, one learner stated, “Because it’s giving negative readings so we changing it” and later, “It’s not adding up - the readings” (Tim, Lesson Observation 13/04/2013). The video footage showed this group being visited by another learner who shared his voltage readings with them.

It appeared that although the learners could identify the patterns in the data collected, some struggled to explain the reasons for the patterns and had to be assisted by the teacher:

- T: Okay now let’s see what readings you have got so far. When you look at the first experiment that you did – the one with the series resistors – what do you notice about the split of the potential between the resistors that you connected?
- L5: It was more
- T: In which one?
- L5: In the series
- T: No I’m not comparing the series with the parallel – I’m saying in the series resistors only – do you see any patterns with the numbers that you got?
- L6: The total is bigger than the individual
- T: Okay so the total is bigger than the individual – any other?
- L8: The one in the middle is the highest
- T: Okay there were slight variations between them. Okay anything else? Besides variations between the two do you see any patterns in the numbers?
- L9: The sums
- T: Ah yes if you add all the individual ones – what did you find?
- A few learners: They equal the total
- T: Okay what does this mean? [Silence]. Eric Lesson Observation, 14/05/2013)

It was established from conversations with some of the learners that they knew what the relationship between the values were because it is discussed in their textbook but they could not explain the reasons for the patterns in the data. When Eric asked the learners to express the values mathematically, one learner said that “resistance 1, resistance 2 and resistance 3 all add up to resistance 4”. Eric corrected the learner by saying that “ V_1 plus V_2 plus V_3 is equal to V_4 ” (Eric Lesson Observation, 14/05/2013). The discussion of the results lasted about six minutes. Once the data analysis was complete, Eric announced that he wanted to discuss the report write-up for the practical. “I’m going to give you a rubric that you are going to use for the write up so you are going to use it and staple it to the front of the write up” (Eric Lesson Observation, 14/05/2013). Eric discussed the assessment rubric and the format of the report write-up:

- T: Okay you are now going to do the write up of this investigation that you have done and you are going to follow the rubric as per usual as you have done with other pracs. So you are going to start with the title page and it’s fairly obvious what needs to go on it. Please note at the top where it says at levels indicate content, effort, presentation - in other words purely having it there doesn’t guarantee you going to get 2 on that particular level. It has to be done neatly, it has to be laid out properly – so it shows you have made some kind of effort – not something out of the book and quickly written out on a scrap of paper. Your introduction. What was your introduction?
- L11: Its what you wanted to do
- T: No no no no. That is the aim or investigative questions. What is in the point of the introduction here? It’s the theoretical background to the work that we doing. So here we have to give a brief theoretical background you will need to explain what a potential difference is, what a resistor is
- L13: Sir can we get our previous pracs to see how we did this?]
- T: No that’s a bad example to follow [Learners laugh].

(Eric Lesson Observation, 14/05/2013)

Eric focused on various aspects of the report write-up such as the structure, answers to the questions in the worksheet, and how the report will be assessed. The learners were attentive when discussing the results and the report write-up. Eric stressed the importance of completing the report thoroughly since it formed a major part of the assessment for the term. The learners did not appear to be overtly interested in or enjoying the practical activity but did appear to be enjoying the opportunities to socialise with other learners.

5.1.4 Learners in groups collect - apparatus setup by teacher: “Boyle’s Law” taught by Bongi

“Verify Boyle’s Law” is listed in the CAPS document as recommended assessment for informal assessment for grade 11 (Department of Basic Education, 2011, p. 12). The materials

are listed for the experiment as, “Pressure gauge, 10ml syringe, 3cm silicone tubing to attach syringe to pressure gauge, water bowl” and guidelines are provided for teachers:

This section is an excellent opportunity to show the relationship between macro and micro e.g. explain the pressure volume relationship in terms of particle motions. It is an important section for illustrating and assessing understanding of investigative process, the relationship between theory and experiment, the importance of empirical data and mathematical modelling of relationships. Link to skills topic in grade 10. (Department of Basic Education, 2011, p. 80)

This lesson is described here as a practical activity that was planned as a teacher demonstration to be followed by large groups of learners collecting and analysing the data. However, the equipment malfunctioned and example data were given to learners. In this section, the consequences of a teacher being unprepared, when expected results are not obtained from the activity, and the importance assigned to assessing the report write-up, will be illustrated. In the pre-practical interview, Bongi (with three years teaching experience) indicated that ‘Boyle’s Law’ was a recommended practical work activity in the CAPS document. However, she taught the lesson so learners could see the relationship between pressure and volume. She stated that the objectives of the lesson were for learners to collect data in groups after she demonstrated the activity, to learn skills, and use the data to complete the report write-up. Bongi used the first 25 minutes of the one-hour practical lesson to revise concepts already taught in theory lessons. Her introduction covered the three phases of matter and touched on the Kinetic Theory of matter. It was noted that either Bongi gave the answers to her own questions or learners read out answers from their textbooks. In the extract below, it can be seen that Bongi revised concepts that were abstract and the learners recited back the answers as learnt in the theory lessons. Bongi questioned the learners:

- T: Okay we looked at “amaGases” (gases) and in “amaGases” we found that – open your textbooks to page 156. Okay page 156. The certain behaviour of matter around us – it is in three phases. We have “amaSolid” (solid), “amaLiquid” (liquid), “amaGases”. And from these three phases we find that they have what – particles in them, “angete” (understand). Of these particles there is a certain arrangement, you find for “amaSolid”?
- L: Tightly packed [Some Learners]
- T: “amaLiquid?”
- L: Loosely packed [Some Learners]
- T: So we find that the behaviour – I’m waiting – *reprimands learners for being noisy* – behaviour of these three phases differs. We don’t expect solids to behave like “amaGas”. And “amaGas” can be compressed. (Bongi Lesson Observation, 13/05/2013)

Bongi proceeded to the next topic in the textbook, “Ideal and Real gases”. She did not link this discussion to the practical activity to be done but discussed the theory:

- T: We get two types of gases. What are those two? Yes?
- L1: Ideal gas
- T: Ideal gas and?
- L1: Real gas

T: Real gas. We know ideally we say in an ideal gas there are no what between the particles? Give me factors of “amaIdeal gas” (Ideal gas). Ya behaviour of Ideal Gas? But in an ideal gas there is a small amount of attraction, “angete”. Another behaviour of an ideal gas?

L2: Identical particles

T: The particles are identical in an ideal gas. Another behaviour of an ideal gas? Yes?

L2: No intermolecular forces

T: No intermolecular forces. In an ideal gas we say that there are no intermolecular forces.

(Bongi Lesson Observation, 13/05/2013)

Bongi then went on to illustrate the concepts of direct and indirect proportion using straight line and hyperbola graphs she drew on the chalkboard. Learners had to arrange themselves in groups where they had to read the method for the practical to be done from the textbook. One group was asked to come to the front of the laboratory to conduct the practical work activity. Bongi started by questioning the group about the “Boyle’s Law” apparatus:

What apparatus will it be? This can read my volume. Every time the volume increases – we know the volume actually expands. The volume is given by the scale at the back starting off at 45 and this one is in cm^3 and inside the pressure gauge I actually have a reservoir of oil. Oil will be giving pressure reading okay. So now it is sitting around atmospheric pressure. As I start pumping the pressure, what happens? You find the pressure on the pressure gauge actually increasing and as it starts increasing you expect a reading on this part okay. So this is the input where you will be controlling. You will be controlling pressure and you will be reading off “iVolume” (volume). Of this two when I am controlling the pressure and reading the volume, which one is the dependent and which one is the independent?

(Bongi Lesson Observation, 13/05/2013)

Thereafter, Bongi pointed out to the learners where they should be controlling the pressure and where they should be reading the volume. The groups were then asked to conduct the practical by following the set of instructions that were given in the textbook on page 179. The first group attempted the practical, while the rest of the learners were unoccupied and noisy. Seven minutes later this group of learners reported to the teacher that they were unable to get any readings. Bongi tried the pump and then told all learners that the pressure pump was faulty. She then turned to the chalkboard and populated a table with example data of pressure and volume. The rest of the one-hour lesson was used to discuss the example data and how it fitted the explanation given in the textbook:

The pressure pump is not working and so as a result, you cannot get readings for the volume. Hence, I given you the input results for the pressure So if the pressure be 100 your volume tube will be reading 15cm^3 . At a pressure of 150 your volume should be 20, at 130 it should be reading 25. Okay looking at those sets of values what does it say about the relationship between pressure and volume? As I say on your page 164 - it says that the volume of the fixed amount of gas is inversely proportional to the pressure of the gas if the temperature remains constant. Okay this practical proved that. As you change the pressure there should be a change in the volume and you should get those readings. (Bongi Lesson Observation, 13/05/2013)

Bongi was not adequately prepared and did not test the equipment before the lesson. The lesson was dominated by teacher talk. The learners had to still complete a report write-up using the example data for assessment purposes. Bongi discussed details of the report write-up during the last 15 minutes of the lesson:

What is the hypothesis for this? Volume of a fixed amount of gas is inversely proportional to the pressure of the gas at constant temperature. So then you write the method and apparatus. Then write the readings in a table like this. Then draw the graph with labels and for discussion say the volume and pressure was inversely proportional. And don't forget the conclusion. I want the report in next lesson. It must neatly be written. (Bongi Lesson Observation, 13/05/2013)

In Bongi's lesson on verifying Boyle's Law, the learners were able to see a Boyle's Law apparatus but were not able to collect data because the apparatus malfunctioned. However, Bongi instructed the learners to complete the report write-up for assessment, using the method written in their textbook, and worksheet (Appendix M5) and the example data she provided.

5.2 Analyses of the Lessons Observed

In the preceding section, four examples of practical work lessons observed were described to illustrate both common and unique characteristics. The lesson observation instruments used to record characteristics of the practical work lessons were described in Chapter 3. What follows is a discussion of the analyses of the data collected from eight practical work lessons as described in Chapter 3. The practical work activity to illustrate Boyle's Law taught by Bongi could not be completed because the Boyle's Law apparatus malfunctioned. This lesson is omitted from the analyses provided in this section where the three focus areas are the types of practical work, the skills taught, and whether the teacher intended objectives were achieved.

5.2.1 The types of practical work activities observed

Eight out of the nine lessons observed were classified according to the type of practical work, using the classification system provided in Appendix F and summarised in Table 3.3. The following aspects of the lessons were examined: the role of the teacher and learners during each stage of the activity; the openness of the activity; and whether the learners knew the outcomes of the activities. The classification of the eight lessons according to the type of practical work is captured in Table 5.4 below.

Table 5.4 Eight practical work lessons classified according to the type of practical work

Practical Work and Teacher	Teacher & Learner Roles	Topic	Question	Method	Collect data	Analyse data	Type of Practical Work
Heating and Cooling Curve (Jiten)	T hands-on T minds-on L minds-on	T	T	T	T & L	T & L	Does not fit existing classification
Titration (Vish)	T hands-on T minds-on L minds-on	T	T	T	T	T & L	Does not fit existing classification
Division of potential (Eric)	L hands-on L minds-on	T	T	T	L	L	Confirmation Investigation
Inter-molecular forces (John)	L hands-on L minds-on	T	T	T	L	L	Confirmation Investigation
Momentum (Lenny)	L hands-on L minds-on	T	T	T	L	L	Confirmation Investigation
Evaporation Capillarity (Sarah)	L hands-on L minds-on	T	T	T	L	L	Confirmation Investigation
Circuits (Jane)	T hands-on T minds-on	T	T: Aim	T	T	T	Teacher conducted cookbook exercise
Precipitates (Betty)	L hands-on	T	T: Aim	T	L		Learner conducted cookbook exercise

T = Teacher L = Learner Teacher Conducted Cookbook Exercise

Six out of the eight practical work activities analysed involved investigations (Table 5.4). The activities included stating the investigative question, collecting data using a given method, analysing the data and reaching conclusions. For the various types of investigations observed, the roles played by the teachers and learners, as well as whether the learners knew the outcomes, were different. Two practical work activities could not be classified using the existing classification and four were classified as Confirmation Investigations. Further, one practical activity was classified as a teacher conducted cookbook-type activity, and another was classified as a learner conducted cookbook-type activity. A characteristic common to the eight practical work lessons was the importance placed on the report write-up, which was assessed to provide a continuous assessment mark. The eight teachers prioritised a large part of the one-hour lesson to discuss the format and contents of the report write-up. In addition, both the teachers and learners were concerned with obtaining the “correct” results to complete

the report write-ups. Another common characteristic was the provision of written instructions on the procedure in worksheets or the textbook and a list of questions to be answered in the report write-up. Further, in all practical work lessons the teachers discussed the relevant theories and concepts at length and appeared to prioritise this over the learners developing skills. Except for the lesson “Precipitates”, all activities involved the teachers or learners manipulating variables. The six practical investigations involved an inquiry question, while the two cookbook exercises followed the aim of the lessons.

Two practical work lessons could not be classified using the existing classification system (Table 5.4) because they did not fit the existing classification system. The teachers conducted the investigations and were hands-on and minds-on, and the learners were minds-on. Here, even though the learners were not hands-on, they were engaged in the activity and were minds-on. These practical activities were the “Heating and Cooling Curve of Water” taught by Jiten and “Titration” taught by Vish. Jiten set up the apparatus, collected data, and were assisted by three learners who completed the data collection. Jiten explained the rationale for the method and the precautions taken, and demonstrated how to collect the data accurately. Jiten provided example data for the learners to analyse and engaged the learners through explanations and questions throughout the activity. Jiten’s discussions were important because he explained concepts such as “latent heat” that occurred at the microscopic level and were not easily observable at the macroscopic level. He explained how inferences had to be made from analysing the data such as the differences in the temperature readings obtained. The learners needed to have prior knowledge of theories such as the “Kinetic Molecular Theory” and Jiten helped learners make links between the theories learnt and the findings from the investigation. Moreover, the data obtained from this investigation differed from that obtained under ideal conditions, as mentioned in textbooks. Jiten’s hands-on and minds-on involvement in the investigation provided opportunities for him to explain why he provided example data. These included the conditions in the school laboratory that were not ideal for obtaining the expected results and the large amount of time needed to collect all the data required. Similarly, the “Titration” practical conducted by Vish provided opportunities for him to engage with the learners, explain various concepts, and demonstrate the specialised skills required to operate the burette. It appeared, from the analyses, that it was most appropriate under the circumstances to teach the practical work lessons on the “Heating and Cooling Curve of Water” and “Titration” as teacher conducted investigations where the

learners were minds-on. This investigation-type practical activity does not fit into the existing classifications and requires a revised classification system. Rogan and Grayson (2003) stated that teacher conducted inquiry practical activities are appropriate for countries with emerging economies where resources might not be sufficient for individual learner activities. In these contexts teacher conducted investigations where the learners are minds-on may be common, necessitating a revised classification system for practical work.

The following four practical work lessons were classified as Confirmation Investigations: “Division of potential” taught by Eric; “Inter-molecular forces” Appendix M7) taught by John; “Momentum” (Appendix M4) taught by Lenny; “Evaporation and Capillarity” (Appendix M8) taught by Sarah. The learners engaged in hands-on and minds-on activities. The teachers provided the topic, question, and method for these investigations and the learners collected and analysed the data. While the learners knew what patterns and relationships to expect from the data, the conclusions had to be reached from analysing the actual data collected from the practical. Due to the availability of sufficient equipment, the learners were able to work in pairs to conduct the investigation on the “Division of potential”. Larger groups of learners collected data in the other four lessons. The teachers began the lessons with a recap of the relevant theory and concepts taught in the theory lessons. They also guided the learners throughout the investigations and assisted them to analyse the data, make inferences, and reach the conclusions.

The practical work lesson on “Precipitates” (Appendix M6) taught by Betty was classified as a learner conducted cookbook type activity. After a short introduction on precipitates, Betty explained the procedure, including the labels on the test tubes. The learners followed the steps in the procedure given and it did not involve the manipulation of variables. The learners had to identify the solutions from the precipitate formed from mixing the reagents and this did not involve analysing the data or making inferences. The learners guessed which precipitates would form based on the information provided in the theory lessons. The lesson on “Series and Parallel Circuits” taught by Jane was a teacher-conducted cookbook type activity. She began the lesson with a revision of concepts learnt in the theory lessons such as current strength, potential difference, and resistance. The learners observed Jane connecting the bulbs in series and then in parallel, and measuring the current strength and potential difference at different points in the circuit. She recorded the measurements on

the chalkboard and explained the differences in the readings taken. Jane proceeded to manipulate variables such as the number and position of the bulbs in the circuit, and pointed out how this affected the current strength and potential difference each time. This teacher-conducted cookbook type activity was adequate for illustrating concepts on series and parallel circuits taught in the theory lessons. Both teachers ended the lessons with a discussion of the format of the report write-up. The learners had to complete and submit a report write-up on the activities.

The teachers followed the direction given in the CAPS curriculum and preferred the prescriptive nature of the CAPS curriculum because it indicated which practical work is important for assessment. Betty stated that the practical work “is a lot more prescriptive” and that by “standardising the practical work” it assisted her teaching, “The CAPS has gone a long way in terms of - for me at any rate - I think it helps” (Betty Interview, 29/05/2013). Some of the typical responses include that of Raj, “When given the opportunity to finishing theory and choosing a prac then I would move in the direction of trying to finish the theory that’s logical ya” (Raj Interview, 23/05/2013). He added, “I like to do it more often but I will never be able to complete the syllabus and the child is not going to be prepared for the examination” (Raj Interview, 23/05/2013). John’s comments were similar, “If I was having a bad term I don’t know whether I would be doing the practical. I would say let me leave out the practical work and focus on the theory for the exam” (John Interview, (13/04/2013). Eric also stated, “So once we know we can leave this prac out and not pay so much attention we can then manage our time a bit better” (Eric Interview, 13/01/2013). John also touched on the advantages of standardising the practical work:

And the thing about the CAPS that I like is that it tells you which is prescribed, which is recommended because what happens when we go for moderation we say that we ought to have done the same practical and a boy that scored 80 percent in my practical was handling the same type of data and method and apparatus as your boy, therefore my 80 percent and your 90 percent we can compare abilities and skills. (John Interview, 13/04/2013)

For Neel, prescribing practical work forces teachers to teach it, “I think in the CAPS it is more theory and they got the prescribed practicals. In that way it is good because the teacher knows that it is compulsory to do it” (Neel Interview, 21/05/2013). Raj mentioned the value of prescribing the type practical work, how, and when it should be done:

I will say that it must be prescribed that all these pracs must be done per section. If you doing ions then this is the pracs and it must be done in this way on these dates. In that particular way then it forces teachers and learners to do the prac. (Raj Interview, 23/05/2013)

Mr Sihle, a subject advisor was in agreement:

The prescribed / recommended experiments are there to emphasise content. The main reason is to make sure that learners are exposed to practicals because if these experiments were not prescribed most educators will be tempted to ignore practicals when teaching to rush work schedules and scope. (Mr Sihle Interview, 21/01/2015)

The subject advisors stressed the importance of complying with the requirements of the CAPS policy. Some teachers stated that if practical work is not prescribed, then they would not teach it because their priority was coverage of content and preparations for examinations. Lungi admitted to only teaching the prescribed practical work because, “I don’t have time to do that – I have to cover all the topics – so I will do only those that are prescribed – I don’t have time to do all the other ones” (Lungi Interview, 19/01/2015). Preggs referred specifically to focusing on the requirements of the high-stakes exit examinations, “We are focusing on mostly the prescribed practicals in grade 12” (Preggs Interview, 08/05/2013). John alluded to using the prescribed practical work to determine the teaching plan, “And a lot of the times you have to say which of the practicals have to be done for the CAPS grid and we work backwards a lot of the time but it should actually be the other way around” (John Interview, 13/04/2013). Subject advisors, Mr Vinay and Mr Thami also mentioned that teachers only taught the minimum required prescribed practicals.

Another observation made in this study was the inconsistent and interchangeable use of experiments and investigations. Vish referred to one practical work activity as both an experiment where he demonstrated the practical activity and an investigation where the learner discovers the concept:

Let’s say you take acceleration due to gravity – you will do a prac with a ticker timer ticker tape in class which is the experiment and then you will try and give them an exercise where you try and get them to do on their own the investigation – discover on their own.

(Vish Interview, 13/04/2013)

John used the terms investigations and experiments interchangeably:

I also believe that part of the success within our school is that we put enough emphasis on the weighting of those pracs in that our investigations are set sufficiently difficult enough to keep the marks fairly under control in a sense. So because we kept our experiments to be challenging and the rubrics are sort of designed to be fair. (John interview, 13/04/2013)

5.2.2 Manipulative skills, procedural understandings and process skills

Grussendorff et al. (2014) reported that manipulative skills, process skills, and procedural understandings are mentioned 267 times in the Physical Sciences CAPS document. They found that the manipulative skills such as setting up and manipulating equipment; measuring; and reading measurements are mentioned 115 times in the CAPS document across grades 10 to 12. Process skills are mentioned 113 times and procedural understandings are mentioned 39 times across grades 10 to 12 in the CAPS document. The word “skill” and related words and phrases were coded 165 times in the 28 interview transcripts. Learners in some of the practical work lessons observed practiced manipulative skills, process skills, and procedural understandings.

In those lessons where teachers taught hands-on practical work, not all learners practiced manipulative skills. Three learners in Jiten’s lesson on the “Heating and Cooling Curve of Water” assisted him with collecting temperature readings. One learner held the thermometer in the beaker of water and read the temperature every two minutes. Another learner used a stopwatch to indicate the two-minute intervals, while the third learner wrote these temperature readings on the chalkboard. Jiten used this time to engage with the rest of the learners who observed the data collection. He discussed, for example, the reasons for using specific equipment such as the stove, the precautions that were being taken, and how to read the thermometer. Once Vish had completed the practical activity on “Titration”, he called learners in groups of four to five to the front of the lecture theatre. Vish permitted the learners to open and close the burette while swirling the conical flask. He guided the learners, mentioning techniques to ensure that the reagents mixed well without breaking the tip of the burette. Due to limited time, not all learners in the groups practiced these manipulative skills and had to observe others. The learners in Eric’s practical work lesson “Dividing Potential” worked in pairs to conduct the investigation. The learners set up the circuits, connected the multimeter, and collected the data. Large groups with the numbers of learners ranging from five to ten learners completed the following practical work lessons: “Inter-molecular forces”, “Momentum”, and “Evaporation and Capillarity”. One to two learners from each of the aforementioned groups collected the data, while other group members noted the data and observed the activities. The learners in Bongi’s lesson on “Boyle’s Law” were expected to collect data from one Boyle’s Law apparatus in large groups. However, the equipment malfunctioned and the learners were not able to collect any data. Large groups of up to ten

learners completed the practical activity “Precipitates”. One to two learners in each group manipulated the objects and materials, for example, measured the reagents, used medicine droppers to add the reagents to test tubes, and mix the reagents. Other group members assisted with observing and describing the precipitate formed, identifying the unknown solution from the precipitate formed, and noted the results obtained. The learners in Jane’s teacher-conducted practical work lesson on “Series and Parallel Circuits” observed her conducting the practical and recorded the readings she obtained from the ammeter and voltmeter. Hence, not all learners had opportunities to be hands-on in the teacher-conducted activities. Additionally, the dynamics of large groups were not conducive to the practicing of manipulative skills by individual learners.

Padilla’s (1990) classification of process skills (Appendix H) was used to identify process skills taught in the lessons observed. A summary of the process skills observed in the nine lessons are captured in Appendix N. Collectively in the nine lessons observed, the teachers taught all six basic process skills and four out of the six integrated process skills, as identified by Padilla. The basic process skills taught were observing; inferring; describing measurements; communicating; classifying; and predicting. The learners had to communicate the results of the practical activities in the form of a report write-up, including for the practical work “Heating and Cooling Curve of Water” and “Boyle’s Law” where the teachers provided example data for the learners to analyse. The learners had to observe phenomena produced by themselves or the teacher, and the manipulating of objects and materials, in all lessons except “Boyle’s Law” where the equipment malfunctioned. Learners in all the lessons except “Boyle’s Law”, “Precipitates”, and “Series and Parallel Circuits” were given opportunities to describe quantities that were measured. The learners had to make inferences from the data collected in the following lessons: “Dividing Potential” and “Momentum” where learners had to collect and analyse the data. In the lesson “Precipitates”, the learners had to use the classification provided to identify the precipitates formed. In contrast to basic process skills, fewer integrated process skills were observed in some of the lessons. Learners had to interpret the data collected or the example data provided by the teachers, together with the teacher or in their groups, in all lessons except the teacher-conducted practical work on “Series and Parallel Circuits”. In the hands-on Confirmation Investigations, “Dividing Potential” and “Momentum” the teachers discussed how to control variables and in all lessons except “Boyle’s Law”, the learners or teachers manipulated variables. Learners formulated the

hypothesis in the “Division of Potential” practical work lesson, while in the other eight lessons the teachers provided the hypothesis. However, all teachers mentioned the research questions, hypotheses, and variables when discussing the report write-up. The integrated process skills, “Design Experiment” and “Formulating Models” were not taught in the nine practical work lessons observed where neither the learners nor teachers planned the experiments or investigations. From the afore-mentioned analyses of the process skills taught in the lessons, it can be concluded that the teachers taught more basic process skills than integrated process skills.

In contrast to the manipulative and process skills taught, there was less emphasis on providing opportunities for learners to develop procedural understandings. The classification of procedural understandings (Appendix G) that can be taught by doing practical work, as identified by Gott and Duggan (1995), was used in this study. Similar to the CAPS document, the procedural understanding identified in the lessons observed was understanding variables. In Jiten’s lesson on the “Heating and Cooling Curve of Water”, he discussed what was meant by the control, dependent and independent variables and why it was important to identify and manipulate these variables. He then helped learners identify the variables in the investigation and discussed how to represent the dependent and independent variables on the axes of the graphs. Similarly, Eric discussed how to identify, manipulate, and measure the variables in the lesson, “Division of Potential”. Jiten also discussed how to represent the data in tables and graphs, the importance of selecting the correct range of values, and the best-fit curve. Both Eric and Jiten, as well as Lenny who taught the practical “Momentum” discussed the importance of using the correct techniques and measuring instruments. One example of this was Eric mentioning how to connect the multimeter in the circuit and the importance of connecting the multimeter correctly. Jiten and Vish, as well as John (Inter-molecular forces), Sarah (Evaporation and Capillarity), and Lenny (Momentum) emphasised the importance of measuring accurately. They mentioned, for example, the meniscus of liquids and avoiding the error of parallax.

5.2.3 The intended and actual teacher objectives achieved

Data on what learners did and learnt during the practical work activities were gathered using the Lesson Observation Framework instrument (Appendix I). To establish whether the learners did and learnt as was intended by the teacher, the achievements of the learners

were compared to the teacher intended objectives. The Lesson Observation Framework instrument based on the “map” of practical work tasks proposed by Miller (2009) and Miller et al. (1999) consisted of the following three sections:

- Section A: Teacher aims and objectives for the lesson
- Section B: What learners did with objects, observables, and ideas
- Section C: Degree of openness and closeness. Learner involvement and interactions.
Motivation and other observations

The rationale for the structure and contents of the Lesson Observation Framework as one of the data collection instruments used in this study was discussed in Chapter 3. During the pre-practical work teacher interviews, the teacher intended objectives for the tasks were established. These intended objectives were compared to the actual objectives achieved by learners. A summary of the objectives achieved in each of the nine lessons observed is provided in Appendix O. What follows is the analyses of the data collected from the nine lessons observed, presented in the format of the three afore-mentioned sections (Sections A, B, and C).

Teacher aims and objectives for the lessons

In the pre-practical interviews, the teachers were asked to indicate what their objectives were in terms of knowledge and skills to be attained. No formal achievements tests were used to determine what learners had learnt from the practical work activities. The achievement of the learning objectives were established from the learners’ responses to the teacher’s questioning, the learning opportunities made available for learners to learn as intended, whether the learners correctly completed the relevant tasks, and by checking what the learners recalled and understood about the activity during the post-practical interviews.

In terms of knowledge and understanding, all teachers mentioned that the objective of their lessons was for learners to learn facts, concepts, and theories. Specifically they mentioned revising theory learnt, verifying theory, learning concepts, learning facts, developing knowledge, understanding laws, and making abstract concepts concrete. For example, Lenny wanted his learners to learn about the Law of Conservation of Linear Momentum and how momentum is conserved. Jiten’s intended learning objectives included the learning of the Kinetic Molecular Theory and concepts such as boiling, evaporation, condensation, and latent heat. John mentioned that he wanted learners to learn about the concept of intermolecular forces and the breaking of bonds when solids and liquids are

heated. All teachers spent an average of 20 minutes revising theory learnt in class. The learners did not learn concepts or theories from the practical activities but the teachers used the theory learnt to explain phenomena observed. No new theory or concepts were taught.

In all nine lessons observed, the learners were able to identify objects as intended by the teachers, for example, learners identified the different parts of the circuits in Eric's lesson. All learners were familiar with the equipment used, including the Boyle's Law apparatus that they saw for the first time because of diagrams in the textbooks. Except for the teacher demonstrations taught by Jiten and Eric, all other teachers intended for learners to learn how to use the equipment. However, except for the learners in Eric's lesson who worked in pairs, not all learners from other lessons were able to practice using equipment because they worked in large groups. The intended phenomena or events were not always easily produced in the lessons observed, for example phenomena such as latent heat in the activity on the "Heating and Cooling of Water". In the lessons on titration, division of potential, intermolecular forces, and evaporation, either the teachers or learners succeeded with producing the intended phenomena, which the learners were able to identify. Learners often knew what results to expect because of theory lessons or information from textbooks, for example a learner from Betty's lesson on "Precipitates" said, "This is Copper Sulphate which should make a white precipitate, but it's not". All teachers were successful with getting learners to follow procedures, analyse data collected or example data given, and communicate findings. None of the learners planned investigations as their teachers had intended and not all learners were given opportunities to conduct investigations. All teachers prioritised the communication of findings through the completing of the report write-up of the practical activity.

What learners did with objects, observables, and ideas

The practical work lessons were analysed to determine what the teachers intended for the learners to do and what the learners actually did. Specifically, the lessons were analysed to establish what the learners did with objects or what they observed, and how they used their ideas to think about what they were doing or observing. In the sections below, the descriptions of the lessons will centre around what learners did and observed, and how they used ideas to think about what they were doing.

