Exploring exemplary physics teachers’ instructional practices in supporting learner access to school physics content

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Abstract

This study explored exemplary physics teachers' instructional practices which place learners at the centre of activities in terms of their abilities and competencies. It was carried out at two senior secondary schools in Botswana at a period when enrolment of learners had been increased. The increase in learner enrolment brought in new groups of learners whose performance in science subject was generally low as evidenced by national examination results. The low national examination results indicated a need for making school science content more accessible for these learners which is a direct responsibility of teachers (Mullis, Martin, & Foy, 2005; Shulman, 1987). Teachers' instructional practices had been characterised by excessive use of chalkboard and teacher-talk which is considered less effective in making school science content accessible for learners of wide ability range (Botswana, 1993; Prophet, 1990b).

Science education research on instructional practices put emphasis on active participation of learners as a way of improving learner access to school science content (Tiberghein, 2000). Learner participation in instructional practices draws largely from Vygotsky's social constructivist perspective (Vygotsky, 2012) which assumes that knowledge must first appear at the social level between people before it can be constructed at an individual level (Minick, 2005). Ideas presented at a social level must be in a form that can be understood by learners in order to construct them as their own (Driver & Oldham, 1986). The teacher plays an important role in making the subject content accessible for learners especially when they take into account learners' characteristics (Shulman, 1987).

The study used qualitative design to explore exemplary teachers' instructional practices in order to understand how they support learners in making sense of school physics content (Gay & Airasian, 2000). A case study approach was used because of limited information on exemplary instructional practices of physics teachers in Botswana (Merriam, 1998). Purposive sampling was used to select two teachers who were identified by the researcher for their exceptional instructional skills in engaging learners (Merriam, 2009; Patton, 2002). The intention for employing purposive sampling was that the teachers' exceptional practices would provide information on instructional activities that could serve as exemplars for physics teachers' instructional support for learners (Kuhn, 1970). Lesson observation was used to collect data on at least seven lessons for each teacher; interviews with teachers and their respective learners were also used to substantiate inferences because of their potential for providing information-rich data. Video and audio recorders were used to capture data because it was necessary to capture activities as close to their occurrence in natural settings as possible; also because these could be replayed to develop deep understandings of the interactions for making and validating inferences. Inductive analysis was used to explore instances of teacher's instructional support for learners from transcripts.

The findings included teachers' engagement of learners in new physics concepts which were structured on learners' knowledge from prior instruction and from events in their lives. The teachers created environments which were sensitive to learners' needs and competencies for accessing new physics concepts and skills. They used discussion and written work to provide opportunity for learners to demonstrate their understanding and to give feedback. The teachers' feedback included performance expectations set by Botswana Examination Council as a standard for learners' understanding of concepts and skills. The findings provide a potential basis for instructional practices in school physics in Botswana. These findings have implications for developing teacher's instructional practices in school physics and for initial teacher education.

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Declaration

I, Rorisang Agnes Rammiki, declare that this thesis is my original and independent work, and it has never been submitted to any other institution or faculty for degree purposes. It is being submitted for the degree of Doctor of Philosophy at the University of the Witwatersrand, Johannesburg.

Signed ---------------------------------------

Date --

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List of Abbreviations

BGSCE	Botswana General Certificate for School Education
COSC	Cambridge Overseas School Certificate
DMSE-INSET	Department of Mathematics and Science Education In-service Education for Teachers
NCE	National Commission on Education
ODA	Overseas Development Administration
SMASSE	Strengthening Mathematics and Science in Secondary Education
TIMSS	Trends in International Mathematics and Science Studies

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Dedication

To my Lord Jesus Christ who sacrificed his life for my undeserving life

and

Prophet T.B. Joshua whose teachings presented Lord Jesus Christ in a new light that saw me through this journey

I also dedicate this piece of work to my late grandfather Clement Kopano Rankhelepe who saw education as the only inheritance he could leave behind for his grandchildren, a legacy which for me was carried on by my parents Mary-Grace and Patrick Mokefane in the absence of my beloved mother Karabo Mmasekhoho Rammiki who died during my infancy.