In the learner hands-on practical activities, the teachers were successful with getting some learners to do with objects, as intended. These learners had opportunities to manipulate objects to generate data, except for the lessons on “Titration”, “Series and Parallel Circuits”, and “Boyle’s Law”. Vish who conducted the investigation on “Titration” and Jane who conducted the lesson on “Series and Parallel Circuits” did not mention that they intended for learners to manipulate objects. Learners were given an opportunity to practice using the burette but did not collect data in the lesson on “Titration”. Bongi intended for the learners to manipulate objects but they did not do so because the equipment malfunctioned. Three learners collected data from the equipment set up by Jiten, while learners in groups collected data in the rest of the practical lessons. In the “Division of Potential”, learners manipulated data in pairs. However, in the rest of the lessons with large groups, not all learners were able to manipulate equipment. In these instances, the learners observed other learners or the teacher manipulating objects and materials. Hence, not all learners were given opportunities to practice manipulative skills.

In the practical on the “Heating and Cooling Curve of Water” taught by Jiten, the phenomena were difficult to generate from manipulating the objects. Jiten set up the equipment and demonstrated how to collect the data. Three learners assisted him to collect the data. The phenomena were not easy to produce from manipulating the objects and the learners were not able to make the expected observations and were only able to watch how the data could be collected. The first temperature recorded by the learners was 10°C. However, in the textbook, the first reading appears as -2°C. Jiten attempted to provide an explanation for this:

The best time to do this experiment was in the morning when it was still a bit cold, right? Now it’s a bit hot so we don’t expect our results to be exactly the same. Now we are not actually going to get negative values, right. Why won’t we get negative values? It’s too hot, isn’t it – I told you if we were in an air-conditioned room it will work nicely or if you were doing this in the freezer that would work nicely as well. (Jiten Lesson Observation, 13/02/2015)

The learners continued to collect the data and record the temperature readings on the chalkboard. It became apparent that the data was not reflecting the expected plateau as seen in the theoretical heating curve of water. Jiten then asked learners to use the example data provided (Table 5.3). Similarly, for the “Cooling Curve of Water”, Jiten was not able to collect data because the ambient temperature was not conducive to decreasing the temperature of the water and cooling of the water would require a lot of time.

Regarding what learners had to observe, with the exception of the lessons on Boyle's Law where the equipment malfunctioned, the learners were given opportunities to observe phenomena. Most learners were able to explain the observations made from the learners or teachers manipulating objects. This required guidance from the teacher. In Eric's lesson, he questioned the learners on the patterns they found in the data collected:

T: No I'm not comparing the series with the parallel – I'm saying in the series resistors only – do you see any patterns with the numbers that you got?

L6: The total is bigger than the individual

T: Okay so the total is bigger than the individual. Any other?

(Eric Lesson Observation, 14/05/2013)

However, in Betty's lesson on "Precipitates", she did not use opportunities to check the learners' observations when they did not get the expected results:

L1: That's what it says but we don't know if is Nitric acid. *Raises hand. Explains to Betty that they are seeing a milky blue colour but it shouldn't be that colour.*

T: *Looks at the test tubes.* Write down your observations.

(Betty Lesson Observation, 29/05/2013)

It was observed that some of the learners struggled to explain their observations using their ideas. The learners had to identify unknown solutions by observing the characteristics of the precipitate formed, when the unknown solutions were reacted with known solutions. Some learners referred to notes from the theory lesson and were confused when their results did not match their notes. In one group, the learners disagreed on the colour of the precipitate. One of the reasons for this was that they did not have a colour reference to compare the precipitates:

L1: This is yellow because see: white, cream, yellow

L2: This must be yellow because Iodine

L1: Yes it is yellow. *All four learners write down the colour.* We need more Silver Nitrate

L1: *Shakes test tube*

L2: What is this one? *Points to a test tube*

L1: This is Copper Sulphate which should make a white precipitate but it's not

L3: It's yellow

L4: It's blue

L1: Yellow. It shouldn't be yellow.

L4: It needs more because there is too much Copper Sulphate

L2: But maybe its Nitric acid. *Refers to the worksheet*

L1: That's what it says but we don't know if is Nitric acid. *Raises hand. Explains to Betty that the milky blue colour is not correct*

T: *Looks at the test tubes.* Write down your observations

L4: Turns milky blue. *All learners write in their worksheet*

L4: And this is AgNO_3

L2: That's the last one

L5: AgCO_3

L4: No we don't work with AgCO_3 . It's AgNO_3

L2: But that is what we added. Sodium dissolves

- L1: Sodium Nitrates. The Nitrates are solid. Now we doing Potassium Nitrate. It shouldn't be like that because Nitrates are white
- L4: Looks blue
- L1: Looks white
- L4: I'm saying blue. You saying?
- L 2: Blue
- L 1: No it's white. It was the light
- L 4: Ya it's the light. It's white
- L 2: It's white
- L 3: Is there a precipitate?
- L 4: There's nothing there
- L 2: AgNO_3
- L3: AgNO_3 ?
- L 2: Ya. Okay next page guys
- L 1: Okay first one we got – see the first one – NaCl
- L 2: NaCl
- L 1: *Adds drops*
- L 3: Its white
- L 2: Its definitely white
- L 1: Ya mix it around and need to see precipitate
- L 3: You know what – it is a white solution. I cannot really see anything
- L 1: Ya It's white. (Betty Lesson Observation, 29/05/2013)

This practical lesson was an example of learners not being able to explain observations made from manipulating objects. After completing the steps in the procedure provided, the learners from one of the groups observed took out their notes from class and looked at a completed table, which was similar to the worksheet given in the practical. While one learner read out the answers softly, the others wrote them down in their worksheets. In this example, the teacher was successful with getting learners to do as intended with objects but less successful with getting learners to think about their observations and make inferences, as intended.

Some teachers provided opportunities for learners to state the aim, make predictions, identify variables, identify patterns in the data, and explain observations made, even when example data was given. Vish stated the aim for the learners, “So in this titration we are going to find the concentration of the HCl. So the aim of the experiment by doing the titration we are going to determine the concentration of the HCl”. Lenny started the lesson on “Momentum” by asking questions, “So what is this practical about? What is the aim? You need to now state the hypothesis”. In the lesson on “Dividing Potential” Eric asked learners to write down the aim, hypothesis, and variables at the start of the lesson. When discussing the report write-up he discussed these concepts again in detail. The teachers helped learners to think about what they were doing and observing, when discussing the report write-up:

- T: Then for investigative question remember it has to be a question. You trying to find something out. So we say what is happening in a parallel circuit and in a series circuit – something like that. And what is the hypothesis?
- L: It is an educated guess [Some learners]
- T: Into what?
- T: Okay it is an informed, an educated guess into what the final answer is going to be. So what the answer to the investigative question is going to be. So you write the investigative question and then you going to answer it.
- T: Then you going to have the variables. So there was a lot of confusion the last time. So what are the variables?
- L: [Silent]
- T: Explain what variables are. What does it mean?
- T: So for independent variables it is what we change. So what are we changing here?
- L12: The resistance
- T: How is it changed? You measuring 1 measuring 2 measuring 3
- T: Its what we change and we see what is affected by this
- L12: The current
- T: No not the current – the potential difference here measured in volts
- T: So is that the dependent or independent variable?
- L: [Silent]
- T: So that is the dependent variable. So what other variables do you get?
- L4: Control
- T: Control variables. So what are control variables?
- L: Things that stay the same [Few learners]
- T: Things that we don't want to change. Remember that when we do an investigation, we want to see how certain factors affect our outcomes and we only look at one thing. We only going to look at how resistance is going to change potential difference – so anything else that could affect potential difference – we want to isolate that and say we don't want that to change. So what are we keeping constant in this case?
- L3: The battery (Eric Lesson Observation, 14/05/2013)

In all lessons observed, the teachers assisted learners with explaining the observations.

An example of this is John explaining evaporation:

So listen – someone is talking about kinetic energy of the particles and someone is talking about the strengths of the intermolecular forces – so look at me boys, we basically looking at the strengths of intermolecular force. So you know that by the time the ten minutes is up the liquid that has lost the most amount of substance – do you think that the particles will be held together by strong intermolecular forces or weak intermolecular forces?

(John Lesson Observation, 14/05/2013)

Jiten and Bongsi discussed observations made from the example data they provided. Jiten attempted to explain concepts such as latent heat:

- T: Is room temperature 100 degrees Celsius? Why is the temperature staying constant? You want to help her?
- L4: Because it is breaking the attractive forces
- T: It is because the energy is being used to break the attractive forces that is holding the liquid particles together without increasing the temperature. What is that energy called? The energy that is being used at the boiling point and the melting point without increasing the temperature? What is that energy called? That hidden energy? Yes?
- L5: Kinetic

- T: That's one word that starts with an 'L'. Look at your practical report questions. What is it called? *Silence. No responses from the learners*
- T: Latent heat. (Jiten Lesson Observation, 22/02/2015)

Learners had to report on the practical work lesson using the data collected or example data. The teachers discussed all aspects of the report write-up in detail. The worksheets were central to the lessons and the teachers structured the lessons according to the format of the worksheet. The teachers followed the sequence of activities, as indicated in the worksheets, for example beginning with stating the aim of the activity, followed by the procedure to follow. The structure and format of the report write-ups were also based on the worksheets. Instructions for the structure of the report write-ups were prioritised with some teachers such as John discussing it at the beginning of the lesson:

Very quickly first one, we going to see that we going to look at intermolecular forces and the strengths of intermolecular forces ... Okay so for today's practical we are going to – starting today you are going to do observations and collect data in groups and then you are going to start most of your observations I am telling you now that the write up - the practical write up there are certain steps that you are going to follow. (John Lesson Observation, 14/05/2013)

Learner interactions during the lessons are summarised in Appendix O. The learners either, watched the activity being demonstrated by the teacher or worked in groups to follow a standard procedure to collect data. Learners were not allocated to groups but formed groups according to where they were seated. The teachers did not allocate roles for group members and usually one learner per group collected the data while others watched. For the lessons taught by Eric, John, Sarah, and Bongsi, the learners often interacted with each other but not about the activities. However, when the report write-ups were being discussed when the learners were most attentive. The learners were assessed on the activities using the report write-up submitted. Learners also interacted with the teacher but this was mostly to answer questions, to check if the data collected was 'correct', or to get clarity on the report write-up and the assessment thereof. In the lesson taught by John, a learner sought clarity on the importance of the report write-up for the term mark, "Sir does our final write up go towards our term mark? Yes that's important. Listen. The final write up – you won't be doing everything today – the final write up ... this is a term 2 practical" (John Lesson Observation, 14/05/2013). Teacher questioning during the lessons were mostly limited to recalling the relevant theory associated with the activity. Eric however, questioned learners on the data collected, "Do you see any pattern? What is the relationship between the

readings?” (Eric Lesson Observation, 14/05/2013). For the lesson on Boyle’s Law, the learners were unable to collect any data because the equipment malfunctioned. However, they had to use the example data provided to complete the report write-up. Bongi explained this in detail at the end of the lesson:

For the report you going to complete the worksheet like im telling you. I want it in the next lesson. This is for the term so don’t copy I will give zero and what headings you gonna use? Right see the worksheet. See the first part that is the method. Now you must first with the aim. What is the aim? To verify Boyle’s Law. Then that table must be completed. You see that? First write the pressure and then the volume. Use these ones (*Points to the chalkboard*). Then do the graph. You are now analysing the data. Answer the seven questions. But before that you must do your discussion. This report is for marks so no copying. Everyone must do their own now.
(Bongi Lesson Observation, 13/05/2013)

In Lenny’s practical work lesson, he asked the learners to explain the data obtained from the practical lesson in terms of what was taught in the theory lessons:

- T: How will you know it is following the Law? Look at the Law of Conservation of Momentum and tell me how it applies to this practical. Remember the relationship between the initial and final momentum I covered in class. What is it?
L1: If the initial momentum is equal to the final momentum.

(Lenny Lesson Observation, 13/02/2015)

The learners were interviewed after the lessons to gauge what they had learnt from the practical activity. The learners recited theory learnt from class and where not always able to say how the theory related to the activity. One of the learners, Nisha was asked whether she knew about the Kinetic Molecular Theory, she replied, “Yes I know. We learnt it. It says molecules move because of energy they have and the spaces between like gases have more spaces” (Nisha Learner Interview, 13/02/2015). Nisha also recited the definitions of latent heat of fusion and how the word “latent” meant hidden, just as her teacher Jiten did during the lesson. She was unable to say how the activity illustrated this concept and mentioned that she was not able to “see” this concept from the temperature readings. Other learners recited Boyle’s Law, Law of Conservation of Linear Momentum, and the formulae for calculating the concentration of the reagent in the titration or for calculating quantities in a circuit.

Except for Eric, all other teachers intended for learners to discover concepts but the learners were not able to achieve this in the lessons observed. The learners in Eric’s practical work lesson were given the opportunity to identify and later discuss the relationships between variables during the discussion of the report write-up. In other lessons, the teacher either told the learners what the variables were or did not discuss this at all. When learners were able to make observations, they had to account for the observations using known explanations or the

teachers provided the explanations. One such instance was the explanation provided by Vish for the colour changes that were observed:

Vish: Acid. Now let me put a little Sodium hydroxide. If I put too much I will bring it back to blue. Okay its blue because too much acid. Obviously if I want it to be accurate I will use a burette etc. Now I have HCl in the burette – I am doing this very carefully now because when I did it before – I shot the end point or I went past the end point. Ah there we are. *Shows green solution in the conical flask after adding HCl.* It has reached end point – pH of 7. So now it is neutral – it has been neutralised. If I went beyond this then it would turn yellow because it would have too much of acid. (Vish Lesson Observation, 26/04/2013)

The teachers were more effective with getting learners to do with objects and observables than with ideas. However, the learners had few opportunities to practice basic manipulative skills. The teachers did not use the opportunities in the lessons to discuss ideas that emerged from the manipulation of objects. Often, when ideas were discussed, for example accounting for observations made, the teachers discussed these ideas in the context of the report write-up. In Appendix O, links between learner or teacher hands-on activities and learner ideas are summarised. Not all ideas emerged from the manipulation of objects or making observations. The learners were able to identify objects, identify some patterns in the data, and report on observations. Some ideas, such as exploring relationships between variables, explaining patterns, and accounting for observations were teacher guided. Pearl stated that she prepared learners for the practical question in grade 12 examinations, “For our matrices, now I give them questions with model answers because there are questions there that are very specifically practical” (Pearl Interview, 22/05/2013). John’s response captures the views expressed by teachers on how the practical work done is influenced by the assessment requirements and what is examined:

Over the past few years the scientific method has come out in the matric exam so we governed by that – we are now trying to get our grade 8 and 9s into writing reports and we throw in a question on especially variables. At matric level especially in chemistry they do put in the scientific method – they actually ask them what apparatus did you use to collect the gas or measure the volume of the gas. (John Interview, 13/04/2013)

Betty summarised what most teachers expressed in the interviews. The learners “just have to understand what a variable is and they could get it right. It is unlike a prac exam because now there is no prac exam so it is a lot of theory ... No one cares about pracs even though a learner may have picked up more skills than the one that got an A”. (Betty Interview, 29/05/2013)

5.3 Conclusion

The video transcripts and the Lesson Observation Framework documents of the lessons observed, were analysed to answer the second research question, “What are the characteristics of the practical work done?” Two out of the nine lessons observed were teacher conducted investigations where the learners were minds-on. This type of practical work activity did not fit into the existing classification system and this necessitated a revised classification. Four practical work activities were classified as Confirmation Investigations. In addition, two practical work activities were classified cookbook type activities where one was conducted by the teacher and the other was learner conducted. The ninth lesson was not completed because the equipment malfunctioned. All practical work lessons followed a similar format in terms of the duration, structure, and focus of the lessons. There were several mismatches between the intended teacher and the actual objectives achieved in the lessons. Known ideas emerged from the manipulation of objects. The teachers provided opportunities for some learners to practice basic process skills but fewer opportunities to practice integrated process skills. The report write-up and the assessment thereof was the main focus of the practical work lessons. In the next chapter, based on the rationale for doing practical work presented in Chapter 4 and the characteristics of the lessons observed presented in this chapter, I will explore possible reasons why practical work was implemented in particular ways.

CHAPTER 6

ANALYSIS AND INTERPRETATION OF THE RESULTS

The aim of this study was to establish the role of practical work in the teaching and learning of Physical Sciences. Using a main focus question and three research questions to guide my study, I was able to collect the necessary and adequate evidence, to generate assertions to answer the research questions. In Chapter 4, to answer the first research question, I presented the rationale for doing practical work, according to the teachers and subject advisors, as well as the stated purposes in the Physical Sciences CAPS curriculum policy document. I then provided descriptions of what happened in the practical work lessons observed in Chapter 5, to answer the second research question on the characteristics of the practical work done. A synthesis of the findings from the previous two chapters provided answers to the third research question on why practical work was done in particular ways. The findings and descriptions from the previous two chapters also provided the context and the evidence that is presented here to support the claims made. Going beyond descriptions, in this chapter I provide analyses and interpretations of the results described in Chapter 4 and Chapter 5. In the next chapter, I present a synthesis of the commentaries made in this chapter to present the role of practical work in the teaching and learning of Physical Sciences in high-stakes examinations, and offer possible recommendations to improve practice.

In this chapter, related sub-assertions with the relevant evidence are clustered to generate assertions that are answers to the research questions. The evidence consists of narrative vignettes, quotes, and extracts from the interviews and observations presented in Chapters 4 and 5. Frequently found evidence from both the interviews and observations are presented to illustrate typical and general trends in the population studied. Non-typical evidence is also presented here. In the commentaries, I compare the findings with those reported in the literature to contextualise the findings of this study and highlight any similarities and differences found.

6.1 Why is Practical Work part of the Physical Sciences CAPS curriculum?

To answer the first research question, “Why is practical work part of the Physical Sciences CAPS curriculum?” in this section I present an assertion with two sub-assertions. The main reasons for including practical work in the Physical Sciences CAPS curriculum are to support the learning of content knowledge and to develop learners’ practical skills. Teachers and subject advisors had views on the rationale for doing practical work that were similar to those published in the Physical Sciences CAPS document.

Assertion 1 Practical work is included in the Physical Sciences CAPS curriculum to support the learning of theory and the development of skills.

Teacher and subject advisor reasons for doing practical work were presented in Chapter 4. Their responses were analysed using the common categories found in the literature that were described in Section 2.3. The Rationale for doing Practical work. These categories are to learn content knowledge; develop skills; learn about the nature of science; and to motivate learners. The main reasons given by the respondents for doing practical work were to learn theory and develop skills (Table 6.1). Other lesser-mentioned reasons for doing practical work were to learn about the nature of science and to motivate learners. There were several similarities between the respondents’ understandings of practical work and that which is expressed in the curriculum document.

Table 6.1 Rationale for doing practical work: Number of times items coded in the interview transcripts

Rationale for doing practical work	Number of times coded
Learn content knowledge	273 times from 28 respondents
Manipulative Skills	140 times from 28 respondents
Process Skills	58 times from 14 respondents
Nature of Science	13 times from 6 respondents
Procedural Understandings	1 mention by a teacher
Motivate	72 times from 27 respondents

6.1.1 Practical work helps with learning theory

Sub-assertion 1a **According to the teachers and subject advisors, practical work helps learners understand and remember content knowledge, particularly abstract concepts. Learners' conceptual understandings improve when they verify theories learnt or discover new concepts.**

One of the reasons given for doing practical work was that it helps with learning content knowledge. Respondents spoke at length about learning content knowledge when asked, “Why do you do practical work?” often citing examples to substantiate their claim. Learning content knowledge from doing practical work was the largest category coded from the interview transcripts (273 times from 28 interview transcripts) (Table 6.1). According to the respondents, learners understand and remember content knowledge when they observe and conduct practical work. The respondents’ claims that practical work helps learn theory and helps learners understand and remember concepts was discussed and several examples were provided in Section 4.1. Practical Work helps with Learning Content Knowledge.

Firstly, the respondents claimed that learners’ conceptual understandings and learning of concepts improve when they conduct practical work. Specifically, when learners do practical work, it “strengthens and reinforces what you are teaching” (Jiten Interview, 22/02/2015). Learners who manipulate equipment will have a better understanding of concepts:

So we were talking about Ohm’s Law – so what I am saying that they see it - they do it – it helps in their understanding of the theoretical constructs. Like the way they set up a circuit – if they have to represent that with scientific symbols then it makes a lot more sense. I will definitely say that the child that has been through the practical work is obviously going to show better understanding. (Sharm Interview, 08/05/2013)

Learning content knowledge depends on the type of practical work activity. Some respondents mentioned that learners learn from verification practical work and for others, it is when learners discover theory. Neel’s comment illustrates this, “Practical work is the learner discovering for himself” (Neel Interview, 21/05/2013).

Secondly, the respondents claimed that when observing practical work, the visual representations help learners understand content knowledge. Fifteen respondents specifically

mentioned abstract concepts and others related how practical work helped learners with assessment because it helps them remember theory.

An example of this is Mr Sharm's explanation:

I think the practical work adds another dimension to the way learners see what is happening – to the way they answer questions and to their understanding of theoretical constructs. You know for an example if you talk about let's say Ohms' Law. You know a child who has never had the experience of seeing these quantities of current and potential difference change will not be able to sort of reflect on it if you set a theoretical question. Now a child that sees those changes would firstly draw on those experiences that they have had – it's a sort of visual perception and it tells them that this is what I've seen. (Sharm Interview, 08/05/2013)

According to the respondents, chemistry concepts are abstract and practical work helps learners to "see" and understand what is happening at a microscopic level when they observe what is happening macroscopically. Pearl's explanation provides evidence for this claim:

Many learners are visual learners. When I am doing a section like bonding or atomic structure which – so you can't see inside an atom so those are the things that you must bring in some sort of practical work that ties in – so what you can see macroscopically and try and explain what is happening microscopically. (Pearl Interview, 22/05/2013)

The teachers stated that observations helped learners understand theory and their thinking is stimulated. Neel felt that "practical work helps in that the child remembers it better for a longer period of time by seeing it...because science is not an abstract subject - it is more like seeing something and believing" (Neel interview, 21/05/2013).

Similar to the respondents' claims, in the Physical Sciences CAPS document (Department of Basic Education, 2011) it is mentioned that practical work "are those practical activities that are practical demonstrations, experiments or projects used to strengthen the concepts taught" (p. 9) and "must be integrated with theory to strengthen the concepts being taught" (p. 11). Further, the respondents made specific references to doing practical work to verify theory learnt and discover new concepts. There are several references to verifying and discovering content knowledge when doing practical work. Examples of these include, "Instructions to verify established theory" on page 9, while "Verify the particulate nature of matter by investigating diffusion and Brownian motion" appears on page 19, and "Verify Boyle's law" appears on page 80. The term "discover" also appears in the context of practical work, "Recommended experiment for informal assessment (2) Discover your own effective natural acid base indicator by using coloured plants" (p. 92). The teachers in this study preferred the prescriptive nature of the Physical Science CAPS curriculum, specifically with regard to practical work and assessment. One of the reasons given was that this assisted them

in their teaching because it gave them direction on what practical work to do and when. John not only indicated that prescribing when practical work should be done gave them direction but also alluded to his view that most practical work in the CAPS are demonstrations:

The thing I like about the CAPS is that it is introducing more demonstrations and it tells you where demonstrations should be done and the thing about the CAPS that I like is that it tells you which is prescribed and which is recommended ... and the prescribed are the ones we are getting done. (John Interview, 13/04/2013)

6.1.2 Learners develop skills and learn about the nature of science

Sub-assertion 1b When learners conduct practical work they develop manipulative and process skills. These skills are especially important for learners pursuing tertiary studies and careers in the sciences.

Regarding the respondents' rationale for doing practical work, the second finding of this study was the view that practical work helped learn manipulative and investigative skills. The gaining of manipulative skills, especially how to use equipment was considered especially important for learners' tertiary studies and science-related careers. The respondents also emphasised the importance of measuring as a skill. The process skills most mentioned related to analysing, interpreting, and representing data collected. The respondents claimed that when writing reports, learners develop communication skills. There was particular mention of the importance of "observing" as a skill that is developed when doing practical work. According to the respondents, when learners conduct the practical work activity by themselves, they are more likely to remember what they did when tested in the examinations. Words and phrases related to "manipulative skills" were coded 140 times in the 28 interview transcripts, making it the second largest category coded (Appendix K). Further, 14 respondents mentioned gaining process skills (58 times) from doing practical work (Appendix K).

Learners gain manipulative skills when using equipment, "Skills are developed through handling equipment" (Shoba Interview, 14/02/2015). References to becoming proficient with handling specific equipment were found 92 times in the 28 interview transcripts. It was argued that learners develop skills from doing practical work because they learn from the physical experiences. This was evident in Mitch's response, "Allowing the hands-on learners to experience the subject in a manner that they will be able to learn skills (Mitch Interview,

22/05/2013). Eric's response also captured this, "Skills where you can actually illustrate and build it, measure it, do it...and they seeing it visually and tactile. If you can make them do stuff then you know that they got the idea" (Eric Interview, 13/04/2013). The learning of manipulative skills was regarded as being important for tertiary education and careers with 13 of the respondents mentioning them. Mr Sharm mentioned that universities have complained about learners lacking laboratory skills. Jay stressed that being able to use equipment was important for learners' success in their tertiary studies:

The learner must be developed holistically. You can't be only content driven and when these learners go to university – are they going to be able to use the lab or are they going to fail because the teacher did not do any practical work? So they must like know what a burette is.

(Jay Interview, 19/01/2015)

It can be seen from Jay's response that it is important for learners to learn both content knowledge and develop skills. It was also mentioned that handling and knowing how to use equipment were important for learners pursuing careers in the sciences, for example, nurses are required to be proficient with using thermometers.

There was particular emphasis on the importance of measuring as a skill, for example, "How to measure, how to read it. Look at my measurements. What do the measurements tell me? In physics, it is vitally important to measure. How do I measure?" (Sarah Interview, 21/05/2013). John added, "Sometimes they learn how to measure, read a meniscus or how to plot a graph or analyse the ticker tape" (John Interview, 13/04/2013). To Jay, while it was important to "figure out what apparatus to use, you must know how to measure" (Jay Interview, 19/01/2015). One teacher mentioned gaining procedural understandings from doing practical work, specifically the reasoning behind choosing a particular way to represent data. The process skills most mentioned (58 times by 14 respondents) related to the data collected. Specifically, they mentioned the importance of analysing, interpreting, and representing data into graphs and tables. Other skills mentioned were drawing conclusions, communicating results, and to a lesser extent, becoming familiar with variables. Interpreting data was important for proving or disproving theories, "Yes for me a lot of it is about whether they can interpret data so that they can either fit into a particular theory that you are trying to either prove or disprove" (John Interview, 13/04/2013). Understanding the steps of a scientific investigation was also considered important. In addition, some of the respondents claimed that practical work helps learners to experience how scientists work. One example is Mr Sharm

who mentioned, “Practical work is when you get a glimpse of how scientists work” (Sharm Interview, 08/05/2013).

In the CAPS document (Department of Basic Education, 2011), there is also emphasis on the gaining of skills from doing practical work. Grussendorff, et al. (2014) found that skills related to practical work appear 267 times in the document (Table 4.1). References to manipulative skills appear 115 times, process skills 113 times, and procedural understandings appear 39 times. Regarding manipulative skills, manipulating and reading equipment; collecting data; and following the steps of an investigation are mentioned most frequently (Table 4.1). The process skills of observing; interpreting data; and drawing conclusions occur most often. Regarding procedural understandings, understanding variables is mentioned most often. Similar to the responses from the teachers and subject advisors, in the CAPS document manipulative skills appear most often, followed by process skills, and then procedural understandings. Further, in the CAPS document process skills are found most frequently in the assessment section, for example, “Practical investigations and experiments should focus on the practical aspects and the process skills required for scientific inquiry and problem solving. Assessment activities should be designed so that learners are assessed on their use of scientific inquiry skills” (p. 144). It is also stated that learners have to be “assessed on their use of scientific inquiry skills, like planning, observing and gathering information, comprehending, synthesising, generalising, hypothesising and communicating results and conclusions” (p. 144).

6.1.3 Commentary

A finding of this study was the respondents’ view that practical work helps learners understand content knowledge. They claimed that practical work provided visual representations of abstract concepts. Specifically, learners developed conceptual understandings when they verified content learnt and discovered concepts themselves when doing practical work. This, together with the visual experiences helps them remember content for assessment. This finding is similar to that of Babalola et al. (2019) who studied teachers’ aims of practical work in four sub-Saharan African countries, namely Ghana, South Africa, Nigeria, and Tanzania. They found that teachers ranked the learning of content knowledge as the most important aim of practical work, followed by the learning of manipulative and

inquiry skills. Similarly, in other studies of teacher aims in Africa, Fessehatsion (2003) and Ghebremariam (2000) cited in Babalola et al. found that teachers ranked the learning of content from practical work as the most important aim. Babalola et al. proposed that the emphasis on learning content from practical work is probably due to the curriculum requirements and the emphasis on written assessments. Earlier South African studies reported similar findings. Colussi (1975) found that teachers perceived practical work as being important for learning and understanding of theory. In the study by Lynch (1976) the teachers claimed that the aims of practical work were to stimulate interest; for developing observation skills, learn theory and develop skills. Hobden (1986) found that commonly quoted aims of practical work were the learning of theory, discovery learning, skills, creating interest, and problem solving. According to the teachers in Ngema's (2011) study, promoting conceptual understanding was the most important reason for doing practical work.

The respondents' views on the rationale for doing practical work were similar to that stated in the CAPS document, which is practical work is used to strengthen the concepts taught. The Physical Sciences CAPS curriculum was found to be content-based where scientific knowledge is presented as objective, certain and infallible (Grussendorff, et al., 2014) and the purpose for doing practical work is to support the learning of this scientific knowledge (Department of Basic Education, 2011). Zipin (2017) argued that the conceptual formulation of the CAPS curriculum was strongly influenced by the ideology of *Social Realism*, which advocates for formal subject specific "disciplinary knowledge" as opposed to "everyday knowledge" (p. 72). Indications that the CAPS is a subject-specific knowledge-based curriculum are reflected in the explicit delineation of subject topics and concepts (Ramatlana & Makonye, 2012). Further, a knowledge-based curriculum focuses on the theoretical knowledge mostly required for assessment (Green & Naidoo, 2006). In the CAPS curriculum, the formal knowledge is closely coupled with assessment (Grussendorff, et al., 2014; Slominsky, 2016; Zipin, 2017). Babalola et al. claimed that the emphasis on learning content from practical work in sub-Saharan countries is a reflection of the curriculum goals that is the learning of theory.

A second finding of this study was the respondents' view that learners gain manipulative and process skills when doing practical work. It was found that while the Physical Sciences CAPS curriculum is content-based, there is also a focus on skills

(Chigumbura, 2016; Gudyanga & Jita, 2019; Lelliott, 2014). However, the emphasis on skills is not reflected in the type of practical work prescribed in the CAPS curriculum (Gudyanga & Jita, 2019). The teaching of skills through practical work is emphasised as part of assessment and it is not clear how the skills should be taught through practical work. Gudyanga and Jita noted that “brief notes on inquiry in the preamble of curriculum documents may not necessarily mean that policy makers intended inquiry-based learning to be the main approach” (p. 727). Nakedi et al. (2012) stated that the knowledge-based Physical Sciences CAPS curriculum “does not masquerade content-oriented science as inquiry-oriented science” (p. 286). Babalola et al. (2019) found that in the sub-Saharan countries studied, low level skills such as using instruments and simple data analyses were valued. While the respondents in this study and the respondents in the study by Babalola et al. (2019) stated that the most important reason for doing practical work was to learn content knowledge, in other international studies, teachers have ranked the learning of skills as the most important reason for doing practical work. Some of the studies that reported this include those done by Abrahams and Saglam (2010), SCORE (2008), Shim, Moon, Kil, and Kim (2014), Swain, Monk, and Johnson (1999), and Wilkinson and Ward (1997a). Abrahams and Saglam attributed the importance given to inquiry skills by teachers to changes in the curriculum that promoted inquiry learning over the years, specifically the introduction of scientific investigations. Most of the teachers in Kibirige, Osodo and Mgiba’s (2014) study stated that the aim of practical work was to learn skills such as observation and experimenting. The teachers in international studies stated similar aims of practical work. Teachers from Egypt, Korea, and the United Kingdom believed that the four most important aims of practical work were to encourage observation, make phenomena real, maintain interest and promote logical thinking (Swain, et al., 1999). In 1979, Swain, Monk, and Johnson also found that teacher aims in the United Kingdom, 35 years later largely remained unchanged. Wilkinson and Ward (1997a) found that Australian teachers’ aims for practical work were to make science enjoyable, promote scientific thinking, and discover and verify facts. Similar to this study, Abrahams and Saglam’s (2010) found that assessment was an important aim of practical work. They believed that this was due to the emphasis of assessment in the curriculum. Shim, Moon, Kil, and Kim (2014) found that South Korean teachers’ aims were to learn scientific inquiry and acquire knowledge. The teachers in Wei and Li’s (2017) study believed that the aims of practical work were to learn and discover theory, see how scientists work, and learn skills.

It was mentioned that one of the reasons for doing practical work was that it showed the methods scientists use to develop and prove theories. Hodson (2014) stated that learners are unlikely to discover what scientists may have taken many years to discover and goes on to say that, “We should drop the pretence that students can arrive at significant science unaided” (Hodson, 2014, p. 2536). Bennett (2003a) stated that school science practical work does not accurately represent the multiple ways in which scientists work. Scientists use arguments and work with open-ended problems, often with no data or established methods rather than a stepwise account of procedures, which is emphasised in school practical work. Lazarowitz and Tamir (1994, p. 98) noted that there are a “multiplicity of scientific methods”. Despite the many different scientific methods available, the Popperian hypothetico-deductive view of science dominates science practical work (Bennett, 2003b). As a result, school practical work fails to reflect the ways research is actually conducted in the scientific world, for example the use of correlation studies. Scientists usually make broad generalisations from observations and patterns, enabling them to provide explanations or theories. Several methods may be used and the processes are often neither linear nor simplistic. The results from their experiments have to be interpreted and negotiated in the community of scientists in order to make their findings a fact (Millar, 1989). Hence, the idea that school science practical work helps learners discover knowledge through inductive approaches, as scientists do, have been rejected (Kirschner, et al., 2006). According to Pekmez et al. (2005), it is unrealistic to expect learners to discover things for themselves because they need to have the necessary theory as well as ideas so that they would know what to look for when doing practical work. Gott and Duggan (1995) claimed that discovery learning is not discovery in the true sense of the word because the learners conduct tightly controlled experiments where the outcomes are known. According to Millar (2004), when doing practical work, learning in the domain of ideas “is not discovery or construction of something new and unknown; rather it is making what others already know your own” (p. 6).

The evidence presented in this section show that according to the teachers and subject advisors, the reasons for doing practical work was to support the learning of theory and the gaining of skills. These rationales given by the respondents are similar to that which is stated in the CAPS document. The findings in this study on the rationales for doing practical work were similar to other studies conducted in Africa that is the learning of content from doing practical work is the most prevalent view, followed by the learning of skills. In contrast, other

international studies showed that the most important reason given by teachers for doing practical work was the learning of skills. In this study, the importance attached to the learning of content is probably due to the value attached to written exit examinations.

6.2 Characteristics of the Practical Work done

In this section, evidence is presented to answer the second research question, ‘What are the characteristics of the practical work done?’ The supporting evidence for each assertion is based on the analyses presented in Chapter 5. Four sub-assertions are used to support the main assertion on the characteristics of the practical work lessons. Several characteristics were common to all practical work conducted. The teacher directed practical work lessons were used to revise theory learnt in class, illustrate phenomena, and for learners to practice few basic skills. The lessons centred around the worksheet provided and the main focus was data collection for completing the report write-up, which was a requirement for assessment. Other characteristics included the 60-minute lessons, the absence of pre- and post-practical discussions, the inconsistent use of terminology, and learners showing interest in the activities.

Assertion 2	Lessons where practical investigations are conducted tend to follow similar patterns in terms of the lesson structure, instructional approach, and the nature of activities. Practical work lessons are mostly used to revise theory learnt. The teachers prioritise data collection to complete the report write-up for assessment. The practical work activities appear to generate situational interest amongst the learners.
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The common characteristics of the practical work lessons were the nature of the activities, the role of the teachers, learner involvement, and the outcome of the activities. The practical lessons observed followed similar patterns in terms of the structure of the lessons, instructional approach, and learner interactions. In the 60-minute lessons, the learners followed worksheets with a similar format. The practical investigations were demonstrated by the teachers or conducted by the learners in groups of varying sizes. The learners practiced low-level skills, no new concepts were learnt, and the main outcome of the activities was the generation of data for completing the report write-up. There were several mismatches between the teachers’ objectives and what the learners actually achieved in the lessons. The practical

work activities appeared to generate interest amongst the learners. In the following section, four sub-assertions will be discussed to support the main assertion on the characteristics of the practical work done. The first sub-assertion addresses the lesson structure, instructional approach, and learner involvement. The second sub-assertion relates to practical work being used to revise concepts and illustrate phenomena, while the third sub-assertion relates to hands-on and minds-on practical work. Practical work and learner motivation is addressed by the fourth sub-assertion.

6.2.1 Lesson structure, instructional approach and learner involvement

Sub-assertion 2a	The structure, instructional approach and learner involvement follow similar patterns in the practical investigation lessons. The learners collect data or observe teachers conducting investigations in the teacher directed lessons.
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In the practical investigation lessons, there were similar patterns in three main aspects of the lessons. These aspects were the structure of the lessons, the instructional approach used, and learner involvement in the lessons. The format of the worksheets used was similar and was central to the lessons. The planning phase of the investigations was distinctly absent. The lessons were teacher directed and the learners were mostly attentive during the lessons.

All practical work lessons were of 60-minute duration and were typically divided into three parts: revision of theory; collection of data; and discussion of the report write-up. With the exception of Eric's lesson on the "Division of Potential", all teachers began the lessons with a revision of the related content taught in the preceding theory lessons. In Jiten's lesson on the "Heating and Cooling Curve of Water", he checked learners' understanding of the Kinetic Molecular Theory and questioned them on concepts such as heat, kinetic energy, evaporation, boiling, and latent heat. The teachers and/or learners collected data during the second part of the lesson and the final part of the lesson was dedicated to discussing the results and the report write-up for assessment. Another pattern found in the practical work lessons was the absence of any planning of the investigations. The learners were not required to plan the investigations but were provided with the aim, the research question, materials, and procedure to follow. There were also no post-practical discussions but the lessons ended with the completion and submission of the report write-up. While the solutions were generally

known to the learners, the conclusions had to be reached from the data collected in the lessons. One example of this was Vish's lesson on "Titration" where the concentration of HCl was determined by titrating it with a known volume and concentration of Sodium Hydrogen Carbonate.

Regarding the instructional approach, the practical investigation lessons were teacher directed and tightly controlled. The teachers decided on the selection of the practical work activity, the materials to use, procedures to follow, the data to collect, and how to analyse the data. In addition, the teachers discussed the findings and determined how the findings were to be communicated. The teachers used discussions and questions to engage with the learners. An additional classification of investigation activities where the teachers conducted the investigations with learner involvement, were identified. The lessons on the "Heating and Cooling Curve of Water" taught by Jiten and "Titration" taught by Vish were teacher-demonstrated investigations. The teachers set up the apparatus, collected data, and analysed the data with the learners. In the discussions, Jiten and Vish made links between concepts learnt and the data collected during the lessons. In this way, they were able to direct the learners' focus to important events during the observations such as when the end-point was reached during the titration. Vish was also able to demonstrate specialised skills such as operating the burette. The learners in these teacher conducted investigations were minds-on. This type of practical work activity could not be classified using the existing classification. This required a revision of the existing classification system. In four practical work lessons observed, the teachers provided the topic, question, and method and the learners collected and analysed the data. The teachers guided the learners throughout the investigations and assisted them to analyse the data, make inferences, and reach conclusions. There were varying degrees of teacher involvement, for example, John provided more direction in the lesson on "Inter-molecular forces" than Eric did in the lesson, "Division of potential". John analysed the data collected with the learners, while Eric guided the learners so they could reach conclusions from the analyses.

Learner involvement and interactions were also similar in the practical investigation lessons with light variations. The learners were attentive during the teacher discussions of the procedure, the analyses of the data, and the requirements for the report write-up. The teachers used questioning and discussions to keep the learners engaged. An example of this was the

lesson on “Titration” taught by Vish where he explained concepts such as endpoint, standard solutions, indicators, and colour changes, while he conducted the investigation. During his narrative, he also mentioned the different aspects and steps of a scientific investigation. In contrast, practical work investigation lessons conducted by learners in large groups were often noisy, possibly due to the large numbers of unoccupied learners where not all learners participated or contributed to group activities.

6.2.2 Practical work used to revise concepts and illustrate phenomena

Sub-assertion 2b In South Africa, teachers use practical work lessons to revise and verify theory taught and illustrate phenomena or processes

In the practical work lessons, the teachers revised content learnt in class and the learners or teachers verified the theory learnt through the practical activities. The teachers did not teach any new theory or concepts but illustrated phenomena or processes. The teachers claimed that practical work activities made abstract concepts concrete for learners. They also mentioned that one of the reasons for doing practical work was for learners to discover new concepts.

The teachers typically took 20 minutes of the hour-long lessons to revise the theory learnt in class and did not introduce new content or concepts. Some of the related theory that was taught prior to the practical work lessons was the Kinetic Molecular Theory; Law of Conservation of Linear Momentum; and Boyle’s Law. The practical work lessons were also used to verify concepts taught, for example the relationship between resistance and potential difference. Regarding the practical work activities, the learners knew the expected results and explanations for the results obtained. When the actual results from the activities did not match the expected results, the learners reverted to their notes or the textbooks for answers. Ben, a learner interviewed after Betty’s practical work lesson on “Precipitates” stated that he did not learn anything new because the Table that they were required to complete during the practical work activity was already completed as part of the theory lesson. When asked what the reason for doing the practical work was since he knew the answers to the worksheet, a typical answer came from Ben who said, “I have no idea. Just less trouble when just learning from the book for it. The prac work takes up a lot of time and could be doing other things” (Ben Learner

Interview, 29/05/2013). In Lenny's practical work lesson on the Law of Conservation of Linear Momentum, another typical response was from Muzi. He stated that he did not learn anything new from the practical activity and knew what results to expect because "we learnt it thoroughly in class" and "Yes, I knew that it will follow the Law of Conservation" (Muzi Learner Interview, 13/02/2015). However, the teachers and subject advisors mentioned that practical work helped learners discover knowledge and learn new concepts. An example of a typical response was from John who mentioned that learners "interpret that data and discover the conclusions by themselves and that's where they discover the concepts" (John Interview, 13/04/2013).

Some teachers were able to illustrate phenomena and processes during the practical work activities. In Vish's lesson on "Titration", learners were able to observe the intended colour change, which he pointed out the precise moment the end-point was reached. This required guidance from the teacher who directed the learners to what they should observe and when. Vish also demonstrated the titration process to the learners. The learners in Vish and Jiten's lessons were not given opportunities to test their explanations after the demonstrations. They listened attentively and made extensive notes during the teachers' discussions of theory and how the activity would be assessed. When asked whether practical work helped them understand the theory learnt in class, most learners indicated that the practical work done did help them understand the theory taught. When questioned about their understanding of concepts through the practical work activity, the learners recited theories and Laws learnt in the theory lessons such as the Kinetic Theory of Matter. The learners interviewed after the lessons were asked about what they learnt from the activities. They all mentioned an aspect of theory learnt in class such as definitions of latent heat.

The expected outcomes or results are not always achieved when doing practical work. In the practical work lesson on "Precipitates" the learners did not always achieve the expected results from the activity, as was learnt in the theory lessons. The learners struggled to identify the colour of some precipitates without a colour reference and were not sure if the precipitates did form or had formed and dissolved. Additionally, the learners were not able to generate certain phenomena from the practical activity, "Heating and Cooling Curve of Water". While the phase changes of water were observable, other phenomena such as latent heat were not easy to generate or observe. Acquiring the desired ambient temperature, keeping the ice at 0°

Celsius, and having sufficient time to produce phase changes from melting ice to evaporation contributed to the difficulty experienced with generating some of the phenomena. The teacher provided example data to illustrate and discuss the concept of latent heat theoretically with the learners. Learners were not made aware of the reasons for the differences between the expected and actual temperature readings, for example, the effects of the ambient temperature, atmospheric pressure, the mass of the ice, sensitivity of the thermometer, or loss of heat through convection. When the expected outcomes are not achieved from the practical work activities, the teacher provides example data.

In this study, concepts such as latent heat were not directly perceptible from the practical work activity but had to be inferred from the data collected. The data collected however did not illustrate this concept because the phenomenon was difficult to generate. For this practical activity, the teacher had to provide example data. It appears that not all school science practical work can provide the necessary concrete perceptible experiences required to understand abstract concepts in the curriculum. The respondents claimed that practical work makes abstract concepts concrete and this helps in learner understandings. In addition to the concept of latent heat encountered in the practical activity “Heating and Cooling Curve of Water”, other abstract concepts included the flow of charge, intermolecular forces and bonds, the concept of energy, and force. Some abstract concepts could be illustrated by observable events such as measureable current strength and potential difference quantities; transfer of heat energy; observable behaviour of solids, liquids and gases under different conditions; and the effect of force on a body. Learners were also able to understand concepts based on everyday experiences such as gravity. However, explaining what was happening at a molecular level and linking this to what was observed was challenging, as was observed when explaining the concept of latent heat, especially when the phenomenon is difficult to generate.

6.2.3 Hands-on and minds-on practical work

Sub-assertion 2c

Teachers do not prioritise the teaching of skills when doing practical work. Learners are given few opportunities to practice basic skills. Ideas do not always emerge from the manipulation of objects and teachers have to help learners make the links between objects, observables, and ideas.

When provided with opportunities, some learners practiced basic manipulative skills. These basic manipulative skills included using a thermometer, measuring, connecting a circuit, connecting voltmeters, and using glassware. In addition, the learners practised a few basic process skills and even fewer integrated process skills and procedural understandings.

Abrahams (2005) identified three requirements to be met for learners to successfully manipulate objects and materials. Firstly, learners need to understand what they are required to do with the objects and materials. For the learner conducted practical work, the teachers explained to the learners what had to be done with the objects and step-by-step instructions for conducting the activities were given in a worksheet. For all practical work lessons observed, procedures known to the learners were used to manipulate objects and materials. Secondly, learners had to be sufficiently proficient with using the equipment and materials. The learners conducting the practical work in this study were able to manipulate the objects and materials without any perceivable difficulty. Learners practiced setting up and connecting circuits prior to the practical lesson on “Division of Potential”. During the lesson, the learners experienced little difficulty with setting up the circuits. Other manipulative skills practiced by the learners were measuring, reading a thermometer, using instruments such as a multimeter, and mixing reagents. The learners were able to measure the required quantities where simple known techniques were required, for example measuring the distance travelled by the trolley using a metre ruler. Thirdly, the equipment has to be in working order. Except for the practical activity on “Boyle’s Law”, for all other activities, the equipment was in working order. The teachers demonstrated activities where it was not practical for learners to do with objects as intended by the teachers. An example of this is the lesson on titration where there was one burette available. The teacher provided opportunities for learners to practice opening and closing the burette.

The teachers intended for learners to learn process skills such as following procedures; identifying phenomena; planning investigations; analysing data; and communicating findings. The teachers were effective with getting learners to follow procedures. The learners were able to follow the step-by-step laboratory procedures in the worksheets provided by the teachers. The learners were able to identify and observe phenomena but not all phenomena were easy to generate. The teachers intended for learners to learn how to measure, how to plan an investigation, how to collect and analyse data, and use data to support conclusions. Some of

the teachers explained how to avoid the error of parallax and how to measure accurately with the meniscus curve in liquids. The teachers guided learners on making predictions and making inferences from the data. While the learners were able to report on the observations made, they were not given opportunities to plan the investigations. The integrated process skills observed were learners stating how to control variables in the practical work lessons on “Division of Potential” and “Momentum”. Regarding procedural understandings, in the practical work lessons on the “Division of Potential” and the “Heating and cooling of water”, the teachers discussed variables, which variables to manipulate and why. In addition, most teachers stressed the importance of repeating measurements and being accurate. The teachers did not use the opportunities presented in the lessons to get learners to think about fair tests; sample size; different types of variables; choosing instruments; appropriate ways to represent data; and how to ensure reliability and validity. In addition, the teachers were more effective with getting learners to do with objects and observables than with ideas, even though the learners had few opportunities to practice basic manipulative skills. The teacher intended objectives that were achieved were using instruments, collecting data, following procedures, and observing phenomena. The ideas did not always emerge from the manipulation of objects and these had to be guided by the teachers. The learners were able to identify objects, identify some patterns in the data, and report on observations. Some ideas, such as exploring relationships between variables, explaining patterns, and accounting for observations were teacher guided.

The learners were able to identify objects and equipment used. For all nine lessons observed, the teachers achieved their intended objectives of learners identifying objects such as the apparatus and equipment used. The teachers were also able to revise the theory and concepts taught in class. Apart from the teacher demonstrations, the intended objectives for the learners to use equipment and collect data were achieved. However, not all learners were given opportunities to engage in hands-on activities. Ideas do not always emerge from manipulating objects or making observations. Doing with ideas refer to thinking about objects and phenomena generated that may not be clearly observable. For the practical investigation on the “Division of Potential”, Eric questioned learners on how the observable voltmeter readings were related to the number of batteries used. The learners had to be familiar with and know how to apply their ideas when observing the manipulation of objects. Eric discussed the properties of resistors as well as series and parallel circuits so that learners could apply these

ideas to their observations of the voltmeter readings when the resistors were connected in series and parallel. The teacher intended objective of identifying patterns in the data were achieved in Eric's lesson and Lenny's practical work lesson on "Momentum". In other lessons such as that taught by Jiten, the learners had to be guided when identifying patterns in the example data.

Not all phenomena were easy to generate or identify. In the practical activity on precipitates, the learners were not able to identify all precipitates that formed. They did not know what could be classified as precipitates and had no reference point from which to report on differences in colour. In addition, the learners also required prior knowledge to be able to make sense of what was being observed in the practical work activities. For the activity on "Momentum", the learners needed to know the concept of momentum to be able to interpret the data collected. Claire (learner in Sarah's lesson) was asked to explain what was happening between the molecules of water and how this is related to the steam that was visible. She could explain the concept of strong and weak intermolecular forces and explained the visible phase changes but could not link the concepts known with what was being observed. Further evidence of phenomena that were not easy to generate was from Jiten's lesson on the heating and cooling curve of water. He discussed concepts that were not visible from the activity and learners appeared not to have understood these concepts:

- T: Latent heat is energy being used during phase change to break those attractive force. At the melting point it is called latent heat of melting. At the boiling point, what is it called?
Silence. No responses from the learners
- T: Come on. At the boiling point, what is it called? Latent heat of boiling?
No, it is not called latent heat of boiling. What is it called? It is being turned into vapour – so latent heat of ... latent heat of vaporisation.
- T: Both boiling and evaporation is phase change from liquid to gas. So what's the difference between evaporation and boiling? What's the phase change? What's the difference between evaporation and boiling?
- L8: It takes more energy for evaporation than boiling.
- T: Good. Boiling occurs at a certain temperature when all the particles can break the attractive force. Evaporation can occur at lower temperatures as well when certain attractive forces can be broken. So here (*points to the demonstration*) it may be evaporating but it is not boiling. You will see that when it reaches boiling point you can see bubbles coming up from the bottom as well. That means that phase change is also occurring from the bottom but evaporation only takes place on the surface.
- (Jiten Lesson Observation, 22/02/2015)

The teachers were more effective with getting learners to make observations and manipulate objects, than to think about what they were doing. Ideas did not always emerge

from observations and manipulating objects, and these links had to be facilitated by the teachers. Learners had to be assisted with making predictions; explaining patterns in the data; explaining relationships between variables; and accounting for observations. The learners practiced few low-level manipulative skills and mostly basic process skills.

6.2.4 Practical work and learner motivation

Sub-assertion 2d Practical work activities appear to generate situational interest amongst learners

Motivation has been defined as being cognitively generated and influenced by the beliefs people have about what they can achieve. The term interest refers to a person's interaction with specific tasks, objects, events, or ideas. During the interviews to ascertain the teachers' reasons for doing practical work, all respondents except one teacher mentioned that practical work motivates learners.

The respondents' explanations on how practical work motivated learners were mostly similar. They stated that practical work was fun, exciting, enjoyable, and interesting for the learners. They added that it encouraged learners, developed their confidence, and motivated them to follow careers in science. The respondents used the words, "motivate", "enjoy", "like", and "interest" when discussing the rationale for doing practical work. Specifically, the words "motivation", "encourage", "encouragement", "motivate", "peak interest", "interest", "interested", "excite", "excitement", "happy", "buzz", "enjoy", "like", "enjoyed", "fun", were coded 75 times in the teacher and subject advisor interviews. While the teachers in this study stated that one of the reasons for doing practical work is that it motivates learners, they did not mention motivation as a specific objective of their practical work lessons.

In this study, it was observed that the learners did not appear to be particularly interested in or overtly enjoying the practical tasks. However, all learners interviewed stated that they enjoyed practical work with some learners specifying that it was an opportunity to do something different. "We get to see things happen and not just read about it and listen to the teacher and it is a great opportunity to do something different" (Carl Learner Interview, 13/04/2013). It appeared that the learners welcomed opportunities to learn in ways different

from the theory lessons. Learners also claimed to like and enjoy practical work. Some of the reasons given by the learners for liking practical work included, enjoying group work, it was better than listening to the teacher, getting to do something, and opportunities to see something for yourself. In the post-lesson interviews, the learners recalled specific phenomena observed. Sue mentioned “bubbles” in the practical work lesson on precipitates (Sue Learner Interview, 29/05/2013); Andile referred to the sudden colour change in the practical work lesson on titration (Andile Learner Interview, 13/04/2013); and Stewart remembered the distinct odour of the evaporated acetone (Stewart Learner Interview, 13/04/2013). In this study, the evidence presented suggests that the teachers referred to motivation when they were actually describing the interest of learners. Further, from the recollections of the learners, it appears that the phenomena observed resulted in learners gaining situational interest.

6.2.5 Commentary

One of the characteristics of the practical lessons was the teacher-centred instructional approach. In Ramnarain’s (2011) study of two Grade 9 Natural Science teachers implementing investigations, the teacher from the previously disadvantaged township school “exhibited tight control over the learning” (p. 1366). Earlier, Stoffels (2005) who studied the instructional decision-making of Grade 9 Natural Science teachers implementing the outcomes-based C2005, found that one teacher persisted with a traditional teacher-centred approach towards practical work even though the curriculum was learner-centred. McNeil (1982) reported on teachers who maintained discipline and control over their lessons through the way they presented their subject content and termed these teacher-centred, tightly controlled lessons as “defensive teaching” (p. 3). Grussendorff, et al. (2014) concluded that in the Physical Sciences CAPS curriculum, the practical work is prescribed but no guidance is given on implementation, leaving teachers to decide on the instructional approach to use. Grussendorf et al. (2014) stated that “coherence is somewhat more difficult to trace through the CAPS” (p. 121) with reference to the absence of any guidance on the pedagogical approach to use. Zipin (2017) stated that the curriculum theory underpinning CAPS is not clearly articulated and the pedagogical approach has to be inferred from the structure of the formal curriculum. Akuma and Callaghan (2018) reported on tightly controlled practical work lessons where the teacher emphasised the importance of following procedures. It is likely that given the short timeframe to complete the practical activity, the teachers preferred an

instructional approach that gave them more control so they could achieve the lesson objectives such as the two teacher conducted investigations where the learners were minds-on. Rogan and Grayson (2003) proposed a theory for curriculum implementation in developing countries such as South Africa. The theory considered the diversity of schools, the range in the knowledge and skills of mathematics and science teachers, and the lack of or inadequate resources for individual learners. They based the theory on three constructs, of which the “Profile of Implementation” was most relevant for classifying practical work. The four levels of practical work in the “Profile of Implementation” included teacher controlled activities and teacher demonstrations, which they found were typical in developing countries. According to Rogan and Grayson, practical lessons with high teacher control are not conducive to open-ended investigations where learners have greater autonomy over the activities. However, if the primary objective is to generate data then teacher directed activities might suffice. Given the afore-mentioned contexts in developing countries, it seems that teacher conducted practical investigations where the learners are minds-on would be most appropriate. This calls for a revision of the existing practical work classification system.

In the pre-practical interviews, the teachers stated that one of the objectives of the lessons was to learn theory from the practical activity. However, a characteristic of all lessons observed was that no new concepts were taught but the teachers revised theory learnt in class, which were required to understand the practical work. Some examples of this include learners understanding concepts such as energy transfer; difference between current strength and potential difference; the purpose of a resistor; indicators and colour change; and what the different precipitates indicate. This finding is similar to that of Hume and Coll (2008) who, in their study of 12 one-hour practical work lessons, found that the teachers prioritised the learning of scientific concepts. Some learners in this study stated that they did not learn anything new from the practical work and it would have been easier to learn the theory from the books. Yager et al. in Abrahams (2005) claimed that some academically able learners may regard laboratory work as being a waste of their time, delaying their learning of theory. According to Woolnough and Allsop (1985), practical work must not be used as a subservient strategy to introduce scientific concepts and develop conceptual understandings because this may affect the quality of the practical work and the understanding of theory. Hodson (2014) stated that explanations of phenomena do not simply emerge from practical work activities because of the complexity of most scientific concepts but the teachers have to make the link

with existing learner ideas. In their reviews of research, Bates (1978), Hofstein and Lunetta (1982), and Lazarowitz and Tamir (1994) have concluded that practical work had no significant advantage for the development of learners' conceptual understandings. Similar to this study, Akuma and Callaghan (2018) found that for at least half of the six practical work lessons observed, the practical work lesson followed the theory lessons and the teachers began with revising the content. Hodson (1990, p. 37) stated that learners need the relevant theoretical knowledge to understand and benefit from practical work because it is the conceptual framework that gives meaning and direction to the practical experience. Hodson (2014) stated that ideas do not simply emerge from objects and observations and teachers need to facilitate this. Stender et al. (2018) found practical work activities were not sufficient for learners to gain content knowledge even from guided inquiry activities. The learners required specific conceptual and procedural understandings in order to learn from the practical activities. The respondents also claimed that learners could discover knowledge when doing practical work. In this study, no new knowledge was taught during the activities. The claim that practical work helps learners learn new theory was questioned by Hodson (1993) who stated that there is insufficient evidence to support this claim. With the possible exception of Open Inquiry, it is believed that school science practical work is not taught to produce new knowledge (Hodson, 1993; Kirschner, et al., 2006; Mundangepfupfu, 1986). When practical work activities lead to known pre-determined answers, this is not learning by discovery (Bennett, 2003b). A finding of this study is that learners require specific content knowledge to understand what is being observed in the practical activity and no new knowledge is learnt or discovered from school practical work. This is probably due to the nature of the practical activities.

In addition, the teachers stated that through the practical work activities, the learners would verify theory learnt. Mundangepfupfu (1986) and others such as Hodson and Bencze (1998) dismissed the much stated claim that practical work helps learners verify the theory learnt. School science involves the understanding of an established body of knowledge and the ways in which this body of knowledge was established, and learners are not required to verify this established body of knowledge (Hodson, 1992, 1993). The learners in this study were asked if they disputed or accepted the theories taught in their Physical Sciences lessons. None of the learners stated that they did not believe the content learnt, for example, one learner stated that Boyle's Law was not done to disprove the Law because it is well known

that Boyle's Law exists. Hodson and Bencze (1998) stated that school science knowledge is presented as absolute truths and practical work is designed to reach pre-determined results and so learners accept it without question. Hence, school science practical work should not be used to verify, confirm or falsify established theory through the hypothetico-deductive method but to teach the scientific method, as one of the methods used in science (Millar, 1989).