CHAPTER 1

Introduction

1.0 Introduction

Botswana expressed a commitment to provide education and science education to learners from the time of independence in 1966 in order to meet the need for skilled human resource (Botswana, 1966). Its commitment to provide education for all learners at World Conference on Education for All in Jomtein, Thailand in 1990 was an endorsement of its policies on school education (Botswana, 1994; Molosi, 1993). Indeed, Botswana has done well in making school education accessible (Lewin, 2009) through equitable provision of education resources within its capacity (Botswana, 1993; Tawana, 2009). However, the quality of education is not satisfactory as expressed in the Long Term Vision for Botswana (R. o. Botswana, 1997) commonly referred to as Vision 2016, that

> Botswana has achieved a marked improvement in the quantity of educational facilities provided to its citizens but the pace of educational change has lagged behind the pace of national development. The challenge is now to improve the quality of education (R. o. Botswana, 1997a p.8).

The poor quality of school science education has been revealed in learners' poor performance in national examinations and international studies. Batswana learners' performance in science at both national examinations and The International Mathematics and Science Studies is low (Council, 2010a, 2010b; Gonzales et al., 2008; Mullis et al., 2005). The relative extent to which learners attain the intended school science education curriculum objectives as revealed through examinations and international studies point to the kind of opportunities provided for learners during instruction in specific topic areas (Mullis, Martin, Ruddock, O'Sullivan, & Preuschoff, 2009). Therefore, low learner performance indicates the need to make school science more accessible for learners.

Teachers play an important role in promoting learner performance by providing appropriate opportunities for accessing science content. Shulman (1986) specified that teachers have special knowledge for teaching which he referred to as pedagogical knowledge. The pedagogical knowledge involves adapting the subject content to the learners' understanding (Shulman, 1987) by "thinking one's way from the subject content as understood by the teacher into the minds and motivations of the learner" (Shulman, 1987, p. 237). Through this knowledge, teachers can provide appropriate opportunities for learners to access science content. While this study is not based on the PCK research domain, it acknowledges its concepts in the teachers' instructional practice.

Science teachers' instructional practices in Botswana have been found defective. The few research studies in this regard were done in junior secondary schools with particular focus on practical activities (Koosimile, 2005; Prophet & Rowell, 1990) language of instruction (Prophet, 1990a) and learners' lives (Koosimile, 2004). The only report on senior secondary school teachers' instructional practices was in a Government document and the focus was on the underutilisation of laboratory resources (Botswana, 1993). The scarcity of published research studies indicates a need for information that could be used in developing teachers' instructional practices. This study intends to contribute to the existing information on teachers' instructional practices by exploring exemplary physics teachers' practices.

The term *'exemplary'* has been used as a comparative term for teachers' expertise with no precise definition. However, different terms have been used to compare teachers' instructional practices in different research agenda. For instance, Berliner (1986) used the term 'expert teachers' and described them as having deep knowledge of the subject and learners' abilities and capabilities. Steffy (1989) referred to such teachers as those able to learn and commit to growth in relation to teaching excellence. Ladson-Billings (1995) used the term good teachers for exemplary teachers in African American communities who were found to relate the subject content to the learners' culture and lives. Bishop and Denley (2003) called them accomplished teachers for their definable qualities of expertise as well as undefinable qualities which contributed to their bounciness where novice teachers flop. Fraser and Tobin (1989a) called them exemplary teachers in that their instructional practices were consistent with intended curriculum in encouraging understanding of science concepts. In line with Fraser and Tobin (1989a) particular use of the term exemplary, this study adopted the term exemplary to refer to the teachers who were found to perform exceptionally well in the delivery of the Botswana science curriculum.

Research on exemplary teachers is within the research domain that focuses on effective teachers. While research on effective teachers tend to use quantitative and mixed method designs to obtain data which can be generalised, research on exemplary teachers has mainly used qualitative design due to its focus on detailed information on teacher's instruction which could be used to inform practice. It has used teachers' lessons, teaching programs and instructional practice as sources of information for in-depth analysis (Alsop, Bencze, & Pedretti, 2005; Fraser & Tobin, 1989a; Penick & Yager, 1983b).

An in-depth study of teachers' instructional practice allows for understanding of its effectiveness (Neumann, Kauertz, & Fischer, 2012). This is in accord with the description of instructional practice by Argyris and Schön (1974) as "a sequence of actions undertaken by a person to serve others, who are considered clients. Each action in the sequence of actions repeats some aspects of other actions in the sequence, but each action in some way unique." (p.6) It also agrees with Schoenfeld, Minstrell, and van Zee (2000) who noted that "each of the action sequences … corresponds to one or more current high priority goals. When that goal or set of goals has been satisfied, another set of goals and a corresponding action sequence are initiated" (p.290). Thus, an in-depth study would make it possible to understand the teachers' instructional practice through their actions. Similarly, this study uses qualitative design.