Another characteristic of the lessons observed was that the activities were designed to generate data and illustrate phenomena. Roth et al. (1997) described phenomena as "regularity, a repeatable and repeatedly observable event" (p. 122). The teachers or learners manipulating objects were able to illustrate phenomena, except for the practical on the "Heating and Cooling Curve of Water". Here, due to the unfavourable laboratory conditions, not all phenomena could be illustrated. When the manipulating of objects fail to produce the required phenomena or events, opportunities to portray science realistically through practical work are missed (Hodson, 1992). Further, it was challenging to explain what was happening at the microscopic level from what was being observed macroscopically. An example of this is the concept of latent heat, which was also difficult for the teacher to explain when using example data. Complex and unfamiliar phenomena are not always easy to see and learners may require guidance (Millar, 2004). Kreidler and Kreidler (1974) earlier stated that experiments could illustrate phenomena but it required more than a single instance for learners to develop concepts and ideas, and they questioned whether experiments are the most economical and efficient way to promote concept formation. Adding to this, when either the teacher or learners have produced the phenomena or events by manipulating objects, it cannot be inferred with certainty that the learners made the required observations from the practical activities because there is a difference between "seeing" and "observing" where observing is more than seeing (Johnstone & Al-Shuaili, 2001). Observations made from sensory experiences are dependent on the theoretical framework of the observer (Abrahams, 2005; Hodson, 1988; Johnstone & Al-Shuaili, 2001) and learners need to be guided as to what to observe (Hodson, 1988). While scientists may theorise based on their observations, school science practical work require learners to make observations based on their theoretical knowledge. According to Hodson (1992), there is insufficient evidence to prove that "observing" and "doing" lead unaided to "understanding". Millar stated that it is highly

unlikely that learners observing specific phenomena without guidance, would lead to the development of conceptual understandings (Millar, 1998).

Further, a characteristic of the practical lessons observed was that there were no pre- or post-practical lessons where the teachers introduced the activities and then later discussed the findings. Pre-laboratory preparation has been defined as the background knowledge, which are the conceptual and procedural knowledge required for the learner to be meaningfully involved in the practical work activities (Johnstone & Al-Shuaili, 2001). This background knowledge acts as a filter for understanding what happens in the laboratory. According to Johnstone and Al-Shuaili (2001), in the absence of adequate background knowledge, the practical activity will be reduced to following instructions using rote learning. In a study of first year chemistry students at a South African university, Rollnick, Zwane, Staskun, Lotz, and Green (2001) found that adequate student preparation in the pre-laboratory lesson in terms of the relevant concepts were critical for the success of the laboratory activities. Equally important is the post-practical discussions because it helps learners make sense of the data. A finding of this study is that there were no pre- or post-practical discussions by the teachers. This was probably due to prioritising data collection, which was the primary objective of the lessons.

The evidence from the practical work lessons observed in this study revealed that the teachers were successful with getting some learners to do as intended with objects through hands-on activities. However, the teachers achieved fewer intended objectives when getting learners to think about the practical work tasks (Appendix P). A finding of this study is that the teachers were more effective with getting learners to practice low-level skills than to get learners to think about what was observed or the data that was collected. This finding is similar to those found by Sitole and Abrahams in their respective studies on practical work. In Sitole's (2016) study of practical work lessons conducted by two teachers, the learners were able to work with the apparatus and handle materials but were less able to use the intended scientific ideas from the data collected. In Abrahams' study of practical work, the teachers were more effective in getting learners to do what was intended with objects and less effective with getting them to think about their data (Abrahams, 2005). The finding in this study that learners practiced low-level skills and could not provide explanations for what was being observed, is similar to the findings of Hume and Coll (2008) who found that the learners

could provide descriptions but not scientific justifications. In Abrahams and Millar's (2008) study of practical work in 25 English secondary schools, they also found that the teachers focused predominantly on the substantive science content of the practical tasks and the practical work activities failed to make the link between the body of scientific ideas and objects. Abrahams and Reiss (2012) found that teachers were able to get learners to do the practical work but failed to incorporate activities to make the links between the scientific ideas and observations. Practical work can provide a link or bridge between previously taught concepts and what is being observed (Abrahams, 2011).

In the CAPS document, the list of skills to be learnt through practical work includes manipulating and reading equipment, observing, measuring, and recording data (Grussendorff, et al., 2014). The teachers intended for learners to practice manipulative and process skills such as using instruments, measuring, using a laboratory procedure, making an event occur, observing an event or quantity, and conducting investigations. A characteristic of this study is that not all learners were given opportunities to practice manipulative and process skills. When learners practiced manipulative skills, these were low-level skills. Some learners were able to observe phenomena, use equipment to collect data, measure, use procedures, and illustrate phenomena. Learners were able to conduct an investigation for the practical activity on the "Division of Potential" in pairs. Where the learners conducted the activities in large groups, one learner manipulated equipment to collect data and the group members performed other tasks such as recording data. Procedural understandings listed by Gott and Duggan (1995) were used to identify procedural understandings in the lessons observed (Appendix G). Procedural understanding involves understanding the purposes of the activity, the processes, and procedures used, and most importantly, knowing why something is done in a particular way (Gott & Duggan, 1995). Gott and Duggan have shown that in addition to substantive knowledge of laws, theories and principles, the learners have to develop procedural understandings of the concepts related to the collection, interpretation and validation of the data collected (Gott & Duggan, 1995). In this study, the evidence indicates that the teachers did not prioritise the practicing of manipulative skills, the learning of process skills especially integrated process skills, or procedural understandings.

A finding from this study is that the teachers were able to successfully engage with learners when demonstrating investigations. This was gauged from the teacher discussions

and questioning while demonstrating the practical. These demonstrations where the outcome was the illustration of phenomena and demonstration of procedures such as titration did not fit into the existing classification system. Teacher demonstrations rely on learners making the appropriate observations. Observations are more than the physical act of seeing but a cognitive process, framed by a purpose and theoretical perspective (Johnstone & Al-Shuaili, 2001). Observations made during demonstrations are actually interpretations because what one observes is dependent on what one already knows (Hodson, 1992; Roth, et al., 1997). The implications are that for teacher demonstrations, unless the learner is familiar with the scientific principles and the related discourse, which the demonstration aimed to illustrate, the learner may fail to learn from it (Roth, et al., 1997). Roth et al. (1997) identified other barriers that can prevent learners from learning from demonstrations. These are the learners' lack of a theoretical framework to separate the phenomena from the "noise"; interference from other discourses and demonstrations learnt; learners not being able to piece together various fragments of information; low importance of demonstrations in assessment; and learners not given opportunities to test their explanations. In this study, the teachers were able to engage with the learners when conducting the investigations where their narratives helped guide the learners' focus and understandings. In a study done by Hume and Coll (2008) the learners, because of their inexperience made observations that were inaccurate or incomplete. This made it difficult for them to draw significant conclusions from the data collected. Further, Hume and Coll claimed that the collection of data through observation and measurement is complicated because our observations are based on our prior knowledge and beliefs. This pre-knowledge act as a lens, influencing what we choose to observe, and what we actually observe.

In this study, it was found that learners did not seem to be overtly interested in the practical activities nor motivated from conducting practical work. However, all 14 learners interviewed stated that they enjoyed practical work. This included the two learners who stated that they did not learn any theory from the practical lesson and they could have learnt more from books. The learners mentioned that they looked forward to a different activity from the theory lessons. The learners also mentioned that it was fun and enjoyable, and they loved doing practical work. However, when probed further, it became apparent that they "loved" the activity rather than the actual practical work. They looked forward to working in groups and learning by doing something instead of listening to the teacher. While most learners stated

that they regarded practical work as being important for assessment, they claimed that they did not learn anything new from the activities. However, they welcomed the practical work lessons because the activity broke the monotony of the theory lessons. Given the definitions of motivation and interest, it appears that the learners were interested in the nature of the activities rather than the actual practical work. Motivation is a cognitive function and is generated and influenced by the beliefs people have about what they can achieve (Bandura, 1994) and as anything that “engenders an inner drive to action” (Abrahams, 2011, p. 24). However, the term interest, according to Abrahams (2011), refers to a person’s interaction with specific tasks, objects, events, or ideas. Situational interest refers to those short-lived experiences that capture the learners’ attention. According to White (1996), learners’ recollections of specific phenomena are due to their situational interest in the activity. During short-term encounters such as practical work activities, teachers can manipulate the conditions to increase the learner’s situational interest (Hidi, et al., 2004). Palmer (2009) found that this was due to opportunities for social interactions, novel experiences, and a change from the monotony of theory lessons. The teachers in Kerr’s (1963) study selected, “Arouse and maintain interest in the subject” as an aim of practical work. The teachers and learners in Wilkinson and Ward’s (1997b) study prioritised the aim, “to make science more enjoyable through actual experience” of practical work. The teachers in the studies by Pekmez, Johnson, and Gott (2005) and Babalola et al. (2019) selected motivation as an aim of practical work. Similar to the study by Abrahams (2009), the teachers in this study used the term motivation as a “catch-all” term for “interest, fun, enjoyment, and engagement” (p. 2336). To summarise, the learners looked forward to activities that were different from theory lessons and were not necessarily motivated by the practical work activities. The phenomena illustrated when doing practical work generated short-lived situational interest in the learners and did not appear to motivate the learners as was claimed by the respondents. This finding supports that of Abrahams (2011) who found that the affective value of practical work was to generate situational interest amongst learners.

6.3 Why is Practical Work being done in particular ways?

To answer the third research question, “Why is practical work being done in particular ways?” evidence to support the main assertion and three sub-assertions are presented in this section. The characteristics of the practical work implemented were discussed in Section 6.2. To summarise, in the teacher-directed practical work lessons the content was revised, the focus was on generating data and illustrating phenomena and no pre- or post-practical discussions were held. The activities were more hands-on than minds-on, basic manipulative and process skills were practised, and the learners showed some interest in the activities the lessons. In the lessons, the teachers followed the worksheets and the main outcome of the lessons was the report write-up for assessment. The main reason for practical work being done in the afore-mentioned ways can be attributed to the influence of assessment.

Assertion 3 **Assessment drives practical work implementation at the *macro*, *meso*, and *micro* levels of curriculum conceptualisation and implementation. Here, the role players are the enablers who influence the teaching and learning of practical work. The published curriculum is conceptualised at the *macro level* and interpreted by the recontextualisers who produce the examined and illustrated curricula. At the *meso level*, the reproducers (teachers) implement the practical work as they receive and perceive it.**

The curriculum is influenced at three levels, the *macro*, *meso*, and *micro levels* (see Figure 2.1, page 46). At the *macro level*, the intended curriculum is produced by the curriculum writers and made available as the published or official curriculum (Physical Science CAPS document). At the *macro level*, the recontextualisers (subject advisors, Department of Education officials, examiners) interpret the curriculum and determine the rules for implementation. These recontextualisers produce the illustrated curriculum and the examined curriculum, which consist of the published curriculum (policy) and accompanying documents that provide the rules for implementation, for example work plans, details of examinable content, and assessment guidelines. At the *meso level*, the reproducers (teachers) comply and implement the curriculum they receive. At the *micro level*, the learners acquire the curriculum. Practical work conceptualisation and implementation is influenced at each of the afore-mentioned levels by the role-players. These role-players at each of the levels determine the type and amount of practical work done, and ensure that assessment requirements are met.

6.3.1 Practical work at the *macro level*

Sub-assertion 3a	The published curriculum, which is conceptualised at the <i>macro level</i> by the curriculum writers reflects the vision and goals for the subject and is the first level where the scope for practical work is introduced. The recontextualisers at this level interpret the curriculum policy on practical work to produce the illustrated and examined curricula.
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The curriculum policy on practical work is first introduced in the published curriculum (Physical Sciences CAPS policy document). All role players accept this document as the official curriculum policy document where the subject content, the practical work to be taught, and the assessment requirements are specified. Analysing the Physical Sciences CAPS curriculum document, the team appointed by Umalusi found that the curriculum is “traditional” with a design that is “knowledge-based” supporting the learning of theory (Grussendorff, et al., 2014, p. 98). Several indicators of a knowledge-based curriculum are found in the Vision of the document (Department of Basic Education, 2011), for example, “High knowledge”, “Minimum Standards for Knowledge”, “curriculum promotes knowledge”, “content and context of each grade shows progression from simple to complex” (pp. 2 - 7). In the content section of the Physical Sciences CAPS document, further indications of a knowledge-based curriculum include statements concerning the application of theories and laws to explain and predict events and the organising of knowledge into disciplines. Practical work activities are listed per grade, topic, and term of the year. Assessment requirements are either listed as prescribed activities for formal assessment or recommended activities for informal assessment. The prescribed practical work that has to be completed for the continuous assessment of the learner is also specified. The requirements for implementing practical work are clearly stated and guidelines on when the practical work is to be conducted for each content area are given. Instructions on how practical work is to be assessed are also stipulated, “Assessment activities should be designed so that learners are assessed on their use of scientific inquiry skills, like planning, observing and gathering information ... practical investigations should assess performance at different cognitive levels” (p. 144). In the assessment section, the skills that learners have to be assessed on are specified, for example, process skills, critical thinking, scientific and problem solving skills, and scientific inquiry skills such as planning, observing, hypothesising, and communicating results. However, there is no guidance on how these skills should be assessed. While the

CAPS curriculum is knowledge-based, it is the practical work skills demonstrated by learners that have to be assessed.

The recontextualisers (subject advisors and examiners) interpret the practical work in the published curriculum and produce the illustrated and examined curricula where the rules for implementing and assessing practical work are outlined. The examiners work nationally and subject advisors work closely with the teachers in the provinces. While the prescribed, compulsory practical work is listed in the CAPS document, the examiners decide on how practical work will be assessed in the written examinations that is the mark weighting and the type of questions. The final learner assessment mark is made up of tests and examinations with a weighting of 75%. The main focus of the written assessment is the testing of content knowledge. Some examples of how practical work is tested in the written examinations include questions on the scientific method, the hypothesis, identifying variables, listing safety precautions, and analysing graphs. The continuous assessment of the learner throughout the year makes up 25% of the School Based Assessment (SBA) mark. Practical work assessment contributes to this 25% SBA mark.

The subject advisors produce the illustrated curriculum and using the guidelines in the examined curriculum, determine the rules of implementation at the school level. They determine how practical work will be assessed as part of SBA and provide supporting resources such as worksheets and exemplar examination questions. The worksheets are aligned to the practical work in the published curriculum and the assessment requirements in the examined curriculum. In this study, the worksheets had a similar format and were central to all activities in the lessons observed. The teachers did not construct their own worksheets but reproduced them from sources such as textbooks or used those that were provided by subject advisors. The worksheets typically began with the aim of the activity; a list of the materials to use; and step-by-step instructions on the procedure to follow (Appendix M1 to M8). The worksheets also contained questions related to the activity that had to be answered by the learners. In most worksheets, instructions on how to complete the report write-up were given, together with the assessment rubric. The subject advisors in this study stressed the importance of a learner's continuous assessment mark, which was moderated and standardised in meetings held with teachers from various schools. They also mentioned that as subject advisors they have no way of knowing if the practical work is actually being taught

because they often get to see only the report write-ups or the learners' continuous assessment mark for the year during these moderation sessions.

6.3.2 Practical work at the *meso level*

Sub-assertion 3b **At the *meso level* the reproducers (teachers) implement practical work as they perceive it from the curriculum received. The teachers comply with the requirements of the published, examined, and illustrated curricula.**

Teachers at the *meso level* are required to conduct the practical work that is listed in the CAPS policy document, particularly the prescribed practical work, at the specified times of the year. The teachers follow the practical work implementation guidelines provided in the CAPS and are influenced by the examined curriculum and the illustrated curriculum. A common emphasis in the prescribed curriculum and the interpretations thereof is assessment.

The reproducers (teachers) who receive and implement practical work in the classroom are guided by the CAPS curriculum, worksheets, examination guidelines and other documents provided. In this study, teacher understandings of policy requirements were mostly centred on assessment. Specifically, they could name the practical, when it should be taught, whether it was compulsory or not, and the weighting for continuous assessment. The teachers mentioned that they focused on the content that had to be covered and the practical work that was compulsory for assessment. Hence, they complied with the published curriculum in terms of teaching the compulsory prescribed practical work. One of the reasons the teachers focus on the prescribed and not the recommended practical work is to fulfil the requirements of assessment.

The teachers are influenced by how practical work is examined in the written examinations. They stated that certain aspects of investigations are examined in the written examinations and they ensured that learners are prepared for these questions. They mentioned that learners had to, for example, list the variables and the hypothesis, state safety precautions, and identify equipment and materials used. When asked how investigations are examined, an example of a typical response is one provided by Eric, "Rote formula rather than a practical investigation ... it is really not testing the practical. It is just another content-based thing they

have to learn” (Eric Interview, 13/04/2013). Other teachers spoke of preparing learners for answering practical-related questions in the written examinations by structuring practical work lessons so that it covers concepts that will be examined. One example given was listing safety precautions when doing the practical activity. Betty summarised what most teachers expressed in the interviews about examining practical work when the learning and assessment of theory is a priority. Betty stated:

The learners just have to understand what a variable is and they could get it right. It is unlike a prac exam because now there is no prac exam so it is a lot of theory ... No one cares about pracs even though a learner may have picked up more skills than the one that got an A symbol”
(Betty Interview, 29/05/2013)

The teachers received the illustrated curriculum from the subject advisors who interpreted the published curriculum and the examined curriculum. The teachers complied with the curriculum requirements, prepared learners to answer practical-related questions in the written examinations, and ensured that the learners are assessed to generate a continuous assessment mark. The subject advisors provided worksheets to guide the activities, and the teachers and learners followed the worksheets consistently from beginning to end that is from stating the aim of the activity and ending with the conclusion reached. Using similar headings from the worksheets, the learners had to complete a report write-up using the data collected. A description of the practical report write-up is as follows: it is a write up of the practical activity, which is completed by learners after the activity and is assessed to generate a mark towards the continuous assessment of the learner. The report write-up usually consists of structured questions on the aim, hypothesis, method, data collected, analysis of results and conclusion.

6.3.3 The importance of the practical work report write-up for assessment

Sub-assertion 3c

**Practical work implementation is influenced by assessment.
In the practical work lessons, the teachers prioritise generating data for completing the report write-up for assessment.**

In the practical work lessons, the teachers used worksheets to guide the activities and prioritised data collection so learners could complete the report write-up for assessment. Common to all lessons observed were the discussions on the structure and requirements of the

report write up, which typically took up 20 – 25 minutes of the lesson. The teachers and learners prioritised the following of worksheets and the completion of the report write-up.

During the practical work lessons, the teachers and learners focused on collecting data to complete the report write-up for assessment. The learners either collected data in groups or observed the teachers collecting data. A practical activity was regarded as a success if the data collected fitted known patterns and explanations. The learners knew the outcomes of the activities and when the manipulation of objects or demonstration of the activity did not produce the expected outcomes, some of the learners changed their data according to the exemplars in the textbooks or copied the results from other learners. In addition, when the desired results were not achieved from the activity, the teachers (for example, Jiten and Bongi) provided example data. According to the teachers, they did not explain why the practical activities gave incorrect results, for example, the equipment was faulty or incorrectly calibrated or the laboratory conditions may have affected the results because of time constraints. For learners, this may entrench the idea that if the expected results did not emerge from the experiment, then the practical work activity was unsuccessful. To the teachers and learners in this study, reporting on the correct data was important because the learners were assessed on the written communication of the findings. In the implementation of practical work, the assessment of the report write-up meant that the focus was on the results of the activities rather than on the practicing of skills and processes, as stipulated in the Physical Sciences CAPS policy.

Some teachers cautioned against the prioritising of the report write-up for assessment. John's statement captured this view, "As a teacher you are doing a practical for the sake of a mark and not for doing a practical" (John Interview, 13/04/2013). Later, he stressed how this influenced the way teachers taught practical work. He claimed that "a lot of the times you have to say which of the practicals have to be done for the CASS grid and we work backwards but it should actually be the other way around" (John Interview, 13/04/2013). The teachers also claimed that assessing the report write-up was not a true reflection of the learners' understandings of the activity because the learners often copy each other's work and their main focus in the lessons is to get the correct answers. Hence, assessing the report write-up was regarded as not being a fair assessment of the learner. Eric summarised the implications of the way practical work was assessed:

The kids see it as another assessment task rather than something that is illustrating the concept or something that is of interest or enjoyment or to increase their investigative knowledge or skills, if you like. It is not really teaching the skills and they not interested in the technique but about the right answer – it's all about getting the answer right – so they can get the prac write up done so they can get good marks for the write up. (Eric Interview, 13/04/2013)

The teachers mentioned that they were not able to assess the skills acquired by the learners during the practical work activity. Subject advisor, Mr Sharm provided a reason why assessing learners' skills was problematic:

Ya I think the way practical work is assessed as well needs to be re-examined. I think that it is quite difficult to assess practical work with just the theoretical perspective only. Ideally, you would like to see learners in action. But the complexities of the classroom is not allowing us to assess the learners as they are doing practical work. We tend to make up for this by assessing reports and making up tests on the practical work and it's not a true reflection of what learners know on practical work. (Sharm Interview, 08/05/2013)

The subject advisors and teachers also stated that in their opinion not all teachers were doing practical work and gave reasons why they had to assess the report write-up and not the skills acquired by the learners. To illustrate this some of the typical statements made by the respondents are given here. Mr Vinay stated that "some teachers just give learners results to do a report without having done anything practically" (Vinay Interview, 23/11/2014). Neel also claimed that "the teacher can do the same practical in theory and take the mark" (Neel Interview, 21/05/2013). Raj explained why he relied on the practical report write-up for the continuous assessment mark, "Yes to give them marks for what they are doing is difficult. So I rely on the assessment of the practical report" and "There is no other way to check" (Raj Interview, 23/05/2013). The teachers also mentioned that the practical work done is determined by the requirements for assessment and there was no time to teach any other practical work. According to Mr Sharm, the teachers and learners did not value practical work because they are aware that practical work is only done for assessment purpose. The respondents also mentioned that the questions in the practical work report write-up prepared learners to answer practical work related questions in the written examinations. They provided examples of questions on practical work that have appeared in past examination papers. John claimed that verification practical work does serve assessment purposes:

We normally do it at the end – which sometimes is not a good thing because it is a forgone conclusion - that is as a teacher you are doing a practical for the sake of a mark and not for doing a practical – what are they actually learning? But at the end they are actually only verifying what they learnt. (John Interview, 13/04/2013)

Report writing is mentioned in the Physical Sciences CAPS document (Department of Basic Education, 2011) but not with specific reference to practical work or assessment, “Note to the teacher: This type of activity (1) should be used to introduce or practice report writing and/or presentation skills” (p. 20). The activity referred to here is the listing of key discoveries of atoms. It can be surmised from the evidence presented here that assessment shapes how the practical work is conducted.

6.3.4 Practical work and the learning of theory and developing skills

Sub-assertion 3d **In the practical work lessons, the teachers focus on revising content knowledge and learners practice a few basic skills. Time allocation for practical work and perceptions of what practical work entails influence the implementation of practical work.**

Typical features of the practical work lessons were revising the theory learnt, the practicing of basic skills, and the absence of pre- and post-practical discussions. The teachers’ perceptions of what practical work entailed also contributed to why practical work was being done in certain ways.

The teachers viewed practical work lessons as another opportunity to revise theory. The assessment of the Physical Sciences is mainly through written examinations of content knowledge, which make up 75% of the final mark. In the interviews, the teachers and subject advisors claimed that practical work activities help with learning theory and understanding concepts, including discovering new concepts. There are possible reasons why the practical work lessons are used to revise theory and why new theory is not being learnt from the activity itself. The task team appointed by the examinations Council for Quality Assurance (Umalusi) to analyse the CAPS curriculum found that in the knowledge-centred Physical Sciences CAPS curriculum, the focus is on content. The teachers shared that they prioritised the teaching of content over doing practical work, to prepare for the examinations. Eric explained the consequence of prioritising the teaching of content over practical work for assessment, “Because teachers did not have enough time to complete a long syllabus they end up rushing through a section and doing the practical at the end for assessment” (Eric Interview, 13/04/2013).

The focus on examining content knowledge has translated into increased emphasis on the teaching of theory, including when opportunities such as practical work lessons arise. The respondents stated that practical work helps learners understand concepts and learn theory. It is likely that learners first need a theoretical background to understand the practical work. To make sense of the data and make certain inferences, the learners require an understanding of the related concepts, for example, momentum, resistance, velocity. This theoretical background, together with the observations and experiences from the activity could contribute to strengthening the learner's content knowledge. Explanations and concepts from the activities may not always be obvious to inexperienced learners because they may require sufficient theoretical knowledge and guidance from the teacher. The respondents mentioned that by doing practical work, the learners would be able to remember theory that will assist them in the assessments. The phenomena illustrated from doing practical work may help learners to remember concepts by being memorable episodes, instances, or events, which the learners can later recall. In the post-practical interviews, all fourteen learners made some reference to an event from their practical work lessons, for example a colour change, negative reading of the multimeter, movement of the trolleys, and colour of precipitates.

Some learners practiced few manipulative and process skills in the practical work lessons. The manipulative skills practiced included measuring, using instruments such as a multimeter, mixing reagents, connecting circuits, and reading a thermometer. The learners did not appear to have any difficulty with practicing these manipulative skills. Regarding process skills, the learners were able to follow the procedures that were detailed in the worksheets. The basic process skills taught were observing, inferring, describing measurement, communicating, classifying, and predicting. Other process skills practiced were identifying objects, analysing data, and drawing conclusions. To a lesser extent, some teachers provided opportunities for learners to develop procedural understandings such as identifying, manipulating, and measuring variables. The variables taught were the control, independent, and dependent variables. However, in the CAPS document, several process skills acquired through practical work activities are discussed in detail in the assessment section:

Practical investigations and experiments should focus on the practical aspects and the process skills required for scientific inquiry and problem solving. Assessment activities should be designed so that learners are assessed on their use of scientific inquiry skills, like planning, observing and gathering information, comprehending, synthesising, generalising, hypothesising and communicating results and conclusions. Practical investigations should assess performance at different cognitive levels and a focus on process skills, critical thinking, scientific reasoning

and strategies to investigate and solve problems in a variety of scientific, technological, environmental and everyday contexts. (Department of Basic Education, 2011, p. 144)

While the practical work skills to be assessed are listed in detail, there is no indication of how these skills are to be assessed.

The time allocated for conducting practical work also contributed to the format of the lessons and what was achieved. The respondents stated that it was due to time constraints that only the report write-ups could be assessed. The one-hour practical work lessons observed were typically divided into three parts. The relevant theory was discussed for about 20 minutes, and then the teacher demonstrated the activity or the learners collected the data, or the teacher presented example data for about 20 minutes. The last part of the lesson, which was typically 20 minutes, was used to discuss the report write-up and the assessment thereof. Hence, the one-hour lessons were sufficient for revising theory, collecting the data using given procedures, and discussing the report write-up. In the interviews, all teachers mentioned that having limited time was one of the main challenges of teaching and assessing practical work. The limitation of time also influenced the type of practical activity, as was summarised by John, “But to really achieve something in a 40 to 50 minute lesson has a tendency to be a bit artificial so often I demonstrate rather” (John Interview, 13/04/2013). All teachers interviewed mentioned that given sufficient time, they would do practical work more frequently.

In the Physical Sciences CAPS curriculum document, practical work is defined in various ways. Analyses of the text in the CAPS document revealed that the terms experiments and investigations are used interchangeably and inconsistently. Experiments are defined as the set of instructions for learners to follow to obtain results and practical investigations are defined as learners following the scientific process. Experiments are associated with verifying or testing a theory and it is stated that for investigations, the outcomes are not known beforehand (Department of Basic Education, 2011). However, some practical work with known outcomes are listed as investigations, for example, “Investigation (Physics) Pattern and direction of the magnetic field around a bar magnet” (p. 12). In the assessment section, an investigation is defined as an experiment, “An experiment is conducted to verify or test a known theory whereas an investigation is an experiment that is conducted to test a hypothesis i.e. the result or outcome is not known beforehand” (p. 145). An example of this is the Table

listing the practical work, titled, “Overview of Practical Work” (p. 12). In this Table, there are five instances where the terms experiment and investigate are used as instructions for the same activity and it is not clear whether investigate refers to investigations. Examples of these instances are, “Experiment: Investigate the relationship between force and acceleration” and “Experiment: (1) Investigate the ratio in which the following elements combine: AgNO_3 and NaCl ; $\text{Pb}(\text{NO}_3)_2$ and NaI ; and FeCl_3 and NaOH to form products” (p. 37). Another example is where an activity is listed as an investigation, “Set up a series-parallel network with an ammeter in each branch and external circuit and voltmeters ... Use this circuit to investigate short circuits and open circuits” while an example of an experiment is “determine the internal resistance of a battery” (p. 13). The practical activity to illustrate the conservation of linear momentum is listed as both an experiment and investigation for Grade 12 Term 2. The “conservation of linear momentum” is listed as an experiment prescribed for formal assessment while “investigate conservation of linear momentum” (p. 13) is listed as an investigation for informal assessment in the overview of practical work. Similar to the CAPS document, the respondents used terms investigations and experiments inconsistently and interchangeably. John’s response was typical of the respondents’ ideas about what experiments and investigations entailed. John declared that at his school they were not clear about the difference between the terms:

The CAPS document in terms of practical work – you got demonstrations, investigations, you got experiments. The one thing that I am still struggling to find out is what is the difference between – my group including Hector was sitting and asking what is the difference between a practical investigation and an experiment because we had to revise our last rubric.

(John Interview, 14/05/2013)

The respondents ideas about what practical work entailed appeared to influence their classroom implementation. Cookbook-type experiments that did not contain any elements of inquiry were introduced to learners as investigations where the teachers used terms such as investigate and scientific investigation.