However, this study differs from the studies reviewed in that it focuses on exemplary teachers' instruction on specific topics in school physics. Research on instructional practice in school physics has been on designs informed by the way learners learn physics concepts and by the way physics content is modelled (Tiberghein, 1994, 2000). Few studies have taken qualitative approach in studying physics teachers' instructional practice and none has been focused on specific topic content. This study therefore takes a different approach in this regard which will fill in this gap.

It is noteworthy that exemplary teachers' practices are exceptional instances of the teachers' instructional practice which are found promising in making science content accessible to learners. While exceptional instances are not appropriate for making generalisations, they can provide solutions for unsatisfactory practices (Kuhn, 1970).

Vygotsky (1978)'s sociocultural theory provides a basis for understanding exemplary teachers' practice in supporting learner performance for this study. In particular, the theory typifies teachers' instruction as a way of enabling learners' performance in tasks which they cannot perform on their own through the concept of the zone of proximal development (Vygotsky, 1978). In line with the zone of proximal development, Wood, Bruner, and Ross (1976) provided a more elaborate definition of support for learners through the metaphor of ‘scaffolding’ (p.98) which describes six functions namely recruitment, reduction in degrees of freedom, direction maintenance, marking critical features, frustration control and demonstration. Similarly, Gallimore and Tharp (1990) categorised teachers’ assistance for learners based on apprenticeship. The theories describe teachers’ support for learners in broad categories which are helpful in directing in-depth explorations of teachers’ instructional support for learners in this study.

1.1 Rationale

This study was motivated by findings of a small baseline study carried out as part of the professional development program for secondary school mathematics and science teachers at the University of Botswana (Rammiki & Motswiri, 2010). The baseline study revealed that physics teachers in Botswana senior secondary schools generally used lecture method, dominated by ‘chalk-and-talk’ with copious note-taking by students. However, a few teachers demonstrated teaching approaches that focused on engaging learners in the subject matter under similar curriculum conditions. Such approaches were consistent with the success of the intended curriculum, thus the teachers were considered exemplary for the context of Botswana. The existence of such teachers provided an opportunity for exploring instructional practice of teachers who showed exceptional teaching approaches in school physics. These exceptional teachers were sampled with an aim to describe exemplary teaching of school physics.

The instructional practices have been explored in order to document the way exemplary teachers transform school physics content for learners. The information can be shared with teachers and pre-service and in-service teacher education, and continuing professional development of teachers for the improvement of instruction in school physics in Botswana. The sharing of teachers’ knowledge in the context of highly centralized school curriculum with equitable distribution of school resources, in the case of Botswana, and local teachers who have gone through the same teacher training program, can be useful in informing effective classroom practice.

1.2 Research Objectives

As has been apparent so far, this study was to analyse the exemplary physics teachers’ instruction by exploring successful and effective instances of the support given during teaching. It was based on the assumption that exemplary physics teachers have relatively adequate pedagogical content knowledge that can enhance physics instruction. In particular the focus was on:

(a) instances of learner support in teachers' instruction

(b) the kind of support provided

(c) learners' needs being targeted by the support

(d) how learners respond to the support provided.

1.3 Research Questions

The following research questions were used to guide the study.

1. What characterizes exemplary teachers' instructional practices in school physics?
2. How do the exemplary teachers' instructional practices support learners in accessing school physics content?
3. Why do the exemplary teachers' instructional practices in school physics support learners in accessing school physics content?

To reiterate, exemplary physics teachers in this study are local teachers who demonstrated exceptional instructional skills in engaging learners in Botswana senior secondary schools.

1.4 Conceptual and Theoretical Framework

The study took a social constructivist philosophical perspective which is concerned with making sense of the world as it is lived and experienced by people (Schwandt, 2001). In particular, it adopted Kuhn's concept of exemplars as the essence of the particular in solving problems (Bird, 2000; Kuhn, 1970). Based on social constructivist perspective, exemplary teachers' practices were viewed as a possible solution to common instructional practices which vary from methods prescribed by the intended curriculum.