6.3.5 Commentary

In Chapter 4, teachers’ and subject advisors’ reasons for doing practical work were discussed. In Section 6.2, the characteristics of the practical work observed were presented. In this section, based on the characteristics of the practical work observed, evidence was presented to answer the third research question on the reasons why practical work was being done in certain ways. In this section, I provided evidence to support the assertion that

assessment drives practical work implementation. Related to assessment is the learning of theory and the effect on practical work implementation. Another underlying reason for practical work being done in particular ways is the respondents' perceptions about practical work. Other reasons include the nature of practical work in the CAPS curriculum, and time constraints. The priority given to the assessment of the content knowledge of the Physical Sciences permeates all levels of curriculum implementation that are at the *macro*, *meso*, and *micro levels*. The role players at each of these curriculum levels influence practical work conceptualisation and implementation, and ensure that the assessment of content knowledge is prioritised.

At the *macro level* of curriculum implementation, the curriculum writers who are guided by the goals and aims of the Physical Sciences subject produce the published curriculum. Specifically, they determine the curriculum priorities, assessment protocols, and weighting of the different content areas. In addition, the type and number of practical work activities, as well as the assessment requirements are stipulated. In an attempt to understand the current CAPS curriculum and in so doing understand the context in which the practical work is found, the CAPS curriculum was compared with previous curricula. The comparison helps understand the nature of the CAPS curriculum and why practical work is prescribed in the way it is. The Ministerial Task Team evaluated the implementation of the pre-CAPS outcomes-based NCS and made recommendations (Department of Basic Education, 2009). Amongst other findings, they found that the teachers strongly resisted designing their own learning programmes and recommended the provision of clear structured content. The design of the curriculum and the terminology used were complicated and needed to be simplified. The content needed to be stipulated and the assessment requirements should be made clearer. The change from the outcomes-based NCS curriculum to the current CAPS curriculum was found to be extreme, leaning towards the opposite end of the continuum that is towards the prescriptive pre-1994 NatEd curriculum (Grussendorff, et al., 2014). While the pre-CAPS outcomes-based NCS curriculum policy promoted teacher autonomy, the current CAPS curriculum was found to be restrictive and similar to the pre-1994 NatEd curriculum (Grussendorff, et al., 2014; Gudyanga & Jita, 2019; Ramatlapanana & Makonye, 2012). Ramatlapanana and Makonye (2012) maintained that the Physical Sciences CAPS curriculum restricts teacher autonomy and is “prescriptive to the point of demanding uniformity in implementation across the nation” (p. 7). The CAPS curriculum was found to be knowledge-

centred (Hoadley, 2015), subject or discipline based (Khoza, 2016; Zipin, 2017), prescriptive about what to teach (Dempster, et al., 2015; Ramatlapana & Makonye, 2012) but not how to teach (du Plessis & Marais, 2015; Grussendorff, et al., 2014). The focus on prescriptive content and the assessment thereof promotes a teacher-centric instructional approach, which is a response to criticisms of the NCS curriculum (Grussendorff, et al., 2014; Gudyanga & Jita, 2019; Lelliott, 2014). To understand how practical work is conceptualised in the CAPS published curriculum and the rationale behind it, the evolution and historical background of the curricula in the country needs to be understood.

The reason practical work lessons were used to revise the content learnt is because the published CAPS curriculum focuses on the learning of content knowledge and the assessment thereof (Grussendorff, et al., 2014). The content is sequenced and described in detail, and stipulated for each term of the year. In the CAPS curriculum, it is stated that practical work must support the learning of theory. The respondents also mentioned the learning of theory as an important purpose of doing practical work. The importance given to learning content is probably the reason teachers use the opportunity provided in the practical work lessons to revise theory. The assessment requirements for testing the content and the weightings thereof are clearly stated. The practical work is linked to and is stipulated alongside the relevant content, for example, the related practical activity associated with Newton's Law appears together with the content. This is possibly the reason for the respondents' perception that one of the most important reasons for doing practical work is to learn theory. The practical work was found to illustrate phenomena and enhance the understanding of concepts. However, without the practical activity, the learners could still learn the concept. While practical work cannot be taught in a vacuum but in the context of the theory, the close coupling of content to practical work has been criticised because the focus becomes the verification of the content rather than learning the skills (Woolnough & Allsop, 1985). While the respondents stated that practical work helps learn theory, it was found that it is the relevant theory that is required for learners to make sense of the practical work that was important. This was probably the reason why the teachers began their lessons with a revision of the related theory.

The respondents in this study claimed that practical work makes abstract concepts concrete. It is probably the linking of content and practical work in the CAPS document that has created the perception that abstract concepts can always be illustrated by doing practical

work. Kirschner and Meester (1988, p. 86) termed this the “illustration and concretization” rationale where it is believed that learners will not be able to grasp the complex and abstract science concepts unless there are concrete experiences in a laboratory. Cantu and Herron (1978) defined abstract concepts as those that do not have perceptible instances or have defining attributes that are not perceptible, for example ideal gas. They stated that to understand abstract concepts it requires more than learners just manipulating concrete objects. It requires reasoning about unseen concepts such as how molecules in gases behave under different conditions. The perception that practical work can always provide concrete perceptible experiences begins at the published curriculum level and permeates down to the subject advisors and teachers.

The respondents claimed that practical work helps with learning theory. However, this has been viewed as being problematic. One of the reasons why new theory is not easily learnt from doing practical work is that the focus on theory in the lessons may result in information overload. Johnstone and Wham (1982) claimed that learners may experience information overload during practical work because of the nature of the activities and described the “working memory” as having “a finite capacity”, which become overloaded with incoming data (p. 71). Tamir (1991) concluded that practical work was ineffective in introducing new theory or developing learners’ conceptual understandings because of cognitive overload, which occurs because of the demands made when simultaneously applying their knowledge and practical skills. Kaheru and Kriek (2016) studied the effect of computer simulations on the acquisition of knowledge and cognitive load of physics topics by 104 Grade 11 learners in four rural South African schools. Regarding knowledge acquisition, the female learners showed that despite having low scores on the pre-tests, they showed significant improvement in the post-tests when using computer simulations. However, when it came to the females demonstrating the ability to apply the concepts, the support by computer simulations was less effective. Overall, for both female and male learners, the cognitive load initially decreased as a result of teaching both with and without the use of computer simulations in the first week but thereafter increased with time. In their study, no significant conclusion could be reached regarding the effect of using computer simulations on cognitive load (Kaheru & Kriek, 2016). Specifically regarding practical work, Johnstone and Al-Shuaili (2001) explained that learners “struggling to operate a piece of equipment may fail to make important observation and gather poor data” resulting “in a classical information overload” (p. 43). In this study, the

teachers did not always make the links between what is being observed from the practical activity and the related theory learnt, for example, using the laws learnt to account for evaporation, condensation, and latent heat. Millar and Abrahams (2009) cautioned against the perception that explanatory ideas and theories can emerge unaided from the data collected. They suggested that this might be the case because teachers may not be aware of the cognitive demand of practical work. In the practical lesson on the “Heating and Cooling of Water”, the teacher attempted to teach several concepts in the 60-minute lesson such as boiling, melting, evaporation, condensation, latent heat, kinetic energy, and “The Kinetic Molecular Theory”. The result was that the teacher could not produce all of the expected phenomena and could not link the theory to what was being observed. He then explained the concepts in theory and provided example data for the learners. The collection of data for the report write-up was a priority for both the teachers and learners because of assessment. In this study, when the teachers and learners could not produce the expected results, the teachers provided example data and the learners adjusted their results. Fairbrother and Hackling (1997) stated that learners may “fudge” results to fit certain preconceived expectations. Nott and Wellington (1997) expressed similar views, stating that there may be “conjuring” or “rigging” of results so that it fitted the expected results. Fairbrother and Hackling further stated that the greater the stakes of the examinations, the greater the pressure to use the “correct” data.

The assessment guidelines provided in the CAPS document include detailed guidelines on the practical work that are compulsory and should be assessed. The subject advisors interpret the published curriculum and provide teachers with the appropriate support, focusing on the content to be covered, and assessment thereof. The subject advisors also provided detailed worksheets that outlined how the practical work activity is to be conducted. The teachers followed the worksheets and prioritised the collection of data to complete the report write-up, which was assessed. In their study, Gudyanga and Jita (2019) described practical work in the Physical Sciences CAPS curriculum as prescriptive “recipe-like procedures that learners have to follow” (p. 727). They described two levels of prescription of practical work. At the national level, there is a list of prescribed practical work in the CAPS document and at the provincial level, “Complete write-ups of the experiments to the minutest detail are provided to teachers. Teachers did not write their own lesson plans for the experiments” (p. 721). Similarly, Akuma and Callaghan’s (2018) study of practical work in two resource-constrained schools revealed that the assessment of the practical work consisted of

“answering post-exploration questions from a worksheet”, which had to be submitted for summative assessment, in the form of a “report” (p. 82). Gudyanga and Jita (2019) found that some provincial education authorities have provided detailed write-ups of the CAPS practical work activities experiments that serve as lesson plans and templates for learner report writing. These templates have distinct headings such as “Title of practical; Aim; Hypothesis; Variables; Materials; Method; Results; Analysis of Results; Questions; Conclusion” (Gudyanga & Jita, 2019). Report write-up templates for the practical work activities are found in most textbooks and in this study were provided by subject advisors. Recording the correct results and “answers” for the report write-ups that were submitted for assessment purposes, were also important to the learners, who paid careful attention to the structural requirements of and answers for the report write-up.

There are few possible reasons why the practical work lessons were teacher directed, involved the following of known procedures, and focused on the examinable practicals. The 60-minute time allocation for practical work is limiting and requires more control from the teachers to ensure that the time is managed appropriately. In the interviews, all respondents claimed that the 60-minute allocations for the practical work lessons were insufficient and this restricted the type of activities. There is no guidance in the CAPS document on the instructional approach for teachers to use and the teachers opted for teacher directed lessons where they had more control of the activities. The listed practical activities are well documented with given procedures to follow. While this leaves little room for open-ended investigations where there are more opportunities for learners to be flexible in their learning, the practical work activities with given procedures helped teachers complete the activities in the allocated lesson time so data could be collected for the report write-up. The respondents’ stated that one of the reasons for doing practical work was for learners to develop skills. In the CAPS document, it is stated that the skills practiced in the lessons should be assessed and provides a list of these skills. However, it is the report write-up that is assessed. In the lessons, the learners practiced few basic manipulative and process skills, and the teachers focused on certain aspects of investigations and drew the learners’ attention to how these would be assessed in the written examinations. Teacher demonstrations are favoured when the lesson time is restricted because it gives the teachers more control over the activities.

From their study of practical work in three schools, Gudyanga and Jita (2019) reported that the teachers mentioned that they were “under pressure to enhance learner achievement rates in national examinations” (p. 726). They concluded that this was the reason these teachers focused only on the examinable practical work. In teacher directed practical work lessons, learners substitute external authority and rote learning for internal authority and understanding (Hodson & Bencze, 1998; Ritchie, Tobin, & Hook, 1997). Hence, learners’ intellectual independence become limited through practical work that creates an “illusion of certainty” regarding the knowledge and skills rather than negotiating and constructing their own meaning (Hodson & Bencze, 1998). Even the statement of the problem, the experimental design, and the interpretation of data and the style of write-up become non-negotiable, under strict teacher control. Teachers rely on methods and conclusions that are ‘indispensable’ and the practical activities are driven by these “proven” methods (Hodson & Bencze, 1998). Further, they stated that the excessive use of recipe-style experiments lead learners to believe that there is one method of science and the success of these experiments reinforces the illusion of certainty. Hodson and Bencze (1998) stated that when knowledge is presented as absolute truths proven by scientists and when practical work is designed to reach pre-determined results, learners accept it without question and focus on verifying results rather than developing higher order thinking skills through practical work.

The respondents’ definitions of practical work were similar to that offered in the Physical Sciences CAPS document. This could be interpreted as an indication of the importance of a curriculum policy document in shaping teacher ideas. In the CAPS document and from the interviews of the teachers and subject advisors, terms such as investigations and experiments have been used inconsistently and interchangeably. Grussendorff, et al. (2014) in their review of the Physical Sciences CAPS policy have reported on the inconsistent use of terminology. It has been claimed that the indiscriminate use of terminology when defining practical work has contributed to school science practical work being “ill-conceived, confused and unproductive” (Hodson, 1990, p. 33) and “over-emphasised and misunderstood” (Osborne, 2015, p. 16). In this study, when conducting cookbook-type practical work, the teachers referred to the activities as investigations. The terminology used by some of the teachers to describe practical work did not reflect the actual type of activity. Mudau and Tabane (2014) also found that teacher views on the aims of practical work did not reflect their practice.

The reason for teachers' preference of the prescription of practical work in the CAPS document was that it provided them with direction and guidance, and indicated to them which practicals were important for examinations. This, together with the worksheets supplied assisted the teachers and gave them confidence to implement the practical work. Similar to the teachers in this study, the teachers in Gudyanga and Jita's (2019) study also viewed the prescription of practical work positively, stating that it gave them clarity, direction, and a reduced workload. They claimed that the prescription of practical work in the Physical Sciences CAPS curriculum document may have achieved the policy maker's objective of clarifying what was expected of teachers but this is at the expense of teacher autonomy. Grussendorf et al. (2014) commented on the consequences of the prescriptive CAPS curriculum saying that some of the stated objectives, for example "an active and critical approach to learning, rather than rote and uncritical learning of given truths" is less likely to be achieved (p. 121).

Jenkins (1999) claimed that measuring accurately, is a skill that needs to not only be taught, but practised by learners. Wellington (1998) stated that there is little evidence to support the claim that skills attained from doing practical work such as observation, measurement, prediction and inference are transferable to other contexts, such as those in which scientists work. Hodson (1996) concluded that one of the common stated aims of practical work that is the learning of process skills are based on a conceptually flawed views of science. He claims that the flawed views of science have led to incorrect assumptions about practical work such as scientific inquiry can only be done through a single scientific method that has sequential, discrete, and fixed steps and processes. Another assumption about practical work is that process skills taught are generic, context-independent, and hence transferable. Scientific investigations specifically, depending on how open ended they are, require sufficient time for learners to plan and conduct the investigation, manipulate variables, analyse the data, and make inferences (Bell, et al., 2005). Other South African studies that have mentioned time constraint as a challenge for implementing practical work include those by Ramnarain (2010); (Tsakeni, 2017); Gudyanga and Jita (2019); and Ogegbo, Gaigher and Salagaram (2019). Sibam (2018) explored how seven teachers from a rural district of the Eastern Cape province managed their time when teaching the Physical Sciences Grade 10 CAPS curriculum. The teachers did not adhere to the prescribed and recommended time

allocations as stipulated in the CAPS curriculum and concluded that the challenge of insufficient time resulted in the teachers not exploring other teaching methods.

6.4 Conclusion

In this chapter, the findings and descriptions from Chapters Four and Five were analysed and interpreted to provide answers to the third research question on why practical work was done in particular ways. The curriculum writers, the examiners, subject advisors, and teachers influence practical work implementation at the different curriculum implementation levels. In a high-stakes examinations system, assessment is the main driver of curriculum conceptualisation and implementation. The role players at each of the curriculum implementation levels influence practical work implementation and ensure that assessment is prioritised. The teachers focused on revising theory learnt, the illustration of phenomena, and generating data for the report write-up for assessment. The learners practiced a few basic manipulative and process skills. The teachers were able to get some learners to manipulate objects but were less effective with getting learners to engage in minds-on activities. The practical work lessons were used to prepare learners for the written examinations by focusing on how the practical work will be assessed. Teachers' and subject advisors' perceptions of practical work influenced implementation. Their rationale for doing practical work was to support learning theory and developing skills. They viewed practical work as being important for assessment and ensured that the assessment requirements are met and learners are adequately prepared for the examinations. In the next chapter, I present a summary of the findings and list possible recommendations for improving practical work implementation. Practical work implementation has become another vehicle for promoting and supporting assessment, which is the key focus in an examinations-driven system. The learning of content for written examinations is prioritised in the CAPS curriculum. Practical work is prescribed and teachers are expected to assess learners on practical work skills. Assessing learners on skills is difficult given the time allocated for practical work, insufficient resources, and the fast-paced syllabus that has to be completed for the high-stakes written examinations. The examiners and subject advisors influence and determine how practical work is implemented. Given the focus on high-stakes examinations, these recontextualisers use worksheets to shape practical work implementation so that it serves the learning of content for assessment.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

The aim of this study was to establish the role of practical work in the teaching and learning of Physical Sciences. This study contributes to the literature on the role of practical work in the teaching and learning of Physical Sciences. The findings from this study provide insights into how teachers conducted practical work in the selected schools. Using purposive sampling, 15 schools that had laboratories and science equipment, where the teachers claimed that practical work was routinely being done, were selected. Nine lessons were observed and in total, 24 teachers, four subject advisors and 15 learners were interviewed. To answer the main focus question on the role of practical work in the teaching and learning of Physical Sciences, three research questions were used to guide this study. Answering these research questions provided evidence to establish the rationale for doing practical work, the characteristics of the lessons observed, and reasons why practical work was being done in particular ways. In this chapter, to determine the role of practical work in the teaching and learning of Physical Sciences, a synthesis of the assertions made in the previous chapter is presented, together with concluding statements and recommendations for improved practice.

7.1 An example of a typical practical work lesson taught in a Grade 10 to 12 classroom

This section provides a generic description of a typical practical work session observed in the study. The teacher schedules the practical work lesson after the related concepts are taught in class. The practical work lesson is usually taught at the end of a section. As the learners arrive at the laboratory, their excitement is visible from their chatter and the expectation that they will be seeing or doing something different from the theory lessons. The teacher hands out worksheets and instructs the learners to sit in groups of four to six learners because there is insufficient equipment and materials for individual work. The format of the worksheet is standard, usually following the format of a scientific investigation. It begins with the title of the practical, followed by the aim of the activity. The materials are then listed and

the procedure is detailed in sequential steps. A table is provided for the learner to record the results. This is followed by a set of questions based on the practical. The learners have to state the research question, hypothesis, variables, results, analysis of data and conclusion. Other questions that might be included are on safety precautions taken and the reasons for the choice of the materials used.

The teacher begins with a revision of the concepts learnt in class and engages the learners using questioning. This usually takes about 20 minutes of the 60-minute lesson. The learners then decide on who would collect the materials from the teacher's desk, conduct the investigation, and record the results. While the learners conduct the investigation, the teacher walks around to the different groups, checking if the learners are conducting the investigation correctly. Learners may request assistance from the teacher if they have any difficulties or do not generate the expected results. The data collection typically takes about 20 to 30 minutes. The learners discuss the results and compare them with the expected results in their notes and textbook. Discussions within the group usually revolve around trying different techniques to get the expected results. The learners often express excitement when they successfully illustrate a phenomenon, for example, a colour change. Not all learners in a group engage in hands-on activities. Obtaining the correct data is a priority for the learners. The learners engage in very little minds-on activities, for example, accounting for the data obtained, thinking about why certain methods were used, and justifying the sample size. Group work is often noisy with some unoccupied learners trying to socialise with each other. This is in contrast to a teacher demonstration where the learners quietly observe the teacher, listen to the teacher's explanations, and record the data collected by the teacher. The teacher usually engages with the learners as the demonstration is being conducted.

While the learners are collecting the data, the teacher discusses the report write-up, how it would be assessed, and the due date for submission. The teacher then discusses and analyses the results with the learners. The discussions follow the sequence of the required headings of the report write-up. The teacher asks the learners to state the research question, the hypothesis, and name the variables. The results are discussed as well as how to represent the data in the report write-up. The teacher makes some links between the theory learnt and the results obtained. When the expected results are not obtained from manipulating the objects and materials, example data are then provided. The questions related to the activity are then

discussed, together with details on how the report write-up will be assessed. An assessment rubric with detailed explanations is given to the learners. The teacher emphasises the importance of the report write-up for assessment and reminds the learners of the due date for submission. The value of a well-written report write-up and its importance for the learners' assessment is emphasised. The teacher also provides other instructions such as how the learner name and class number must appear in the report write-up and whether the report should be handwritten or typed. The learners return the apparatus and materials to the teacher and then leave the laboratory. Conspicuously, there were no pre- or post-practical work discussions.

7.2 Summary of Findings

Using a qualitative approach, 24 teachers and subject advisors as well as 15 learners were interviewed, and nine lessons were observed. The data were collected using interview schedules, an observation framework, and document analyses. Guided by the research questions and through an interpretivist paradigm, the data analyses enabled the generation of a number of assertions, which were the answers to the research questions. The role of practical work was established after generating answers to the three main research questions, which guided the inquiry. In this section, a synthesis of the answers to the three afore-mentioned research questions will be used to answer the main focus question, "What is the role of practical work in the teaching and learning of Physical Sciences?"

7.2.1 The rationale for doing practical work

The teachers' and subject advisors' reasons for doing practical work were to learn theory and develop conceptual understandings, develop skills, to assess learners, and to motivate learners. There were several similarities between the respondents' reasons for doing practical work and that mentioned in the Physical Sciences CAPS document. In the CAPS document, it is stated that practical work should support the learning of theory, help learners gain skills, and form part of learner assessment. These benefits were also mentioned by the respondents. However, using practical work to motivate learners is not mentioned in the CAPS document but was mentioned as a benefit of doing practical work. The skills most mentioned in the CAPS document are manipulative skills, followed by integrated process

skills and then basic process skills. Gaining procedural understandings through practical work was least mentioned. In the CAPS document, practical work is listed for each of grades 10 to 12 as either prescribed for formal assessment or recommended for informal assessment. The manipulative and process skills to be assessed are listed in the assessment section of the document. However, what is not specified is how these skills have to be assessed.

Several reasons were given by the respondents for doing practical work. It was mentioned that it helps learners understand and remember content knowledge, particularly abstract concepts. Learners' conceptual understandings improve when they verify theories learnt or discover new concepts. The visual experiences from observing phenomena help learners understand and remember concepts. When learners conduct practical work they develop manipulative and process skills. These skills are especially important for learners pursuing tertiary studies and careers in the sciences. The respondents made special mention of the skill of "measuring" that is learnt from doing practical work. The process skills most mentioned related to analysing, interpreting, and representing data collected, as well as communicating findings when learners write report write-ups. There was also mention of the importance of "observing" as a skill that is developed when doing practical work. According to the respondents, when learners conduct the practical work activity by themselves, they are more likely to remember what they did when tested in the examinations. The respondents' rationale for doing practical work and that which is stated in the CAPS document, was to support the learning of content knowledge, followed by learning of skills. Similar findings were made on the ranking of the aims of doing practical work in other African countries. However, in western countries it was found that the aim of gaining skills was ranked higher than learning content knowledge. In summary, to answer the first research question on the rationale for doing practical work, the following assertion can be made:

The main reasons for including practical work in the Physical Sciences CAPS curriculum are to help learners understand content knowledge and develop skills. The teachers' and subject advisors' views on the rationale for doing practical work are similar to that stated in the curriculum document.

7.2.2 The characteristics of the practical work implemented

The nine practical work lessons were classified using existing classification systems for investigations. Another investigation-type practical work lesson was found to be successful.

This was a teacher-conducted investigation with learners being engaged. This type of lesson did not fit into the existing classification systems. While investigations are traditionally learner conducted, the teacher-conducted investigations included learner engagement. The teachers were hands-on and minds-on and the learners were minds-on and occasionally hands-on. The teachers directed the learners' focus through questioning and providing a narrative of the procedures. They drew the learners' focus to key areas of the investigation and made references to the theory learnt. Rogan and Grayson (2003) stated that teacher conducted inquiry practical activities are appropriate for countries with emerging economies where resources might not be sufficient for individual learner activities. In these two teacher-conducted investigations, the teachers used the time effectively and attempted to explain abstract concepts that were not perceptible from the activities but had to be inferred. Although these investigations were teacher-directed, it was appropriate for practical work where link-making between what is observed and the ideas that had to be inferred, was required. Four lessons were classified as Confirmation Investigations conducted by learners. Although these investigations were conducted by the learners, the lessons were still teacher-centred because the teachers provided the topic, research question, the procedure to follow, and the learners collected and analysed the data. The learners knew the outcomes of the activities and practiced a few basic skills. One teacher conducted a cookbook practical lesson and another lesson was classified as a learner conducted cookbook practical lesson. One practical lesson could not be completed because the equipment malfunctioned.

A Lesson Observation Framework, introduced in Chapter 3, that was adapted from the that proposed by Millar et al. (1999) was used to determine the characteristics of the lessons observed. The main characteristics common to all of the practical work lessons observed related to the nature of the activities, the role of the teachers, learner involvement, the focus of the lessons, and the outcome of the activities. The practical lessons observed followed similar patterns in terms of the structure of the lessons, instructional approach, and learner interactions. In the 60-minute lessons, the learners followed worksheets with a similar format. The practical investigations were demonstrated by the teachers or conducted by the learners in groups of varying sizes. The learners practiced basic skills, no new concepts were learnt, and the main outcome of the activities was the generation of data for completing the report write-up. The practical activities appeared to generate interest amongst the learners. All activities were teacher directed and close-ended where either the teacher or learners followed known

procedures to produce known outcomes. The teachers determined all aspects of the lessons, including which practical activity, the instructional approach, the equipment, the procedure, the discussions, and learner assessment. The worksheets provided by the teachers were central to the lessons and guided the activities of the teacher or learners. The worksheets had a similar format that is the title, aim of the activity, the materials and method, as well as questions on the activity. The lessons followed a similar format where the teachers began with revising theory learnt, stating the aim of the activity, and the procedure to follow. The teachers then discussed the findings from the data collected or the data provided, interpreted, and analysed the data, discussed the hypotheses and variables, and the conclusion. Further, the focus of most of the lessons was to illustrate phenomena and generate data. However, not all phenomena were easy to generate, especially those that could not be explained at a microscopic level based on what was being observed macroscopically. In addition, some results obtained from the activities did not resemble expected results from textbooks or the theory taught. In both of the aforementioned instances, the teachers provided example data, which the learners had to discuss and report on for assessment purposes. In the teacher demonstrations, not all phenomena were easily visible to all learners.

For the learner conducted practical work activities, not all learners were given opportunities to manipulate equipment. However, in the CAPS document manipulative skills are specified, for example, conducting experiments and investigations, manipulating equipment, and collecting data are mentioned. However, in the CAPS document, there is greater emphasis on integrated process skills (appears 69 times) compared to basic process skills (mentioned 44 times), while in the lessons observed, there was greater emphasis on basic process skills such as observing and communicating findings. Some learners conducting practical work activities were given opportunities to practice the basic process skills of describing measurements, predicting, and inferring. Learners practiced the integrated process skills of determining how to control variables and controlling variables in two practical work lessons. The learners conducting the practical work investigations were given more opportunities to practice skills. However, the only opportunity provided for learners to develop procedural knowledge was through “understanding variables”.

There were mismatches between what the teachers intended to achieve and actually achieved in the lessons. For the learner conducted practical work, the teachers were most

successful with getting some learners to do as intended with objects and observables rather than with ideas. All teachers achieved their objective of learners identifying objects and materials. The teacher-controlled lessons where the teachers determined the equipment and procedure to follow, involved learners practicing some basic skills. However, the teachers were not always successful with getting learners to think about and learn from objects, observables, and ideas, as intended. In the learner-conducted practical investigations, the learners were given opportunities to think about the observations made and how to control variables. The teachers were successful with making some links between the objects and observables, and learner ideas through these practical work activities.

In the teacher- and learner-conducted practical work activities observed there was no evidence to indicate that the learners were motivated from engaging in the activities but the activities appeared to generate situational interest amongst the learners. This was concluded from the learners' recollections of phenomena and other memorable incidents after the lessons. However, the respondents used motivation as a catchall term to describe all affective experiences of the learners. The learners did not appear to be overly excited from the activities or to be having fun but used the opportunities to socialise with their peers. The learners mentioned that they liked the practical activities and welcomed the break from the monotonous theory lessons. The teachers on the other hand reported on their preference for conducting demonstrations. Some of the reasons given were that teacher demonstrations were convenient when time was limited, they had more control over the outcomes, they did not have to provide equipment for every learner, especially expensive equipment, and through their explanations, they could guide learners to understand what they were observing and draw their attention to what was important.

The teachers intended for learners to discover knowledge or learn content from the practical work activities. However, all teachers revised content already learnt in class, at the beginning of the practical work lessons. The teachers spent about a third of the one-hour lessons discussing the report write-up and the assessment thereof. Both the teachers and learners prioritised the report write-up, which was based on the worksheets provided. The format of the report write-ups were similar and were based on scientific investigations that is it contained headings for the aim of the activity, the hypothesis, the variables, the materials and method to be used, the results, analyses of the results, discussion, and the conclusion, as

well as questions on the activity. The teachers discussed each of these aspects of the report write-up, including how the report will be assessed. The teachers and learners prioritised the recording of the correct data and example data were used if the data could not be collected. The main outcomes of the lessons observed were illustrating phenomena, generating data from the activities or providing example data, revising theory learnt, and completing the report write-up for assessment.

The following assertion summarises the characteristics of the practical work lessons observed:

Lessons where practical investigations are conducted tend to follow similar patterns. The structure of the lessons, the instructional approach used, and the nature of activities are mostly similar. Practical work is mostly used to revise theory learnt, illustrate phenomena, and for learners to practice basic skills. The teachers prioritise the collection of data to complete the report write-up for assessment. The practical work activities appear to generate interest amongst the learners.

7.2.3 The reasons practical work were done in particular ways

The teachers' and subject advisors' definitions and ideas about practical work were similar to those provided in the CAPS document and this has influenced the implementation of practical work. Examples of shared meanings in the Physical Sciences CAPS curriculum document and the teachers and subject advisors include defining both teacher demonstrations and virtual activities as practical work, and the inconsistent and interchangeable use of terms such as investigations and experiments. The purposes for doing practical work according to the teachers and subject advisors were also similar to that mentioned in the CAPS document, which are to support the learning of theory, for developing skills, and assessing learners. The teachers and subject advisors mentioned that practical work motivates learners. The practical work in the CAPS policy document is cookbook-type activities for which there are known methods and outcomes. The teachers preferred the prescriptive nature of the CAPS policy. Practical work in the CAPS document is closely coupled with assessment, for example, practical work is prescribed or recommended for assessment, and the skills to be assessed are listed. The implementation of practical work has largely been influenced by how practical work is conceptualised in the CAPS policy, teachers' ideas about what constitutes practical work and the reasons for doing practical work.