Further, sociocultural theory was found appropriate for the study due to its inclination towards processes and interactions in educational setting (Vygotsky, 1978; Wertsch, 1991). This adoption was also influenced by the literature that characterized exemplary teachers practice in terms of engagement of learners in instructional activities (Tytler, 2003). The zone of proximal development as a sociocultural model for explaining cognitive processes in a learning situation was particularly useful in framing the teachers' support on topic content within the learners' cognitive abilities (Vygotsky, 1978).

1.5 Methodology

In this study, qualitative research design was used to access detailed information on exemplary teachers' instructional interactions with the learners (Gay & Airasian, 2000). Within the qualitative design, a case study approach was used to obtain detailed data on the teacher's instructional practice. Yin (1994) described a case study as "an empirical inquiry that investigates a contemporary phenomenon within its real-life context especially when the boundaries between phenomenon and context are not clearly evident" (p. 13). Merriam's (1998) description of case study as particularistic was used to explore exemplary teachers' instructional practices in what Schön (1987) termed the "swampy zone of practice" (p.3). As a study of the particular, complexity of practice through the differing perceptions and teaching styles of the participant teachers and learners were represented and supported (Adelman, Kemmis, & Jenkins, 1980).

The qualitative research design and case study approach made provision for capturing the teachers' instructional interactions (Gay & Airasian, 2000; Robson, 2011) through multiple data collection methods which enabled validation of information and viewing data from different perspectives.

1.5.1 Data Collection Methods

Data collection methods used for the study were observation and interviews. Observation method was used to collect data as it unfolded during instructional interaction. Observations make use of senses of sight, touch, or hearing (Adler & Adler, 1994) which provide opportunities to refine understandings and validate information. Semi-structured observations roughly guided by the research questions were employed to collect data. The semi-structured observations differ from structured observations which follow clearly defined criteria and from unstructured observations which are open-ended (Opie, 2004). In making observations the researcher took the role of a peripheral-member-researcher to better understand the participant teachers practice by interacting with the teachers as former colleagues (Adler & Adler, 1994). More information on data collection is provided in Chapter 5.

Interviews were used to establish, clarify and confirm ideas and interpretations from observations. Unstructured and semi-structured interviews were used to obtain elaborate information from the participants by not imposing restrictions on the content and expression of the interviewees' responses (Kerlinger & Lee, 2000). Video recorded instructional activities and learners' scripts were used during interviews to assist participants to reflect on the activities and interactions on which the interview questions were based (Gay & Airasian, 2000).

1.5.2 Data capturing techniques

The data was captured in four ways including audio-video recordings of lessons, audio recording of interviews, scrutiny of lesson hand-outs and taking of field notes to provide data for analysis (McMillan & Schumacher, 2006). Audio-video was used to capture verbal and non-verbal communication, and photo records of written and laboratory learning material used during instructional interaction. Audio recording was used to record learners' and teachers' interviews. The recordings were replayed to gain insights into the information during analysis (Gall, Gall, & Borg, 2007). Field notes were taken during observation to avoid distortion of the impressions of the lesson. The field notes were checked with the participant teachers on an ongoing basis to reduce researcher's personal influence and biases (McMillan & Schumacher, 2006). Hand-outs and worksheets were collected and studied to help develop an understanding of data. The names of learners on the worksheets have been kept confidential.

1.5.3 Data analysis

Inductive approach have been used to analyse data (Gall et al., 2007; McMillan & Schumacher, 2006). It involved looking for subtle nuances from the words, sentences, statements and actions relevant to the research questions and moving back and forth between the words, sentences or statements from data to form constructs and patterns (Merriam, 2009). The analysis was guided by an analytic scheme by Tiberghein and Buty (2007), more on this in Chapter 4 section 4.6.0.

1.5.4 Case selection

Purposive intensity sampling was used to select exemplary physics teachers. Gay and Airasian (2000) describe purposive sampling as judgment based on researcher's knowledge of the target group. In this view, physics teachers who demonstrated good instructional practices in the 2009 DMSE-INSET classroom observation study were requested to participate in the study. The rationale for purposive sampling for this study is based on Patton's (2002) view that the logic and power of purposeful sampling lie in the selection of "information-rich" cases for an in-depth study. Patton (2002) describes information-rich cases as "those from which one can learn a great deal about issues of central importance to the purpose of inquiry" (p.230). Two senior secondary school physics teachers in separate schools were selected to allow for a detailed in-depth study and to account for school effect. Due to limited funds, the teachers who were sampled served in secondary schools that were less than 200 kilometres away from Gaborone City where the researcher resided during data collection. The sampled teachers selected classes for the study so that they could take into account inconveniences that could result from the study. The two secondary schools had different background contexts.