Practical work implementation serves the purpose of assessment. It is not feasible for teachers to assess learners' practicing of skills during practical work because of time allocated for doing practical work and the large numbers of learners that have to be assessed. Instead, the report write-ups of the activities were assessed. The teachers focused on generating data for the report write-up and completing the theory for examinations and possible questions on practical work in the written examinations. The teachers complied with the CAPS policy requirement for generating an assessment mark through prescribed practical work activities. The teachers used the practical work lessons to revise theory, illustrate some phenomena, and complete the report write-up for assessment. When analysing the teacher stated aims for doing practical work over the years, it appeared that the aims have not changed considerably. This is probably due to the nature of the practical work that has not changed much over the years even though the focus of practical work shifted during the successive movements such as the focus on experimentation, process skills, investigations, and science practices. In South Africa, the focus has shifted back to the pre-1994 period where the focus was on the prescribed cookbook-type practical work that was used to support the learning of theory. The following assertion summarises the main reason for practical work being implemented in the ways described in previous sections:

Assessment drives practical work implementation at the macro, meso, and micro levels of curriculum levels. Here, the role players are the enablers who influence practical interpreted by the recontextualisers who produce the examined and illustrated curricula. At the meso level, the teachers implement the practical work as they receive and perceive it.

7.2.4 Proposed revised frameworks to analyse practical work and to classify investigations

To analyse the practical work lessons to determine what the teacher achieved against what was intended, I explored the “map” proposed by Millar et al. (1999). The challenge was that, from my experience in schools and from the literature reviewed on research in South African schools (Akuma & Callaghan, 2018; Gudyanga & Jita, 2019; Hattingh, et al., 2007; Rogan & Grayson, 2003), the items in the “map” did not cater for classrooms or laboratories with limited resources and time, and where known procedures exist for the prescribed practical work. Firstly, the “map” was appropriate for individual learner practical work activities where learners manipulate objects and materials or observe phenomena or events generated from them manipulating objects. In the South African context, due to space, limited

resources, and the nature of the activities (e.g. conducting a titration with one burette), the learners often conduct practical work in groups. Secondly, there was a need to include teacher aims for the lessons, in the categories that were familiar to South African teachers, as was revealed in the teacher and learner interviews. These aims were to learn theory, learn skills, for assessment, and to motivate learners. Thirdly, there needed to be additional categories for teacher demonstrations, teacher conducted investigations, teacher and learner conducted investigations, and cookbook types of practical work as was observed in South African classrooms. In the “map”, teacher demonstrations and learner involvement are mentioned under the nature of student involvement but these items need to be expanded. Fourthly, the “map” has details on items that may not be applicable to South African classrooms, such as giving four alternatives for the duration of the practical lesson, learners interacting with technicians, laboratory equipment used together with computers, and the purposes for the learners’ record of the tasks. A simple and clear framework that can be used by the teachers or observers to get a comprehensive but instant sense of what was achieved in the lesson against what was intended, was required. The result is a two-page Lesson Observation Framework document where the intended and actual objectives achieved can be captured (Appendix I).

A classification system for investigations that is inclusive is proposed from the findings in this study for South African schools (Table 7.1). An additional type of investigation is proposed that is the Type A Observation Investigation. This is in line with the recommendations made for curriculum implementation in developing countries proposed by Rogan and Grayson (2003). Their theory was based on the realities of schooling in South Africa, including the diversity of schools, the range in the knowledge and skills of mathematics and science teachers, and the lack of or inadequate resources for individual learners. The Type A Observation Investigation is where the teacher demonstrates the investigation and the learners observe the teacher and is fully engaged. One scenario is where the teacher demonstrates and is hands-on and minds-on and the learner is minds-on. In another scenario, the teacher starts the investigation and the learners continue to collect the data. Here, both the teachers and learners are hands-on and minds-on. The teacher and/or learners analyse the data and provide the solutions. The solution may or may not be known to the teacher and learners. This classification of investigations (Type A Observation Investigation) is an addition to the classification of investigations proposed by Fitzgerald et al. (2019). Learner conducted investigations where the learners were hands-on and minds-on and

the solution is known to the learner, was classified as Type B Confirmation Investigation. In Type C Structured Investigations, the learners are hands-on and minds-on, the teacher provides the topic, question, and method; and the solution is unknown to the learner. In Type D Guided Investigations, the teacher provides the topic and question; and the method and solution is unknown to the learner. In Type E Learner-Initiated Investigations, the learner decides on the topic, question, and method; and the solution is unknown to the learner. The classification covers a range of practical work types and is simple to use based on the role of the teachers and learners. In this study, it was found that the teachers preferred the curriculum to be prescribed to them. The recontextualisers of the CAPS curriculum could specify the practical work to be done and how it should be conducted, for example, using a guided investigation or a teacher-conducted investigation, depending on the objectives of the practical work.

Table 7.1 Revised classification system to determine the nature of practical work conducted

Role of Teacher and Learners at each stage of activity							
		Topic	Question	Method	Collect data	Analyse data	Solution / Conclusion
Type of Practical Work: Investigations							
Type A Observation Investigation	T hands-on T minds-on L minds-on	T	T	T	T	T & L or L	Known or unknown to L
Type B Confirmation Investigation	L hands-on L minds-on	T	T	T	L	L	Known to L
Type C Structured Investigation	L hands-on L minds-on	T	T	T	L	L	Unknown to L
Type D Guided Investigation	L hands-on L minds-on	T	T	L	L	L	Unknown to L
Type E Learner- initiated Investigation	L hands-on L minds-on	L	L	L	L	L	Unknown to L
Type of Practical Work: Teacher conducted activity							
	T hands-on T minds-on	T	T	T	T	T	Known or unknown to L
Type of Practical Work: Cookbook exercises							
	L hands-on	T		T	L	L	Known to L

7.3 Recommendations for Improving the Implementation of Practical Work

Improving the implementation of practical work should begin with clear intentions and realistic objectives in the curriculum policy document. Teachers need to understand what can be achieved through the practical work task, the objectives of practical work lesson, the context required for achieving these objectives, and how to assess practical work.

7.3.1 Teachers follow the Physical Sciences CAPS curriculum policy document and the recontextualisers influence how the policy objectives are achieved by influencing the nature, type, and the way practical work is implemented

In this study, it was found that role players influence the curriculum at the *macro*, *meso* and *micro levels*. The teachers, who operate at the *meso level*, implement the published curriculum and related documents as received from the producers and recontextualisers at the *macro level*. Teachers ideas about what can be achieved through practical work and how they teach practical work are influenced by how practical work is portrayed in the curriculum policy document. The curriculum writers and the subject advisors are influential in determining what practical work should be done, the frequency of conducting practical work, and how it should be conducted. They need to be clear about what they wish to achieve through the teaching of Physical Sciences practical work. The objectives of practical work need to be clearly articulated in the Physical Sciences curriculum policy document, for example, the skills that learners should acquire. The requirements of the curriculum policy such as the assessment of practical work should be aligned with what can be achieved through practical work, given the context of implementation. Together with the possibilities presented by practical work, the limiting contexts of schooling conditions need to be considered when designing and prescribing practical work. The amount of time required to illustrate phenomena and learn skills should correspond with the time available for practical work activities and the availability of resources. If individual learners are required to practice the skills then sufficient resources should be made available. The adapted Lesson Observation Framework proposed in this study could be used to determine which intended objectives were achieved through the practical work activity and the levels of effectiveness achieved.

7.3.2 Clearly stated objectives of practical work is required in the policy document and in all other supporting documents. The role players need to have a common understanding of these objectives and need to use the related terminology correctly

Given the many definitions of practical work, simple and clear definitions of practical work is required. The policy document should contain clear, correct, and consistent terminologies related to practical work. It is important to consistently use the correct terminology such as investigate, investigations, experiment so the type of practical work to be implemented and the instructional strategy to use is unambiguous. Curriculum writers, subject advisors, and teachers need to have a common understanding of the purpose and objectives of the practical work, and what can be achieved through practical work in the context in which it is being taught. For example, if the objectives of the curriculum are to develop scientifically literate citizens, then the appropriate skills such as problem solving and how to conduct environmentally safe experiments should be taught through the practical work.

It was also found that there was inconsistent and sometimes incorrect use of terminology. The teachers' and subject advisors' use of terminology mirrored those used in the CAPS policy document. The role players at the different curriculum implementation levels need to be consistent in their use of terminology. This would assist teachers to understand the nature and types of practical work, the objectives to be achieved, and how these could be achieved. In addition, through their influence, the role players could debunk commonly held misconceptions of practical work and its implementation. One example of this is that practical work motivates learners. There is insufficient evidence in the literature to support the claim that practical work motivates learners. The teachers need to see the value of episodes and memorable events observed during practical work activities in generating situational interest in the learners and how this could be achieved through practical work. Other examples include the notion that learners must be proficient in the use of equipment for them to be successful with their tertiary studies and science careers. While this is recommended, it is not essential because the skills learnt in school are simple enough to be learnt in later years. Teachers' and subject advisors' reference to all practical work activities as being investigations influences their teaching of practical work and is counter-productive. Thus, for

improved achievement of objectives, they should be clear about the difference between the different types of practical work activities and the learning potential of each activity.

In the CAPS document, it is stated that doing practical work illustrates how scientists work. The teachers and subject advisors also stated that by doing practical work, learners get to practice how scientists work. In the literature, it was reported that scientists work in diverse ways and these did not include the ways in which practical work is implemented at the school level. Incorrect assumptions about the way scientists work influence how practical work is conceptualised and implemented, for example, the respondents in this study were of the view that scientists follow the scientific method. While scientists may on occasion use elements of the scientific method, this is not the only method used, for example, they have been reported to use a lot of argumentation and logical thinking in their work.

7.3.3 Practical work should not be subservient to the learning of theory or used as a means to an end. In a system that is controlled by high-stakes examinations, assessment could be used to influence the implementation of practical work in meaningful ways

In this study, it was found that up to a third of the 60-minute lessons was spent on revising theory learnt. The teachers use the practical work lessons as another opportunity to teach theory. While the Physical Sciences CAPS curriculum was found to be content-based with a large emphasis on assessment, practical work should not be sacrificed for the learning of theory. Practical work activities cannot be implemented in a vacuum and is context-dependent. Practical work and the learning of theory should be complementary rather than sacrificing the learning from conducting practical work for the learning of theory. In this study, it was found that teachers relied on the content knowledge acquired by the learners to explain ideas related to practical work. Learners need the relevant background knowledge to benefit fully from the practical work activities. The content knowledge provides a frame of reference for the learners to understand what is being observed and to interpret the data gathered from the practical work activities.

There are more appropriate, less expensive and direct ways to learn the substantive body of scientific knowledge, than only through practical work. Other supplementary activities

such as inquiry-based activities, case studies, and virtual activities could support the learning of theory. The theory component of the practical activity can be assessed in the written examinations where it is more appropriate to test the learners' procedural understandings. To assess the skills obtained from doing practical work, the awarding of marks for a report write-up is not useful. The skills that are acquired through practical work need to be assessed appropriately.

7.3.4 A range of practical work activities is required to teach a variety of skills

In this study, it was found that most of the practical work activities were verification exercises that were similar, for which well-documented procedures and explanations exist. The learners need to benefit from a wider range of practical work activities. Through a range of practical work activities, a variety of skills can be taught. Practical work should include different levels of inquiry-type activities, experiments, open- and closed-ended investigations, project work, Observation Investigations, and other teacher demonstrations. The range of activities will provide opportunities for learners to practice a variety of transferable as well as context-specific skills. A set of manipulative skills, process skills, and procedural knowledge with progressive levels of complexities should be identified for learners to achieve. Making sense of data sets, making decisions based on data, constructing arguments, drawing inferences, exposure to different types of reasoning, argumentations, and problem solving techniques, as well as developing their observational skills, are important skills that can be taught through practical work. Practical work activities should be crafted so that learners would be able to practice and acquire these skills rather than practical work being used to teach theory. In addition to learner-conducted practical work, other activities that support practical work activities should be included such as teacher demonstrations and inquiry-type activities. The traditional verification and cookbook-type practical work activities prescribed in the CAPS policy can be used to achieve some objectives. However, these activities are limiting regarding the range of skills that can be acquired through practical work, for example 21st Century skills. In addition, the role of practical work, specifically in school science as opposed to within the scientific community, needs to be differentiated.

7.4 Assumptions and Limitations

Gaining access to the practical work lessons was problematic and had to be negotiated with the teachers. Given that the prescribed practical work was conducted once a term, the teachers had to invite me to their lessons and I could not visit their classrooms unannounced. The teachers could have prepared for the lessons to be observed. One of the precautions taken was that I only confirmed on the morning of the school visit. Two teachers cancelled when I arrived at the school without confirming my visit. One of the assumptions in this study was that the practical work lessons observed were part of the curriculum delivery and not artificially staged for the purposes of this research. Another assumption was that the practical work lessons were not rehearsed where learners were prepared to behave in certain ways. Claims that could not be verified had to be accepted, for example the teachers stated that practical work was being done routinely or there was insufficient materials for all learners to conduct the practical work activity individually. It was also assumed that the responses given in the teacher interviews were their own and not reproduced from other sources such as textbooks.

Attempts were made to get a good sample size. The final sample was obtained from the population of schools that did practical work as part of the curriculum. While the findings may be typical of schools in KwaZulu-Natal that carry out practical work, the intention is not to generalise to other contexts. Further, the practical work studied was restricted to only those classrooms where access was gained. The range of grades, types of schools, and types of practical work lessons observed were determined by the access granted by teachers and the practical work activity prescribed for that period. Another limitation of this study was the small range of practical work that can be studied in a year due to relatively few compulsory practical activities being conducted for assessment. Hence, the number of times each practical work activity could be studied was limited. The teachers determined the instructional strategies, for example, whether the lesson would be a teacher demonstration or learner activity. In addition, the study was published ten years after data collection and this has raised concerns about age of data set. Unfortunately the final publication of the thesis was delayed by author moving to new work in different city and then Covid-19 lockdowns. Significantly, there has been no changes or revisions to the physical science practical curriculum from 2010 to 2020 which might have had an impact on the value and relevance of older collected data or

current study recommendations. Unequal power relations between myself as a Department of Education official and the interviewees is acknowledged as a possible limitation that could have influenced the outcome of the findings. The interviewees could have provided what they thought were “correct” responses or could have staged their lessons for the purposes of this study. In an effort to prevent this I reminded the interviewees that this was my personal study and not departmental work so they were not being evaluated. I made an effort to visit the school on more than one occasion to engage with and observe teachers so they became used to my presence and did not view my classroom observations as a special assessment as is normally conducted by departmental advisors. Further, the two curriculum writers approached to participate in the study, declined. Their contributions as producers at the macro level would have provided valuable insights into the rationale for including practical work in the ways that they did.

Suggestions for further studies include studying a larger sample across other parts of the country to add to the knowledge base on the characteristics of practical work implemented. A study of practical work in primary school classrooms could give insight into the type of practical work activities and instructional strategies that would provide a good foundation of practical work for future years. Further, a study on the learning of practical work by primary school learners who are operating at the concrete-operational stage of development could give insight into how concrete and abstract concepts could be taught through practical work. Exploring scaffolding during the teaching of practical work could contribute to our understandings on how to improve practice. A study of learner conceptual understandings from doing practical work could clarify the value of practical work for teaching content knowledge. Studies that explore the reasons teachers use practical work to fulfil assessment requirements rather than prioritise the learning of concepts and skills would be valuable.

7.5 Conclusion

In this study, it was found that the role of practical work in the teaching and learning of Physical Sciences is to illustrate some phenomena, learn basic manipulative and process skills, and generate situational interest in the learners. Clear definitions, more guidance and specific information on practical work implementation, and statements on the objectives of

the activities in the Physical Sciences CAPS curriculum policy document are necessary. In addition, to improve practice, practical work should be portrayed in the curriculum in ways so it debunks myths about what can be realistically achieved from implementation. Practical work in the CAPS curriculum should not be closely coupled with the learning of theory or assessment. Practical work implementation should be viewed as unique opportunities to develop skills in learners. The possibilities and limitations of the stipulated practical work in the Physical Sciences CAPS curriculum need to be revisited with the aim of introducing a variety of practical work activities that are relevant, authentic, and appropriate given the implementation contexts. Teachers would then be clearer on what can be achieved through practical work, the instructional strategies to use and how to make the activities more effective. There are numerous benefits to doing practical work and these can be achieved if the practical work activities are conceptualised and implemented appropriately in the context of high-stakes examinations.

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30 May 2012

Mrs K Naidoo (205522272)
School of Education

Dear Mrs Naidoo

Protocol reference number: HSS/0206/012D

Project title: The value of practical work in the teaching and learning of Physical Sciences in the context of high stakes examinations

In response to your application dated 11 January 2012, the Humanities & Social Sciences Research Ethics Committee has considered the abovementioned application and the protocol has been granted **FULL APPROVAL**.

Any alteration/s to the approved research protocol i.e. Questionnaire/Interview Schedule, Informed Consent Form, Title of the Project, Location of the Study, Research Approach and Methods must be reviewed and approved through the amendment /modification prior to its implementation. In case you have further queries, please quote the above reference number. Please note: Research data should be securely stored in the school/department for a period of 5 years.

I take this opportunity of wishing you everything of the best with your study.

Yours faithfully

.....
[Redacted Signature]
.....
Professor Steven Collings (Chair)
Humanities & Social Science Research Ethics Committee

cc Supervisor: Professor PA Hobden
cc Academic Leader: Dr MN Davids
cc Mr N Memela / Mrs S Naicker



Founding Campuses: ■ Edgewood ■ Howard College ■ Medical School ■ Pietermaritzburg ■ Westville

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Appendix A Permission to conduct research: Department of Education



kzn education

Department:
Education
KWAZULU-NATAL

Enquiries: Sibusiso Alwar

Tel: 033 341 8610

Ref.:2/4/8/138

Ms. Krishnaveni Naidoo
8 Willem Appelgryn Place
Queensburgh
Durban
4093

Dear Ms. Naidoo

PERMISSION TO CONDUCT RESEARCH IN THE KZN DoE INSTITUTIONS

Your application to conduct research entitled: **The Value of Practical Work in the Teaching and Learning of Physical Science in the Context of High Stakes Exit Examination**, in the KwaZulu-Natal Department of Education Institutions has been approved. The conditions of the approval are as follows:

1. The researcher will make all the arrangements concerning the research and interviews.
2. The researcher must ensure that Educator and learning programmes are not interrupted.
3. Interviews are not conducted during the time of writing examinations in schools.
4. Learners, Educators, Schools and Institutions are not identifiable in any way from the results of the research.
5. A copy of this letter is submitted to District Managers, Principals and Heads of Institutions where the intended research and interviews are to be conducted.
6. The Period of investigation is limited to the period from 01 January 2012 to 29 February 2013.
7. Your research and interviews will be limited to the schools you have proposed and approved by the Head of Department. Please note that Principals, Educators, Departmental Officials and Learners are under no obligation to participate or assist you in your investigation.
8. Should you wish to extend the period of your survey at the school(s), please contact Mr. Alwar at the contact numbers below.
9. Upon completion of the research, a brief summary of the findings, recommendations or a full report / dissertation / thesis must be submitted to the research office of the Department. Please address it to The Director-Resources Planning, Private Bag X9137, Pietermaritzburg, 3200.
10. Please note that your research and interviews will be limited to the following Schools and Institutions in the:
 - 10.1 Umlazi District
 - 10.2 Pinetown District
 - 10.3 Ilembe District

Nkomo Nathi S.P. Sisoni, PhD
Head of Department: Education

2012 02 02
Date

...dedicated to service and performance
beyond the call of duty.

KWAZULU-NATAL DEPARTMENT OF EDUCATION

POSTAL: Private Bag X9137, Pietermaritzburg, 3200, KwaZulu-Natal, Republic of South Africa

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Appendix B Letter to Principals: Permission to conduct research at their schools

8Place
Queensburgh
Durban
4093

10 April 2013

The Principal:
The Physical Science Teacher:
.....School

Permission to Conduct Research at your school

I, K Naidoo, a PhD student at the University of KwaZulu-Natal (student number: 205522272) hereby requests permission to conduct research at your school. Based in the Faculty of Education (Edgewood Campus), my study is being supervised by Prof PA Hobden. The title of my study is: “The value of practical work in the teaching and learning of Physical Sciences in the context of high stakes examinations”.

Practical work is an essential part of science education. However, little is known about whether or how practical work results in learning. The purpose of this study is to contribute to an understanding of the value of practical work in the teaching and learning of Physical Sciences in terms of learner attainment of scientific skills and knowledge. This would lead to a clearer understanding of how practical work could be done so that it adds value to teaching and learning. The aim of this study is to examine the rationale for using practical work, the characteristics of the practical work done, as well as learner understandings of concepts in order to understand the value of practical work done. Importantly, the aim of the study is not to evaluate your teachers or learners abilities but gain insight into what effective practical work entails.

A significance of this study is that it will contribute to the debate on the role of practical work in the teaching and learning of Physical Sciences in South Africa as a developing country. Further, a study on the value of practical work that highlights possibilities and limitations could be useful for decision makers in four ways. Firstly, curriculum policy makers could make informed decisions about the inclusion of, the amount of and the type of practical work to be included in the curriculum. In addition, in terms of the curriculum, this study could lead to statements of new and/or clearer learning objectives for practical work. Secondly, this study could inform the provision of costly laboratories and science equipment in a reality of competing priorities. Thirdly, this study could inform the objectives and content of teacher training on practical work. Finally, in light of practical work being typically time consuming, the findings of this study could be important for school managers who may need to make decisions about staff allocations and timetabling. Hence, apart from being significant at a systemic level, the findings of this study could contribute to more effective practical work practices at your school.

Your school was selected to participate in the study because it is well managed and stable in terms of teaching and learning. Further, science practical work at your school is being done routinely. The study will entail classroom observations, learner interviews (a sample of 3) and teacher interviews. One grade 10, one grade 11 and one grade 12 Physical Science class at your school will be selected for the study. The selection of the classes will be negotiated with your teachers. Access to the lessons selected for the study will be pre-arranged with the teachers and will fit into their timetables. The period for data collection will be from April to August 2013. However your school will be visited for about four times during this period when practical work takes place. The classroom will be observed with minimum interruptions and learners and teacher interviews will be conducted after school hours. The lessons will be video-taped and interviews will be conducted only with the permission of the teachers and learners.

Teacher and learner participation in the study is voluntary and they are at liberty to withdraw from the study at any given time without any negative consequences. The name of your school, the name of your teacher and learner names will not be used in the study. Pseudonyms will be used instead. All responses by participants will be treated in a confidential manner. The data from the study will be kept for five years and thereafter destroyed. All efforts will be made to ensure minimum disruptions to teaching and learning. Neither the school nor the participants will incur any costs for participating in the study. Permission to conduct research at your school has been granted by the KZN Department of Education as well as the UKZN Ethics Committee (attached).

My contact details are as follows:

K Naidoo

Tel: 031- Fax: 033-

Cell: 083

krishnien@

My Supervisors contact details are as follows:

Prof PA Hobden

Tel: 031-

hobden@

It would be appreciated if the attached consent form as well as the work schedule of your teachers are completed and faxed/e-mailed to me. Work schedules are requested to enable me to plan my data collection at your school.

Thank You

Appendix C The sample: school, teacher, and learner profiles

School	School Type	School Location	Teachers Interviewed & Length of Interview	Years Taught	Practical Work Lesson Observed	Learners Interviewed	Grade
School A	Ex-White	Urban, Residential	Anne (34min19s)	18			
School B	Ex-Indian	Urban, Residential	Raj (52min58s)	24			
School C	Ex-Indian	Urban, City	Vish (17min45s)	21	Titration	Andile, Bongani	12
School D	Ex-African	Township	Sipho (15min54s)	6			
			Kanye (7min25s)	3			
			Thuli (10min7s)	6	Boyles Law	Sihle, Zama	11
			Bongi (16min11s)	3			
School E	Ex-African	Township	Sizwe (8min37s)	7			
School F	Ex-White	Urban, Residential	Eric (50min44s)	24	Division of potential across series and parallel resistors	Tim, Joey	10
			John (26min)	24	Intermolecular Forces & Evaporation	Carl, Stewart	11
School G	Ex-White	Urban, Residential	Sarah (33min16s)	25	Evaporation, Solubility, Capillarity	Tracey, Claire	11
			Neel (15min13s)	30			
			Jane (7min18s)	24			
			Lab Assistant (9min)	35	Series and Parallel Circuits	Jen	10
School H	Private	Urban, Residential	Jake (18min)	6			
			Mitch (11min32s)	16			
			Pearl (14min03s)	25			
School I	Ex-White	Urban, City	Sam (11min)	21			
			Betty (17min38s)	7	Precipitates	Sue, Ben	10
School J	Ex-Indian	Urban, Residential	Jay (25min08s)	19			
School K	Ex-African	Township	Lungi (28min05s)	15			
School L	Ex-Indian	Urban, Residential	Lenny (18min42s)	5	Momentum	Muzi	12
School M	Ex-Indian	Urban, Residential	Shoba (16min23s)	27			
School N	Ex-Indian	Urban, Residential	Jiten (19min05s)	12	Heating and Cooling Curve of Water	Nisha	10
School O	Ex-Indian	Urban, Residential	Pregs (17min41s)	27			

Appendix D Summary of the practical work lessons observed

School	Name of Teacher	Name of Practical	Grade
School C	Vish	Titration: To investigate how to use an acid-base reaction to determine the concentration of a solution of hydrochloric acid	12
School D	Bongi	Verify Boyles Law	11
School F	Eric	Electrical Circuits: division of potential across series resistors and parallel resistors	10
School F	John	Effect of Intermolecular Forces on Evaporation	11
School G	Sarah	Evaporation, Solubility, Capillarity	10
School G	Jen	Series and Parallel Circuits	10
School I	Betty	Precipitates	10
School L	Lenny	Law of Conservation of Linear Momentum	12
School N	Jiten	The Heating and Cooling Curve of Water	10

Appendix E1 Interview schedule: Teachers

Name of teachers (pseudonym):

Date of Interview:

Introductions; purpose of the interview; anonymity; rationale for the study; permission to audio-tape

1. How long have you been teaching Physical Science?
2. As a learner yourself, can you remember doing practical work?
3. How often do you do practical work? Do you look forward to practical work lessons? Why?

Questions about the aims and why we have practical work:

1. What do you think is the aim of schooling for the learner?
2. Why do you think practical work is included in the CAPS? How do you know this?
3. What do you think is the aim of practical work? Where have you heard/read this?
4. Excerpt from CAPS about rationale read. Do you/teachers achieve these aims? If yes, how?

Questions about practical work and examinations

5. What role do examinations play in the schooling of learners?
6. Do the grade 10, grade 11, and grade 12 examinations test practical work? If yes, how?
7. Why do you think practical work is included in examinations?
8. Does practical work influence learner performance in examinations? If yes, how?

Questions about benefits of practical work:

9. By doing practical work, are there any benefits to learners? If yes, what are these?
10. Do you think that practical work influences the way learners understand concepts? If yes, how?
11. Do you think that practical work has any influence over learner achievement? Why? How?
12. For the learner, is there any value in doing practical work? ... is this what you experienced or read? Where did you read this? Why, in your opinion, do we have practical work in the teaching and learning of Physical Sciences?
13. What do you see as the role of practical work in the teaching of Physical Sciences?
14. What do you see as the role of practical work in the learning of Physical Sciences?

Questions about how practical work is being done:

15. How do you conduct PW? Type do you do? When do you do PW relative to a section taught?
16. Are the practical work linked to the concepts you teach? If yes how?
17. How do you check for learner understanding of the practical activity done?
18. From your experience as a teacher, how is practical work being done in schools? How often do teachers do practical work? Why is this so? How often should teachers do practical work?
19. When, in relation to concepts taught, do teachers do practical work? Why is it done this way? Can you give an example?
20. How do you think learners feel about/experience practical work? Why do you say so?
21. How do you decide which practicals to do and when to do it?
22. How do you decide which type of practical would be best suited?
23. What are the essential elements/parts of a practical work activity? Which part of practical work is most important for learners?
24. When doing practical work, what do you focus on the most?
25. When, according to you, is a practical task successful?
26. Do you look forward to practical lessons?
27. What to you is the biggest challenge when doing practical work?

Questions about how practical work could be done:

28. Do you see a need for more or less practical work. How should practical work be done? Why?
29. If you had to change the way practical work is done, how would you change it? Why?

Appendix E2**Interview schedule: Subject advisors**

Name of Subject Advisor (pseudonym):

Date of Interview:

Introductions; purpose of the interview; commitment to anonymity; rationale for the study; permission to audio-tape interview; withdraw at any time

1. How long have you been a Physical Sciences Subject Advisor?
2. When you were a learner yourself, can you remember doing practical work?
3. How has practical work policy changed over the years, during NATED, C2005, CAPS?
4. What changes did you see in practical work implementation over the years?

Questions about the aims and why we have practical work:

5. What do you think is the aim of schooling for the learner? How do you know this?
6. Why do you think practical work are included in the CAPS?
7. What do you think is the aim of practical work? Where have you heard/read this?
8. Excerpt from CAPS about rationale read. Do you/teachers achieve these aims? If yes, how?

Questions about practical work and examinations

9. What role do examinations play in the schooling of learners?
10. Do the grade 10, grade 11, and grade 12 examinations test practical work? If yes, how?
11. Why do you think practical work are included in examinations?
12. Does practical work influence learner performance in examinations? If yes, how?

Questions about benefits of practical work:

13. By doing practical work, are there any benefits to learners? If yes, what are these?
14. Does practical work influences the way learners understand science concepts? If yes, how?
15. Do you think that practical work has any influence over learner achievement? Why? How?
16. For the learner, is there any value in doing practical work? ... is this what you experienced or read? Where did you read this? Why, in your opinion, do we have practical work in the teaching and learning of Physical Sciences?
17. What do you see as the role of practical work in the teaching of Physical Sciences?
18. What do you see as the role of practical work in the learning of Physical Sciences?

Questions about how practical work are being done:

19. What have you observed about how teachers conduct practical work?
20. Are the practical work linked to the concepts taught? If yes how?
21. How do teachers check for learner understanding of the practical activity done?
22. From your experience as a subject advisor, how are practical work being done in schools? How often do teachers do practical work? Why is this so? How often should teachers do practical work?
23. When, in relation to concepts taught, do teachers do practical work? Why is it done this way? Can you give an example?
24. How do you think learners feel about/experience practical work? Why do you say so?
25. How do teachers decide which practicals to do and when to do it?
26. What are the essential elements/parts of a practical work activity? Which part of practical work is most important for learners?
27. When, according to you, is a practical task successful?
28. What to you is the biggest challenge when doing practical work?

Questions about how practical work could be done:

29. Do you see a need for more or less practical work or practical work. How should practical work be done? Why?
28. If you had to change the way practical work is being done, how would you change it? Why?

Appendix E3**Post-lesson teacher and learner interview schedule**

Name of Learner (pseudonym):

Date:

Title of practical work lesson:

Introductions; purpose of the interview; commitment to anonymity; rationale for the study; permission to audio-tape interview; withdraw at any time

LEARNERS

General questions:

1. Do you like studying Physical Sciences?
2. Do you like doing practical work? What about practical work do you like? Why?
3. How often do you do practical work?
4. Why do you think you have to do practical work?
5. Does practical work help with learning Physical Sciences?
6. Are you tested on the practical work? Do you find the questions to be easy or difficult?

Questions about the practical work lesson observed:

7. What was this practical lesson about?
8. What did you have to do? And other learners?
9. Did you know about Concept? Did you study it in class?
10. What did you learn from this practical work activity? Did you know/understand this concept.....before?
11. Is this practical work important? For marks, tests exams?
12. Questions probing understandings of the specific practical work ...
13. What happens next? What do you submit to the teacher? Why? Where will you get answers?

TEACHERS

Name of Teacher (pseudonym):

I began the interview with a recap of the objectives for the lessons, as indicated in the pre-practical telephonic conversation.

1. Do you think this practical lesson was successful? Why?
2. Did you achieve your intended objectives? If, yes which ones?
3. What worked well and what didn't in this lessons?
4. Why did you do/select the following: location of lesson; equipment; type of practical activity; specific to the activity
5. Did learners benefit from the activity? If yes, how?
6. Did they learn skills?
7. Which concepts were learnt in this activity? Where these concepts new to the learners?
8. Will this practical activity be assessed? If yes, how?

Appendix F Classification to identify the types of investigations

Type of Investigation Practical Work	Role of Teacher and Learners	Stage of Activity					
		Topic	Question	Method	Collect data	Analyse data	Solution
Confirmation Investigation	L hands-on L minds-on	T	T	T	L	L	Known to L
Structured Investigation	L hands-on L minds-on	T	T	T	L	L	Unknown to L
Guided Investigation	L hands-on L minds-on	T	T	L	L	L	Unknown to L
Learner-initiated Investigation	L hands-on L minds-on	L	L	L	L	L	Unknown to L

T: Teacher L: Learner

**Appendix G Procedural understandings associated with practical work
(Gott and Duggan, 1995)**

Lesson:

Teacher:

Concepts of Evidence and Descriptions		Times mentioned / observed
Design	<i>Variable identification:</i> Understanding what a variable is; identifying variables; which variable to change and measure	
	<i>Fair test:</i> Understanding the structure of the fair test: controlling variables and validity of results	
	<i>Sample size:</i> Understanding the significance of an appropriate sample size	
	<i>Variable types:</i> Understanding the distinction between categoric, discrete, continuous and derived variables	
	<i>Relative scale:</i> Understanding the need to choose sensible values for quantities for meaningful measurements	
Measurement	<i>Range and interval:</i> Understanding the need to select a sensible range of values for the variables, e.g. a line graph will have sufficiently spread out values to illustrate the 'whole' pattern. Adequate number of readings taken	
	<i>Choice of instrument:</i> Understanding the relationship between the choice of instrument and the required scale, range and spread of readings required, and accuracy	
	<i>Repeatability:</i> Understanding that the inherent variability in any physical measurement requires repeats, if necessary, for reliable data	
	<i>Accuracy:</i> Understanding the appropriate degree of accuracy that is required to provide reliable data for meaningful interpretation	
	<i>Tables:</i> Understanding when and how tables can be used to organise data	
Associated with data handling	<i>Graph type:</i> Understanding that there is a close link between graphical representations and the type of variable, e.g. the behaviour of a continuous variable is best shown in a line graph	
	<i>Patterns:</i> Understanding that patterns represent the behaviour of variables as can be seen in tables and graphs	
	<i>Multivariate data:</i> Understanding the nature of data: how variables can be held constant to show the effect of one variable on another	
	<i>Reliability:</i> Understanding the implications of the measurement strategy for the reliability of the data	
	<i>Validity:</i> Understanding implications of the design for validity of the data: overall view of the task to check if inquiry question answered	
Associated with the evaluation of the task		

**Appendix H Instrument to identify process skills in Physical Sciences CAPS
document (Padilla, 1990)**

Lesson:

Teacher:

Process Skills	Description	Number of times mentioned/observed
Basic Process Skills		
Observing	Using the senses to gather information about an object	
Inferring	Making a guess about an object or event based on previous information	
Describe Measurements	Describe the dimensions of an object using measurements	
Communicating	Using words or graphics to describe an action, object or event	
Classifying	Grouping or ordering objects or events into categories based on criteria	
Predicting	Stating the outcome of a future event based on a pattern of evidence	
Integrated Process Skills		
Controlling Variables	Identifying and manipulating variables	
Defining Operationally	Stating how to measure a variable	
Formulating Hypothesis	Stating the expected outcome of an experiment	
Interpreting Data	Organising data and drawing conclusions from it	
Design Experiment	Being able to design an experiment or investigation	
Formulating Models	Creating a mental or physical model of a process or event	

Appendix I The Lesson Observation Framework adapted from Miller (2009)

LESSON:

TEACHER:

SECTION A1: TEACHER AIMS FOR THE LESSON

According to the teacher, what were the aims of the practical work lesson?	Intended	Actual
Learn Theory		
Learn Skills		
Assessment		
Motivation		

SECTION A2: LEARNING OBJECTIVES FOR THE TASKS: INTENDED VS ACTUAL

OBJECTIVE 1: DEVELOP KNOWLEDGE AND UNDERSTANDING	Intended	Actual
Facts, concepts, theory, model		
Relationships		
To identify objects		
OBJECTIVE 2: LEARN ABOUT SCIENTIFIC APPROACH AND INQUIRY		
How to use equipment		
To follow standard procedure/method		
To identify phenomena		
To observe phenomena		
How to plan an investigation		
To conduct an investigation		
How to analyse data		
How to use data to support conclusion		
How to communicate findings		

SECTION B: OBJECTS, OBSERVABLES AND IDEAS: INTENDED VS ACTUAL

B1: OBJECTS / OBSERVABLES

<i>Did learners do with and/or observe objects and materials as was intended?</i>	Intended	Actual
Use instrument/device/apparatus/equipment to measure/collect data		
Follow a method or procedure		
Make an event occur		
Make/present an object/material		
Observe material, event, or quantity from manipulating objects & materials		
Observe material, event, or quantity from the teacher manipulating objects & materials		
Manipulate objects		

B2: IDEAS

<i>Did learners think/discuss/explain what they were doing and observing?</i>	Intended	Actual
Describe/explain observations made from manipulating objects & materials		
Describe/explain observations made from the teacher manipulating objects		
Design a procedure or method		
Make a prediction from a Guess/Hypothesis or Law/Theory		
Test a prediction		
Explore relations between objects		
Explore relationships between variables		
Explore relations between objects and variables		
Identify a pattern		
Determine a value which is not measured directly		
Account for an observation/finding using given/known explanation		
Account for an observation/finding by proposing a new explanation		
Report on observations made		

SECTION C: DEGREE OF OPENNESS/CLOSENESS

Who decides on the following?	Teacher	Learner	Teacher & Learner
Question to be addressed			
Equipment to use			
Method/Procedure to follow			
How to collect and record data			
Analyse results			
How to communicate findings			
To whom is the solution/conclusion known?			

LEARNER INVOLVEMENT & INTERACTIONS

LEARNER INVOLVEMENT

- Teacher demonstrates; Learners watch
- Teacher demonstrates then Learners do/assist
- Learners do practical in groups
- Learners do practical individually

LEARNER INTERACTIONS

- With other learners about the practical
- With other learners not about the practical task
- The teacher occasionally
- The teacher often

What information was given to learners?

- Verbal
- On chalkboard
- Worksheet
- Textbook
- Other

How were the learners assessed?

- Learners questioned during lesson
- Learners assessed on manipulative skills
- Learners submit written report and/or answers to questions at end of lesson
- Learners submit written report and/or answers to questions later

MOTIVATION: Observations and evidence of learner interest

- from learner interactions
- between learners and the teacher
- from the practical task
- other

OTHER OBSERVATIONS:

Appendix J Excerpt of notes made from initial reading of transcripts:
Motivation and assessment

Cluster Item	Words / Phrases noted
Motivation: interest; confidence	When learners see colour change they will become interested; gives them confidence; motivates them; keeps them interested
Motivation: Enjoy	Learners enjoy practical work; excited about practical work because they know they will be discovering for themselves
Motivation: Fun	Practical work keeps learners interested because it is fun; it's fun they look forward to it
Assessment	<p>Need to read instructions; assess; ability to work in a group; put together the report; complete report under test conditions; prac has a rubric; learners: it is all about the right answer and getting good marks for write up; every prac done for assessment; contribute to CASS; move about classroom and pick if learners understand;</p> <p>Can get an 'A' in exam without doing pracs; private school: cannot get an 'A' without doing pracs because they have to do a prac exam. Exams: give a scenario: ask what is the hypothesis.</p> <p>Pracs tested theoretically; what is the hypothesis – you can study this; give a scenario and test how to draw a graph; learners study for pracs and focus on what can be tested on</p>

Appendix K Node structure report clustered: Purposes for doing practical work

TEACHER AND SUBJECT ADVISOR INTERVIEWS			
Hierarchical Name Parent Nodes	Number of coding references	Sources	User Assigned Colour
LEARNING CONTENT			
Nodes\\Aims of Prac Work Learning content	3	3	Blue
Nodes\\Benefits of Practical Work\\Abstract to Concrete	33	27	Blue
Nodes\\Benefits of Practical Work\\Benefits for Learning\\Doing	92	28	Blue
Nodes\\Benefits of Practical Work\\Observing	8	5	Blue
Nodes\\Benefits of Practical Work\\Discover Knowledge	4	3	Blue
Nodes\\Benefits of Practical Work\\Helps to consolidate	5	3	Blue
Nodes\\Do Weaker learners or brighter learners benefit	4	4	Blue
Nodes\\Doing Practical Work\\How teacher makes links between theory and Practicals for learning	23	8	Blue
Nodes\\Prescriptive vs Discovery Learning	15	5	Blue
Nodes\\Benefit\\Value Learning\\ Learning by observing	22	25	Blue
Nodes\\Benefit\\Value Learning\\content	5	2	Blue
Nodes\\Benefit\\Value Learning\\remember	7	2	Blue
Nodes\\How children learn\\Verify	12	6	Blue
Nodes\\Definitions\\Definition of practical work\\learning	4	3	Blue
Nodes\\Why do you do Prac Work\\Learn content knowledge	36	14	Blue
	273		
MANIPULATIVE SKILLS			
Nodes\\Benefits of Practical Work\\Benefits Skills\\Manipulate Use Equipment	92	28	Pink
Nodes\\Benefits of Practical Work\\Benefits Skills\\Learn by doing	25	28	Pink
Nodes\\Benefits of Practical Work\\Benefits Skills\\Hands-on\\Collect Data	10	7	Pink
Nodes\\Benefits Tertiary Education Careers	13	13	None
	140		
PROCESS SKILLS			
Nodes\\Benefits of Practical Work\\Benefits Skills\\Process Skills\\Investigations\\Scientific Method\\investigative skills	58	14	Yellow
PROCEDURAL UNDERSTANDINGS			
Nodes\\Benefits of Practical Work\\Procedural\\How to analyse represent data	1	1	None
MOTIVATION			
Nodes\\Benefits of Practical Work\\ Motivation\\Motivate	38	27	None
Nodes\\Benefits of Practical Work\\Motivation\\Confidence	13	11	Orange
Nodes\\Benefits of Practical Work\\Motivation\\Enjoy	31	27	None
Nodes\\Benefits of Practical Work\\Motivation\\Fun	15	8	Orange
Nodes\\Benefits of Practical Work\\Motivation\\Interest	5	1	None
Nodes\\Benefits of Practical Work\\Motivation\\Enthusiasm	8	2	None
	72		

Hierarchical Name Parent Nodes	Number of coding references	Sources	User Assigned Colour
DOES NOT MOTIVATE			
Nodes\\No Benefit\\Prac work does not motivate	1	1	None
NATURE OF SCIENCE			
Nodes\\Benefits of Practical Work\\Motivation\\Motivate	13	6	None
ASSESSMENT			
Nodes\\Benefits of Practical Work\\Improves performance in Exams	20	8	None
Nodes\\Examinations Assessments\\Class Assessment	3	2	Red
Nodes\\Examinations Assessments\\Class Assessment\\Assessing Learners	37	16	Red
Nodes\\Examinations Assessments\\Class Assessment\\Report Writing	15	10	None
Nodes\\Examinations Assessments\\Class Assessment\\When is Practical Work Successful	23	13	Red
Nodes\\Examinations Assessments\\Practical Work and Examinations	52	21	Yellow
Nodes\\Examinations Assessments\\Practical Work and Examinations\\Testing Practical Work	44	19	Yellow
Nodes\\Why do you do Prac Work: Assessment	2	2	None
	196		
CHALLENGES			
Nodes\\Challenges of doing Practical Work\\Administrative Work	1	1	None
Nodes\\Challenges of doing Practical Work\\Class Size	6	5	None
Nodes\\Challenges of doing Practical Work\\Equipment	29	16	Purple
Nodes\\Challenges of doing Practical Work\\Group Work	9	6	Purple
Nodes\\Challenges of doing Practical Work\\Language	1	1	None
Nodes\\Challenges of doing Practical Work\\Safety of learners	4	4	None
Nodes\\Challenges of doing Practical Work\\Syllabus	22	9	None
Nodes\\Challenges of doing Practical Work\\Teacher training	7	3	None
Nodes\\Challenges of doing Practical Work\\The Teacher	31	14	Purple
Nodes\\Challenges of doing Practical Work\\Time	75	21	Purple
Nodes\\Challenges of doing Practical Work\\Type of Child	19	11	Purple
	204		

Appendix L Purposes for doing practical work: Words and phrases coded

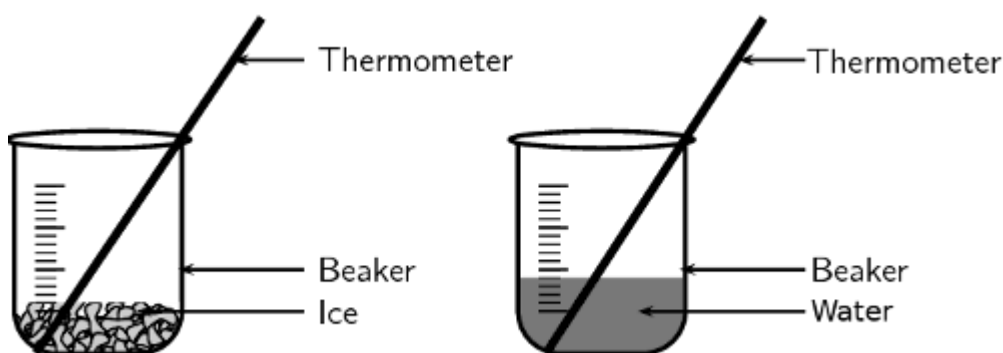
Theme	Excerpt: Words and Phrases Coded
Practical work is a way to learn theory	application of what you learnt; apply what you learn; reinforcement of concepts; gives them a better understanding of the concepts; to understand a concept; helps them to understand a concept a lot better; it consolidates theoretical understanding; better theoretical understandings; experiments are there to emphasise content; learn theory better; learn theory; learn content; can see theory; understand what is taught in class; learn concepts practically; activities to make you understand theory; helps learn theoretical concepts; verify theory; for verification; is a way to learn science; important for learning science; always part of Physical Science; verify content; verify theory; practical aspect of theory
Practical work is doing science	practical work is just them doing it ; body movement; not demonstration but doing it; using equipment: beakers, thermometers, tongs, test tubes; how to light a Bunsen burner, how to read the practical worksheet; abstract for the child so has to do it; see science in action; doing science; physical activity; physically doing it; learner activity; science in action; ; learn how to use apparatus; learn skills; is about the learner discovering for himself; where they can learn about variables; to actually see it happen before it actually gets told to them; they get to see it; apply what they learnt; apply theory; theory in action; application of theory; they are able to see science; learners work together to do a practical; there is a skills aspect to it; development of skills; more a skills based aspect of science; skills that they are achieving from working together; it is for them to actually to do it; learn how to do things; do experiments themselves; learn skills like reading a voltmeter; learn how to read a meniscus; learn skill of observing; learn to observe, classify, compare; skill of collecting data; representing data in tables and graphs; drawing conclusions; learning by doing, observing and seeing – hands on; trying to prove something; doing rather than observing; learn to work with apparatus; collect data and analyse data; verify stuff; verification of theory; taking data and being able to transfer information in different ways from writing to tables to graphs and then interpreting a graph; they have to draw a graph; is when data is transformed into tables and graphs, the interpreting of data; see the difference between direct and indirect proportion; give an explanation for your conclusion; child is discovering for themselves; the child can go through the experience of science with pracs
Practical work is learning about science	this is how discoveries are made in science; how would you prove and what steps would you need to; show how scientists work - doing things many times so you get the same results; to get a glimpse of how scientists work; understanding the scientific method; how would you prove and what steps would you need to take; if you were proving a theory you would be doing it 20, 30, 40 times to makes sure that you get the same results; also gives you the opportunity to write out to write in the scientific way; the nature of science; it allows you to go through that process of investigative questions of going through the method; how do you tabulate data in groups etc.; so what science does how science does it; how theory comes about; teach the very nature of how did that come about; all the theories, all the laws and all the principles we got have to come to a particular way of science; a person has to see something, observe something – why is that happening? tries to get an explanation for that; then he tries to see if his explanation is correct – that's his hypothesis

Appendix M1**Heating and cooling curve of water****Aim**

To investigate the heating and cooling curve of water.

Apparatus

- beakers
- ice
- Bunsen burner
- thermometer
- water

**Method**

1. Place some ice in a beaker. Record the temperature. Heat the ice with some water until it boils. Measure and record the temperature of the water every 2 minutes until boiling point is reached.
2. Be careful when handling the beaker of hot water. Do not touch the beaker with your hands, you will burn yourself.
3. Once boiling point is reached, remove the water from the heat and measure the temperature every 2 minutes, until the beaker is cool to touch.
3. After 2 minutes measure the temperature again and record it. Repeat every 2 minutes

Results

Record your results in a table and plot the graphs of time versus temperature for the heating of water and cooling of water.

SECONDARY SCHOOL

PHYSICAL SCIENCE- GRADE TEN

PRACTICAL 1 –HEATING AND COOLING CURVES FOR WATER

25

NAME: _____

GRADE/DIV: _____

RUBRIC

CRITERIA	1	2	3	4	TOTAL
INVESTIGATIVE QUESTION	INCORRECTLY STATED	CORRECTLY STATED			
HYPOTHESIS	INCORRECTLY STATED	CORRECTLY STATED			
APPARATUS	SOME OMISSIONS	DETAILED			
METHOD	SOME OMISSIONS	DETAILED			
DATA TABLES (HEADING, UNITS, CORRECT DATA)	ONE ASPECT	TWO ASPECTS	ALL ASPECTS		
GRAPH 1 HEATING CURVE (HEADING, PLOTTING, SHAPE. AXES)	ONE ASPECT	2/3 ASPECTS	ALL ASPECTS		
GRAPH 2 COOLING CURVE (HEADING, PLOTTING, SHAPE. AXES)	ONE ASPECT	2/3 ASPECTS	ALL ASPECTS		
CONCLUSION	INCORRECTLY STATED	CORRECTLY STATED			
PRECAUTIONS	SOME OMISSIONS	ALL PRECAUTIONS LISTED			
QUESTIONS	1-3	4-9	10-12	13-15	

25

ANSWER THE QUESTIONS BELOW

1. Convert the units

1.1 $296\text{ K} = \text{ }^{\circ}\text{C}$

(1)

1.2 $-63\text{ }^{\circ}\text{C} = \text{ K}$

(1)

1.3 $214\text{ }^{\circ}\text{C} = \text{ K}$

(1)

2. Define the terms:

2.1 Temperature.

(2)

2.2 LATENT HEAT.

(2)

2.3 Boiling Point.

(2)

3. Explain why the temperature of water remains constant during a change of phase, even though it is heated.

(3)

4. Explain why ICE floats on liquid water.

(3)

[15]

QUESTIONS

- 2.5 sterling silver
2.6 concentrated swimming pool acid
2.7 copper
2.8 sugar and sand

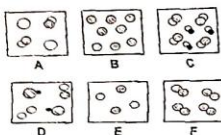
Question 3

Complete the table and determine if each of the substances is a pure substance or a mixture. If it is a pure substance, say whether it is an element (E) or a compound (C). If a mixture, say whether it is homogeneous (1) or heterogeneous (2).

Substance	Pure substance (E - element ; C - compound)	Mixture (homogen. - 1 ; heterogen. - 2)
3.1 chlorine gas (Cl ₂)		
3.2 diluted acid		
3.3 steel		
3.4 table salt (NaCl)		
3.5 magnesium ribbon		
3.6 Coca Cola		
3.7 air at a factory plant		

Question 4

Classify the accompanying as pure substances (P) or mixtures (M).



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Question 5

- 5.1 How do we work out the valency of an atom in group V (15) or group VI (16) or group VII (17)?
- 5.2 Write down the valency of the following atoms:
5.2.1 N 5.2.2 Na 5.2.3 Al
5.2.4 Na 5.2.5 O 5.2.6 Mg
5.2.7 I
- 5.3 Write down the symbol of:
5.3.1 a nitride ion 5.3.2 an oxide ion
5.3.3 a fluoride ion
5.3.4 a phosphate ion 5.3.5 a nitrate ion
- 5.4 Consider the following chemical formulae:
CS₂; Ca(ClO₃)₂; NO₂;
NH₄C; HNO₃; Mg(OH)₂
- Which formulae represent the following:
5.4.1 a chloride 5.4.2 a chlorate
5.4.3 an acid 5.4.4 a hydroxide
5.4.5 a sulphide 5.4.6 a dioxide
- 5.5 Choose the correct word between brackets:
5.5.1 The suffix of a (metal / non-metal) atom changes to 'ide' when it forms an ion.
5.5.2 Two identical non-metal atoms combine to form a molecule that is an (element / compound).
5.5.3 HF is an example of an (element / compound).

Question 6

Give the name of the following compounds:

- 6.1 Li₂O 6.2 KBr 6.3 Al(NO₃)₃
6.4 SO₃ 6.5 NO₂ 6.6 Ag₂O
6.7 HgCl₂ 6.8 Fe₂S₃ 6.9 Ca(OH)₂
6.10 KMnO₄ 6.11 MgCO₃ 6.12 H₂S

Q2

Question 7

Give the chemical formula for each of the following compounds:

- 7.1 magnesiumhydroxide 7.2 copper(II)sulphate
7.3 potassium carbonate 7.4 mercury(II)chloride
7.5 barium sulphite
7.6 sodium hydrogen carbonate
7.7 carbon monoxide 7.8 tin(II)iodide
7.9 phosphor(V)oxide 7.10 ammonia
7.11 aluminium sulphide 7.12 silver bromide

Question 8

- 8.1 Explain why metals can easily be moulded (malleable or ductile).
8.2 Which property of non-metals allows oxygen to be a gas at room temperature?
8.3 How does the electrical conductivity of metals and metalloids change with an increase in temperature?
8.4 Describe a simple experiment to:
8.4.1 compare the thermal conductivity of substances.
8.4.2 compare the electrical conductivity of substances.
8.5 Give an explanation for each of the following facts:
8.5.1 It is better to use a wooden spoon than a metal one when making fudge or sweets on the stove.
8.5.2 Toilet seats are always cold, even when the temperature in the room is warm.



- 8.5.3 You can put your hands into a very hot oven for a few seconds to remove a hot dish from the oven, without getting burnt, but if you touch the dish or the hot-plate just for a fraction of a second, you will get burnt.

- 8.6 For each of the following materials, say which special properties of the material are utilised for the specific function:

- 8.6.1 cotton clothes
8.6.2 carbon electrodes
8.6.3 plastic cups
8.6.4 steel gates

Phases of matter and the kinetic molecular theory

Question 9

- 9.1 What is Brownian motion and what is it used to verify?
9.2 Give one word for the following:
9.2.1 the phase change from a solid to a liquid.
9.2.2 the phase change from a gas to a liquid.
9.2.3 the phase change from a solid to a gas.
9.3.1 Define boiling point.
9.3.2 What phase change occurs when a liquid reaches boiling point?
9.3.3 Can this phase change also occur at other temperatures? Explain.
9.3.4 Describe the transition of a gas to a liquid in terms of the kinetic molecular theory.
9.4 Explain why the metal lid of a bottle or jar unscrews more easily after holding it in boiling water for a few minutes.

Question 10

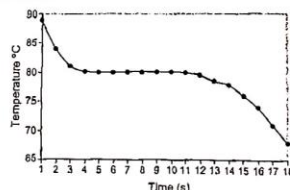
Use the table below and determine in which state/phase each of the compounds (A - D) will be at room temperature (25 °C).

Compound	Melting point (°C)	Boiling point (°C)
10.1 A	-218	-183
10.2 B	0	100
10.3 C	51	320
10.4 D	-20	40

- 10.5 What can we deduce about the strength of the forces between the molecules of A compared to that of the molecules of B?

Question 11

Below is the cooling curve from liquid to solid for a substance called naphthalene. Answer the questions that follow.



- 11.1 What is the melting point in °C for naphthalene?
11.2 Explain how you know this from the graph.
11.3 Use the kinetic molecular theory to explain why the graph is 'flat' from time 4 - 11 s.
11.4 Consider the following substances:
Na, CO₂, CaBr₂, NH₃, Ni
Which of these substances:
11.4.1 is (are) covalent molecule(s)?
11.4.2 is a good conductor of heat?
11.4.3 sublimates at room temperature?

Q3

- 11.4.4 is a ferromagnetic substance?
11.4.5 has the lowest ionisation energy?
11.4.6 can only conduct electricity in its melted or dissolved state?

The atom

Question 12

- 12.1 Define the following terms:
12.1.1 nucleons
12.1.2 atomic number
12.1.3 atomic mass or mass number
12.1.4 isotope
12.2.1 What is meant by the relative atomic mass of an element?
12.2.2 Use the ${}^A_Z\text{E}$ notation and give the number of protons, neutrons and electrons of the following elements:
(1) ${}^{39}_{19}\text{K}$ (2) ${}^{137}_{56}\text{Ba}$
12.2.3 Use the ${}^A_Z\text{E}$ notation to represent the isotope of a chlorine atom with 18 neutrons (use the Periodic Table to find the other information you need).
12.3 Complete the following table:

Symbol	Number of p ⁺	Number of n ⁰	Number of e ⁻	A	Z
12.3.1 ${}^3_1\text{H}$					
12.3.2 ${}^7_3\text{Li}$					
12.3.3 ${}^{14}_6\text{C}$					
12.3.4 ${}^{23}_{11}\text{Na}^+$					
12.3.5 ${}^{40}_{20}\text{Ca}$					
12.3.6 ${}^{31}_{15}\text{P}^{3-}$					
12.3.7 ${}^{127}_{53}\text{I}$					

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QUESTIONS

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Appendix M2

Worksheet: Titration

KNOWLEDGE AREA	Chemical change	LEARNER GROUP ACTIVITY
THEME	Types of reaction	
ACTIVITY	Acid-base reactions 4. Standardisation of an acid by titration with a standard base	

TO INVESTIGATE: how to use an acid-base reaction to determine the concentration of a solution of hydrochloric acid.

In this investigation you will prepare a basic solution accurately and thus you will know its exact concentration. You will then react this base with an acid of unknown concentration to determine the concentration of the acid.

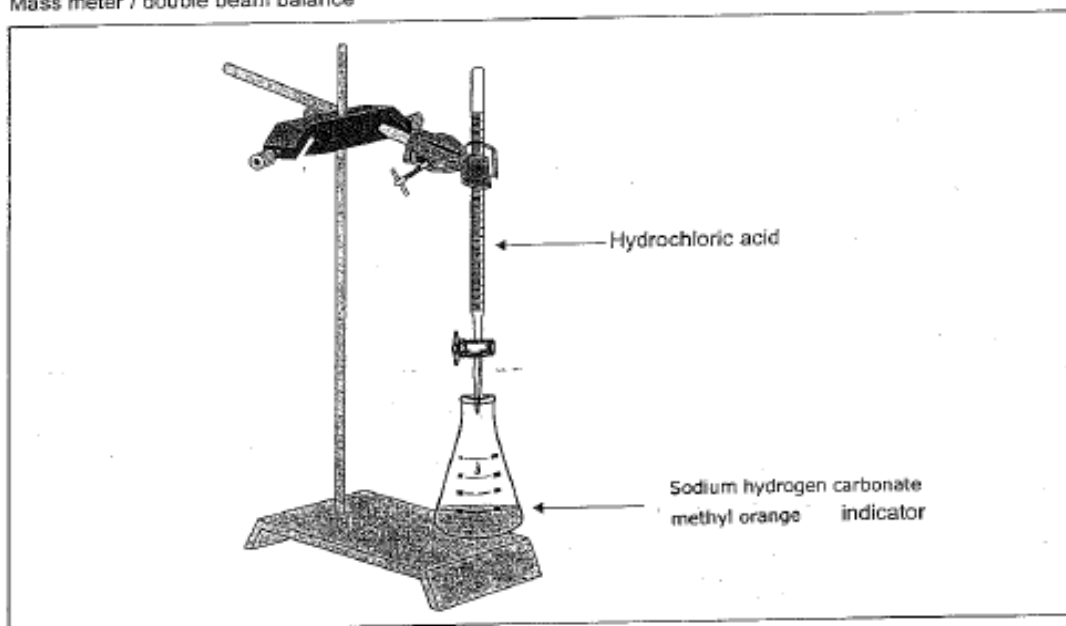
Because the base has a concentration that we know accurately, we call it a **standard** or a **standard base**. Because the acid's concentration is going to be determined by accurate reaction with the standard base, we say that we are going to **standardise** the acid (we are going to work out its concentration accurately).

WHAT YOU WILL NEED:

Burette
Clamp and bosshead
Retort stand
Bromothymol blue
Mass meter / double beam balance

beaker
spatula
glass rod
pipette and pipette sucker

conical flask
Sodium hydrogen carbonate
hydrochloric acid
funnel

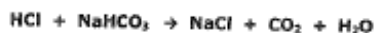
**WHAT TO DO:**

1. Prepare a hydrochloric acid solution by dissolving about 5ml of concentrated acid in 500ml water. (This solution can be stored in any large bottle if a volumetric flask is not available. A 500ml mark could be made on the bottle before it is used for the above purpose by measuring exactly 500ml of water into it with the measuring cylinder.) This has a concentration of **approximately** $0.1\text{mol}\cdot\text{dm}^{-3}$. (Note: we do not know the exact concentration).
2. Now prepare a standard solution of sodium carbonate of precisely $0.1\text{mol}\cdot\text{dm}^{-3}$. This can be done by dissolving exactly 5.2g of any sodium carbonate in exactly 500ml of water.
3. Place the burette in the clamp.

4. Use the funnel to fill the burette to **above** the zero mark with the acid solution.
5. Then, holding the beaker, with which you used to pour the acid, beneath the burette, gradually open the tap.
6. Allow the level of the acid to come down to exactly zero (reading from the bottom of the meniscus).
7. Pipette exactly 25ml of the sodium carbonate into a conical flask.
8. Add a few drops of methyl orange to this.
9. Hold the conical flask beneath the burette with your right hand and gradually open the tap with your left.
10. Swirl the conical flask continuously and watch it closely for the first sign of colour change.
11. As you see that you are reaching the point of neutralisation, close the tap slightly so that you are adding drop by drop.
12. When the colour changes completely the titration is finished.
13. Close the tap and read from the burette how much acid was used.
14. Repeat this procedure at least twice so that you have three readings for the volume of HCl.
15. Take an average of these three and use it to calculate the concentration of the HCl.
16. Put a label on the HCl bottle indicating the exact concentration of the contents. Keep this solution as it will be used in the next investigation.

CALCULATION

The reaction which occurs is:



Experiment	NaHCO ₃ - Volume (cm ³)	HCl - Volume (cm ³)
1		
2		
3		
Average		

Questions

1. Is HCl a strong or weak acid? Give a reason for your answer.
2. Why is methyl orange used as the indicator?
3. What is the approximate pH of the solution at end point.
4. Calculate the original concentration of the HCl solution used.
5. Calculate the pH of the original HCl solution used.
6. State 2 precautions taken.

Appendix M3 Worksheet: Division of potential - resistors in series and parallel

Experiment 1:

- **Aim:** **To investigate the division of potential in a series circuit.**
- Set up a circuit of 3 identical resistors in series. (Use crocodile clips to join the resistors)
- Connect the battery pack to the three resistors.
- Use the voltmeter, set to measure 20V DC, to measure and record the potential difference across each of the resistors.
- Measure the potential difference across all 3 resistors at once.
- What do you notice about the mathematical relationship between the readings?
- What happens to the potential that is supplied by the battery in a series circuit?

Experiment 2

- **Aim:** **To investigate the division of potential in a parallel circuit.**
- Set up a circuit of 3 identical resistors in parallel. (Use crocodile clips to join the resistors).
- Connect the battery pack to the three resistors.
- Use the voltmeter, set to measure 20V DC, to measure and record the potential difference across each of the resistors.
- Measure the potential difference across all 3 resistors at once.
- What do you notice about the mathematical relationship between the readings?
- What happens to the potential that is supplied by the battery in a series circuit?

Assessment Rubric for Practical Activity

Name: _____

Date: _____

Grade & Set: _____

Teacher: _____

ALL LEVEL INDICATORS RATE CONTENT, EFFORT AND PRESENTATION.			
Level Indicators	Achieved with merit	Partially achieved	Not achieved
1. Title Page: Name, Class, Date, Title of the activity	2	1	0
2. Introduction; Brief theoretical background to the activity	2	1	0
3. Investigative question (Ask a question)	2	1	0
4. Hypotheses: Statement of a possible outcome or result)	2	1	0
5. Variables.	2	1	0
6. Method (3 rd person, past tense)	2	1	0
7. Labelled diagram – List of apparatus.	2	1	0
8. Results; Tabulated	2	1	0
9. Conclusion (related to the hypothesis.	2	1	0
10. Discussion of results including errors, mistakes and improvements	2	1	0
TOTAL:	/20		

Appendix M4

Worksheet: The Law of Conservation of Linear Momentum

Grade 12 – Practical Investigation

Marks : 20

The law of conservation of linear momentumEducator: MrDue Date:

Aim: To study the effect of the rate of an objects distance in an explosion type problem, to determine

Whether the momentum in a system is conserved

Variables: distance, time taken, mass of objects, momentum

Apparatus/Materials: two trolleys of known different masses, measuring tape or long ruler, smooth non- inclined surface, stopwatch

Experimental Procedure

1. Place trolleys back to back on the centre of smooth surface
2. Release the spring and let the trolleys move apart
3. Measure the distance covered and the time it has reached that distance
4. Repeat procedure two more times for accuracy

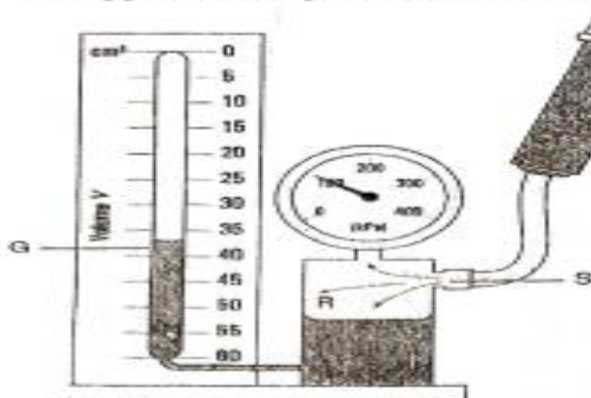
Learner Task

- 1) Analyze the distances and the time taken to reach these distances
- 2) Determine the momentum before and after being released
- 3) Determine whether the procedure was elastic or inelastic
- 4) The practical should have the following layout:
 - Background information (also include law of conservation of linear momentum)
 - Investigative Question
 - Hypothesis
 - Variables
 - Experimental procedure
 - Diagrams/ drawings of procedure or apparatus
 - Calculations (also include whether elastic or inelastic)
 - Table of calculations
 - Line graph of (momentum vs time) for each result
 - Line graph indicating (displacement vs time) for each trolley (for at least one trial)
 - Conclusion
 - Additional pictures
 - Make sure practical is neat and well laid out
 - Printed projects will be accepted

Appendix M5

Worksheet: Boyle's Law

Step 4 Pump in more air, measure and record. Repeat this several times. The apparatus they used is shown below.



The results of the investigation are

Pressure (kPa)	Volume (cm ³)

- 1 Give the name of the gas law that the learners investigated.
- 2 Why do the learners wait a few minutes every time before they take a reading?
- 3 Formulate a suitable hypothesis for this investigation.
- 4 Which variables did the learners keep constant during this investigation?
- 5 Identify:
 - S.1 the independent variable
 - S.2 the dependent variable
 - S.3 constants.
- 6 Draw a graph of the dependent variable on the y-axis versus the independent variable on the x-axis.
- 7 Determine the mathematical relationship between the pressure and volume of the enclosed gas. Use the graph obtained to justify your answer.

A group of Grade 11 learners wants to know how pressure affects the volume of an enclosed gas. They perform a scientific investigation in order to establish a relationship between pressure and volume of an enclosed gas.

They follow the method below:

- Step 1** Attach a bicycle pump at S.
- Step 2** Pump air into the reservoir R until a desired pressure is reached.
- Step 3** Wait a few minutes then measure and record the volume of the air in G at this pressure.

Appendix M6

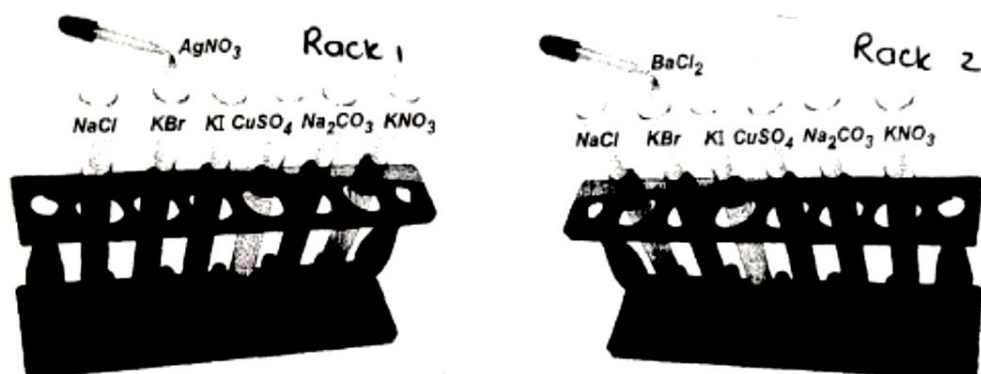
Worksheet: Precipitation

TOTAL : 40 MARKS

TIME : 1 LESSON

Practical Experiment : Precipitation Rates**QUESTION 1**

In this experiment the solubility of salts are investigated. Various solutions of salts have been prepared in test tubes. The order of the solutions are given in the diagram below. A few drops of silver nitrate must be added to each test tube in rack one and a few drops of barium chloride must be added to rack two.



Record your observations in the table below. The first column is filled in for you.

(22)

SOLUTION ADDED	SOLUTIONS IN RACK 1					
AgNO_3	NaCl	KBr	KI	CuSO_4	Na_2CO_3	KNO_3
Observation	White precipitate formed					
Formula of precipitate	AgCl					

SOLUTION ADDED	SOLUTIONS IN RACK 2					
	NaCl	KBr	KI	Cu SO ₄	Na ₂ CO ₃	KNO ₃
BaCl ₂						
Observation						
Formula of precipitate						

QUESTION 2

In the reaction between NaCl and AgNO₃ a precipitate is formed. Write out the chemical equation (in formula form) for this reaction. Show all phases. (4)

QUESTION 3

Write out the complete ionic equation for this reaction showing all the ions. (7)

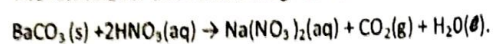
QUESTION 4

AgCl is insoluble in water. Explain why some salts are insoluble in water in terms of the strength of bonds (3)

QUESTION 5

Add a few drops concentrated nitric acid to the test tube marked with * (Rack 2). Observe the reaction.

The formula for this reaction is given as follows



Explain your observation using this equation. (4)

Appendix M7**Worksheet: Intermolecular forces and evaporation****INVESTIGATING THE EFFECTS OF INTERMOLECULAR FORCES**

The following four experiments investigate the effect of various physical properties

(evaporation, surface tension) of substances and determine how the intermolecular forces between the molecules relate to these properties.

Each experiment looks at a different property.

PART 1: EVAPORATION RATE

AIM: TO VERIFY EVAPORATION AND TO DETERMINE THE RELATIONSHIP BETWEEN EVAPORATION RATE AND INTERMOLECULAR FORCES.

Substances: ethanol, water, acetone, methylated spirits

METHOD

1. Place an evaporating dish onto each of four electronic mass meters placed in the same warm spot in the laboratory.
2. Zero each balance (so that it will only read the mass of the substance placed in the dish).
3. Measure 20 ml of each substance into each of the evaporating dishes.
4. Measure the mass of 20 ml of each substance.
5. After 6 minutes, measure the mass of each substance.

PART 2: SURFACE TENSION**AIM:**

To verify surface tension and to determine the relationship between surface tension and intermolecular forces

Substances: water, cooking oil, glycerine, acetone, methylated spirits

METHOD

1. Place about 50 ml of each substance into separate small measuring cylinders.
2. Observe the shape of the meniscus. (This is the level of the liquid). Note what happens at the edges where the liquid touches the glass. (You can place a few drops of food colouring in each substance to help you see the meniscus more clearly.)
3. Now place a drop of the substance on a small piece of glass. Observe the shape of the drop.

Appendix M8

Worksheet: evaporation and capillarity

The effects of intermolecular forces

Aim

To investigate evaporation and to determine the relation between evaporation and intermolecular forces.

Apparatus

You will need the following items for this experiment:

- ethanol, water, nail polish remover (acetone), methylated spirits
- evaporating dishes (or shallow basins)

Method

1. Place 20 ml of each substance given in separate evaporating dishes.
2. Carefully move each dish to a warm (sunny) spot.
3. Mark the level of liquid in each dish using a permanent marker. Make several marks at different positions around the dish. If the permanent marker is leaving a smudge rather than a noticeable mark, carefully wipe the side of the dish and try again.
4. Observe each dish every minute and note which liquid evaporates fastest.

Results

Record your results in the table below. You do not need to measure the level of the liquid, but rather just write how much the level had dropped (e.g. for water you might write did not notice any decrease in the level or for ethanol you might write almost all the liquid had evaporated).

Substance	Liquid level after 11 min	22 min	33 min	44 min	55 min
Ethanol					
Water					
Nail polish remover					
Methylated spirits					

Discussion and conclusion

You should find that water takes the longest time to evaporate. Water has strong intermolecular forces (hydrogen bonds). Ethanol ($\text{CH}_3\text{CH}_2\text{OH}$) and methylated spirits (mainly ethanol ($\text{CH}_3\text{CH}_2\text{OH}$) with some methanol (CH_3OH)) both have hydrogen bonds but these are slightly weaker than the hydrogen bonds in water. Nail polish remover (acetone (CH_3COCH_3)) has dipole-dipole forces only and so evaporates quickly.

Substances with weaker intermolecular forces evaporate faster than substances with stronger intermolecular forces.

Appendix N Summary of process skills observed

Process Skills	Heating & Cooling Curve	Titration	Division of potential	Inter molecular forces	Momentum	Boyles Law	Precipitates	Evaporation Capillarity	Circuits
Basic Process Skills									
Observing	√	√	√	√	√		√	√	√
Inferring			√		√				
Describe Measurements	√	√	√	√	√			√	
Communicating	√	√	√	√	√	√	√	√	√
Classifying							√		
Predicting		√	√	√				√	
Integrated Process Skills									
Controlling Variables			√		√				
Defining Operationally (Stating how to measure a variable)			√		√				
Formulating Hypothesis			√						
Interpreting Data	x	√	√	√	√	x	√	√	
Design Experiment									
Formulating Models									

√ Process skill taught in lesson

X Process skill taught in lesson but using example data

Appendix O Summary of the data collected using the Lesson Observation Framework instrument for the nine lessons observed

SECTION A: LEARNING OBJECTIVES FOR THE LESSON

	Heating & Cooling Curve		Titration		Division of potential		Intermolecular forces		Momentum		Boyles Law		Precipitates		Evaporation Capillarity		Circuits	
	I	A	I	A	I	A	I	A	I	A	I	A	I	A	I	A	I	A
OBJECTIVE 1: DEVELOP KNOWLEDGE AND UNDERSTANDING																		
Facts, concepts, theory, model	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Relationships	√		√	√	√	√	√	√	√	√	√				√	√	√	√
To identify objects	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
OBJECTIVE 2: LEARN ABOUT SCIENTIFIC APPROACH AND INQUIRY																		
How to use equipment	x		x		√	√	√	√	√	√	√	x	√	√	√	√		
To follow standard procedure/method	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
To identify phenomena	√		√	√	√	√	√	√	√		√		√		√	√		
To observe phenomena	√	√	√	√	√	√	√	√	√	√	√		√	√	√	√	√	√
How to plan an investigation	x		x		x		x		x		x		x		x		x	
To conduct an investigation	√	x	√	x	√	√	√	√	√	√	√	√	√	√	√	√	x	x
How to analyse data / example data	√	√	√	√	√	√	√	√	√	√	√	x	√	x	√	√	√	√
How to use data/example data to support conclusion	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
How to communicate findings	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√

SECTION B: WHAT LEARNERS DID WITH OBJECTS, OBSERVABLES, AND IDEAS: INTENDED VS ACTUAL

B1: OBJECTS / OBSERVABLES	Heating & Cooling Curve		Titration		Division of potential		Intermolecular forces		Momentum		Boyles Law		Precipitates		Evaporation Capillarity		Circuits	
<i>Did learners do with and/or observe objects and materials as was intended?</i>	I	A	I	A	I	A	I	A	I	A	I	A	I	A	I	A	I	A
Use instrument/device/apparatus/equipment to measure/collect data	√	√	x	x	√	√	√	√	√	√	√	x	√	√	√	√	x	x
Follow a method or procedure	√	x	x	x	√	√	√	√	√	√	√	x	√	√	√	√	√	x
Make an event occur	√	x	x	x	√	√	√	√	√	√	√	x	√	√	√	√	√	x
Make/present an object/material	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	√	x
Observe material, event, or quantity from manipulating objects & materials	√	√	√	x	√	√	√	√	√	√	√	x	√	√	√	√	√	x
Observe material, event, or quantity from the teacher manipulating objects & materials	√	√	√	√	√	√	√	√	√	√	√	x	√	√	√	√	√	√
Manipulate objects	√	√	x	x	√	√	√	√	√	√	√	x	√	√	√	√	√	x

B2: IDEAS	Heating & Cooling Curve		Titration		Division of potential		Intermolecular forces		Momentum		Boyles Law		Precipitates		Evaporation Capillarity		Circuits	
<i>Did learners think/discuss/explain what they were doing and observing?</i>	I	A	I	A	I	A	I	A	I	A	I	A	I	A	I	A	I	A
• Describe/explain observations made from the teacher/learner manipulating objects & materials	√	√	√	√	√	√	√	√	√	√	√	x	√	x	√	√	√	√
• Design a procedure or method	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
• Make a prediction from a Guess/Hypothesis or Law/Theory	√	√	√	√	√	√	√	√	√	√	√	x	x	x	√	√	√	√
• Test a prediction	x	x	x	x	√	√	√	√	√	√	√	x	x	x	√	√	x	x
• Explore relations between objects	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
• Explore relationships between variables	√	x	√	√	√	√	√	√	√	√	√	x	x	x	√	√	√	√
• Explore relations between objects and variables	x	x	√	√	√	√	√	√	√	√	√	x	x	x	√	√	√	√
• Identify a pattern	√	√	√	√	√	√	√	√	√	√	√	√	√	x	√	√	√	√
• Determine a value which is not measured directly	x	x	√	√	√	√	x	x	√	√	√	x	x	x	x	x	x	x
Account for an observation/finding using given/known explanation	√	√	√	√	√	√	√	√	√	√	√	x	√	√	√	√	√	√
Account for an observation/finding by proposing a new explanation	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Report on observations made	√	x	√	√	√	√	√	√	√	√	√	x	√	√	√	√	√	√

SECTION C

DEGREE OF OPENNESS/CLOSENESS

Who decides on the following?	Heating & Cooling Curve	Titration	Division of potential	Intermolecular forces	Momentum	Boyles Law	Precipitates	Evaporation Capillarity	Circuits
Question to be addressed	T	T	T	T	T	T	T	T	T
Equipment to use	T	T	T	T	T	T	T	T	T
Method/Procedure to follow	T	T	T	T	T	T	T	T	T
How to collect and record data	T	T	T	T	T	T	T	T	T
Analyse results	T	T	T	T	T	T	T	T	T
How to communicate findings	T	T	T	T	T	T	T	T	T
To whom is the solution/conclusion known?	L			L		L	L	L	L

LEARNER INVOLVEMENT & INTERACTIONS

	Heating & Cooling Curve	Titration	Division of potential	Intermolecular forces	Momentum	Boyles Law	Precipitates	Evaporation Capillarity	Circuits
LEARNER INVOLVEMENT									√
Teacher demonstrates; Learners watch	√	√							
Teacher demonstrates then Learners do/assist	√								

Learners do practical in groups			√	√	√	X	√	√	
Learners do practical individually									
Who is hands-on and/or minds-on?	T hands-on T minds-on L minds-on	T hands-on T minds-on L minds-on	L hands-on L minds-on	L hands-on L minds-on	L hands-on L minds-on	L hands-on L minds-on	L hands-on	L hands-on L minds-on	T hands-on T minds-on
LEARNER INTERACTIONS									
Learners interact with:									
Other learners about the practical			√	√	√			√	
Other learners not about the practical task			√	√		√		√	
The teacher occasionally	√	√		√		√	√	√	√
The teacher often			√						
Information given to learners	Heating & Cooling Curve	Titration	Division of potential	Intermolecular forces	Momentum	Boyles Law	Precipitates	Evaporation Capillarity	Circuits
Verbal									
On chalkboard/whiteboard			√						
Worksheet	√	√	√	√	√	√	√	√	√
Textbook						√			

How were the learners assessed?	Heating & Cooling Curve	Titration	Division of potential	Intermolecular forces	Momentum	Boyles Law	Precipitates	Evaporation Capillarity	Circuits
Learners questioned during lesson									
Learners assessed on manipulative skills									
Learners submit written report and/or answers to questions at end of lesson									
Learners submit written report and/or answers to questions later	√	√	√	√	√	√	√	√	√

- **MOTIVATION:** Observations and evidence of learner interest
- from learner interactions
- between learners and the teacher
- from the practical task

OTHER OBSERVATIONS:

Appendix P Summary of links between objects & observables and ideas

X: Teacher facilitated

Practical Work Lesson	Domain of Objects & Observables	Domain of Ideas
Heating and Cooling Curve of Water (Jiten) Type A Observation Investigation	<ul style="list-style-type: none"> Three learners manipulated apparatus/equipment to collect data following teacher manipulating objects (stopwatch; thermometer; stove) 	<ul style="list-style-type: none"> Three learners collecting data expressed ideas and answered questions about what they were doing (how to use thermometer; using wire gauze) Learners identified objects
	<ul style="list-style-type: none"> Three learners measured & obtained values (temperature readings) 	<ul style="list-style-type: none"> X Learners told units of measurement (temperature; time) Learners explored relations between simple variables (time; temperature)
	<ul style="list-style-type: none"> Three learners followed teacher's instructions on procedure 	
	<ul style="list-style-type: none"> Three learners made a phenomenon occur (melt; boil; evaporation) 	<ul style="list-style-type: none"> Learners identified melting; boiling; evaporation
	<ul style="list-style-type: none"> Learners observed event (bubbles; steam) 	<ul style="list-style-type: none"> X Learners did not make predictions from Kinetic Molecular Theory X Learners accounted for observations (Why bubbles; steam? At what temperature was this observed?) but not latent heat X Learners could not explain patterns in example data Learners reported on observations/patterns in example data

Practical Work Lesson	Domain of Objects & Observables	Domain of Ideas
Titration (Vish) Type A Observation Investigation	<ul style="list-style-type: none"> Teacher manipulated apparatus/equipment to collect data 	<ul style="list-style-type: none"> X Learners did not select equipment; how to use burette Learners identified objects
	<ul style="list-style-type: none"> Teacher measured & obtained values on quantities of reagents 	<ul style="list-style-type: none"> X Teacher explained how to measure X Teacher discussed relations between variables (amount of reagents; colour indicators) Learners determined a value which was not measured directly: concentration of HCl
	<ul style="list-style-type: none"> Teacher followed procedure 	<ul style="list-style-type: none"> X Teacher narrated procedure and discussed reasons for choices
	<ul style="list-style-type: none"> Teacher made an event/phenomenon occur; produced end-point and colour changes 	<ul style="list-style-type: none"> X Teacher provided explanations on end-point and colour changes
	<ul style="list-style-type: none"> Learners observed event: end-point and colour changes 	<ul style="list-style-type: none"> X Teacher accounted for observations: colour changes and provided explanations for observations Learners reported on observations made

Practical Work Lesson	Domain of Objects & Observables	Domain of Ideas
Division of potential (Eric) Type B Structured Investigation	<ul style="list-style-type: none"> • Learners manipulated apparatus/equipment to collect data: connected resistors in series and parallel; connected multimeter 	<ul style="list-style-type: none"> • X Learners given instructions on collecting data (how to connect circuit) • Learners identified objects
	<ul style="list-style-type: none"> • Learners measured & obtained values 	<ul style="list-style-type: none"> • Learners provided reasons for no / negative readings on multimeter • X Teacher provided units of measurement: ampere; volts • Learners explored relations between variables resistors in series and parallel: effect on current strength and potential difference • Learners determined a value which was not measured directly
	<ul style="list-style-type: none"> • Learners followed given laboratory procedure 	X
	<ul style="list-style-type: none"> • Learners made an event/phenomenon occur 	<ul style="list-style-type: none"> • Learners connected resistors and multimeter and showed differences when connected in series and parallel
	<ul style="list-style-type: none"> • Learners observed event 	<ul style="list-style-type: none"> • Learners provided explanations for values obtained • X Teacher guided learners to make predictions from theory: resistors in series and parallel: how current and potential is divided • Learners accounted for observations: increase/decrease in current strength and potential difference • Learners identified patterns in data • X Teacher guided learners to explain patterns in data • Learners reported on observations/patterns in data

Practical Work Lesson	Domain of Objects & Observables	Domain of Ideas
Intermolecular forces (John) Type B Structured Investigation	<ul style="list-style-type: none"> • Learners manipulated apparatus/equipment to collect data 	<ul style="list-style-type: none"> • X Learners given instructions on collecting data • Learners identified objects
	<ul style="list-style-type: none"> • Learners measured & obtained values 	<ul style="list-style-type: none"> • Learners considered units for measuring reagents • Learners explored relations between variables: time and evaporation
	<ul style="list-style-type: none"> • Learners followed given laboratory procedure 	X
	<ul style="list-style-type: none"> • Learners made an event/phenomenon occur 	<ul style="list-style-type: none"> • Evaporation
	<ul style="list-style-type: none"> • Learners observed event 	<ul style="list-style-type: none"> • Learners provided explanations for values obtained • X Teacher guided learners to make predictions from theory: Intermolecular Forces; Kinetic Molecular Theory • Learners accounted for observations: rates of evaporation • X Teacher guided learners to identify patterns and provide explanations for patterns in data: evaporation rates for different chemicals • Learners reported on observations/patterns in data

Practical Work Lesson	Domain of Objects & Observables	Domain of Ideas
Momentum (Lenny) Type B Structured Investigation	<ul style="list-style-type: none"> Learners manipulated apparatus/equipment to collect data 	<ul style="list-style-type: none"> Learners collecting data expressed ideas on how to collect data Learners identified objects
	<ul style="list-style-type: none"> Learners measured & obtained values 	<ul style="list-style-type: none"> Learners considered units for measuring Learners explored relations between variables
	<ul style="list-style-type: none"> Learners followed given laboratory procedure 	X
	<ul style="list-style-type: none"> Learners made an event/phenomenon occur 	<ul style="list-style-type: none"> Learners release trolley and observed distance travelled
	<ul style="list-style-type: none"> Learners observed event 	<ul style="list-style-type: none"> Learners provided explanations for values obtained X Teachers made predictions from theory Learners accounted for observations Learners identified patterns and provided explanations for patterns in data Learners reported on observations/patterns in data

Practical Work Lesson	Domain of Objects & Observables	Domain of Ideas
Precipitates (Betty) Cookbook exercise	<ul style="list-style-type: none"> Learners manipulated apparatus/equipment to collect data 	<ul style="list-style-type: none"> X Learners given method to collect data
	<ul style="list-style-type: none"> Learners measured 	<ul style="list-style-type: none"> X Learners given amounts of reagents to use
	<ul style="list-style-type: none"> Learners followed given laboratory procedure 	X
	<ul style="list-style-type: none"> Learners observed and made an event/phenomenon occur 	<ul style="list-style-type: none"> X Learners did not identify all precipitates Learners made predictions from theory learnt in class X Learners did not account for observations: why did the precipitate form? Learners reported on precipitates observed

Practical Work Lesson	Domain of Objects & Observables	Domain of Ideas
Evaporation and Capillarity (Sarah) Type B Structured Investigation	<ul style="list-style-type: none"> Learners manipulated apparatus/equipment to collect data 	<ul style="list-style-type: none"> X Learners given method to collect data Learners identified objects
	<ul style="list-style-type: none"> Learners measured & obtained values 	<ul style="list-style-type: none"> X Learners given units for measuring reagents Learners explored relations between variables: time and evaporation
	<ul style="list-style-type: none"> Learners followed given laboratory procedure 	X
	<ul style="list-style-type: none"> Learners made an event/phenomenon occur 	<ul style="list-style-type: none"> X Teacher explained evaporation and capillarity
	<ul style="list-style-type: none"> Learners observed event 	<ul style="list-style-type: none"> Learners provided explanations for values obtained X Teachers made predictions from theory: Intermolecular Forces; Kinetic Molecular Theory Learners accounted for observations: rates of evaporation; liquid rising Learners identified patterns and provided explanations for patterns in data: evaporation rates for different chemicals. Concept of evaporation; capillarity Learners reported on observations/patterns in data

Practical Work Lesson	Domain of Objects & Observables	Domain of Ideas
Series and Parallel Circuits (Jen) Teacher conducted investigation	<ul style="list-style-type: none"> • Teacher manipulated apparatus/equipment to collect data • Teacher manipulated variables 	<ul style="list-style-type: none"> • X Teacher explained how to connect circuits and why • Learners identified objects • X Teacher explained variables
	<ul style="list-style-type: none"> • Teacher measured & obtained values 	<ul style="list-style-type: none"> • X Teacher explained which instruments to use: How to use ammeter and voltmeter
	<ul style="list-style-type: none"> • Teacher followed laboratory procedure 	X
	<ul style="list-style-type: none"> • Teacher made an event/phenomenon occur 	<ul style="list-style-type: none"> • Brightness of bulbs in series and parallel
	<ul style="list-style-type: none"> • Learners observed event 	<ul style="list-style-type: none"> • X Teacher discussed and accounted for data obtained with learners • X Teacher helped learners establish patterns in data • Learners reported on data collected by teacher