1.6 Significance of the study

While available literature has been on foreign context, much research on science education tends to focus on the general deficiencies of teachers' instructional practices. The present study has the potential to show some of the best possible instructional skills used by the local exemplary physics teachers to support learners in school physics in Botswana. The findings will hopefully enhance physics teachers' instructional practice by providing actionable skills in that they would have been developed through experience by teachers in local classrooms. The information will also be used to guide professional development programs on how teachers can support effective learning. On pre-service teacher training, the findings will serve as cases that can be used to prepare student teachers for classroom instruction.

In Botswana, physics teachers' pedagogical content knowledge is mainly developed through teaching experience due to limitations in professional development programs. The development of the teachers' knowledge and skills is challenged by factors that are external and internal to instruction. Examples of external factors include large wide ability classes and pressure posed by national examinations while internal ones include relatively high cognitive demand of the syllabus (Prophet & Vlaadingerbroek, 2003) and communication barriers emanating from difficulties with the language of instruction (English) (Prophet & Towse, 1999). Teachers are expected to have deep knowledge of learners and skills to transform content to the learners' knowledge level (Steffy, Wolfe, Pasch, & Enz, 2000). The teachers' experience has a large influence in the development of the teachers' knowledge in this regard. Notably, the average science teachers' experience in Botswana is relatively low which is considered less than that of teachers who are found effective in supporting learners (Rivkin, Hanushek, & Kain, 2005).

In spite of these challenges, some teachers appear to be able to support learners to access school physics content. However, it has not been clear how they manage to offer such support to learners. The present study was therefore an attempt to explore instructional practices of these physics teachers who have been more successful in supporting their learners. It is the teachers who have been more successful in supporting learners that are referred to as exemplary teachers in this study.

1.7 Chapter Summary and Structure of the Report

The chapter has been an introduction to the study by presenting the rationale, research objectives, research questions, methodology and significance of the study. The rest of the report is organized as follows.

Chapter 2 provides a background of the study setting. It is a literature review on the science teachers' instructional practices in secondary school science in Botswana. It shows a gap that exists between the intended and implemented science curriculum. Drawing mainly from Government documents, due to limited empirical research studies, it outlines the successes on increased learner enrolment in school education and curriculum designs that take into account a wide range of learner abilities and interest. It also reflects challenges in teachers' instructional practices characterized by approaches that do not take into account the wide range of learner abilities.

Chapter 3 provides a review of literature on exemplary teachers' instructional practices. The review shows a range of effective instructional skills that are consistent with the constructivist theory on facilitating learner understanding of science concepts and physics concepts. It served as a basis for Vygotsky's sociocultural theory that was found appropriate for the study due to its inclination towards processes and interactions in educational setting. Also discussed in Chapter 3 is the zone of proximal development that has provided an analytical framework for the teachers' support relative to learners' cognitive understandings.

Chapter 4 provides a methodological approach and philosophical viewpoints for the study. The approach was based on the social constructivist philosophical viewpoints for its concern on how individuals make sense of the social world they live in and how they conduct their activities in that world. It presents an argument for the qualitative research design and the case study approach.

Chapter 5 presents details of the actual field data collection. It includes details of processes used to seek permission for carrying out the study and the actual conduct of the study and about exit from the field, data processing and analysis.

Chapter 6 reports on Teacher A's instructional practice and learner support on thermal physics topic. The report consists of a description of the seven lessons observed and the analysis of the instructional activities to capture the support provided for the learners.

*Chapter **7*** reports on Teacher B's instructional practice and learner support on waves and light topic. It consists of descriptions of the eight lessons and the analysis of the instructional activities to capture the instructional support provided for the learners.

Chapter 8 presents the findings and conclusion. The findings were consistent with literature. Recommendation and implication were made targeting teacher education and professional development.

CHAPTER 2

Teachers' Instructional Practice: Botswana Context

2.0 Introduction

This chapter provides a context for physics teachers' instructional practice in senior secondary schools and the way it supports learner participation. The literature review is mainly based on reports of the National Commissions on Education and the National Development Plans due to limited published empirical research literature on physics teacher's instruction in Botswana. The chapter begins with a discussion of the general goals of school education defined through the first National Commission on Education and the subsequent development towards achieving them. It then draws from a few studies on development of science curricula for junior and senior secondary schools to show the apparent mismatch between the intended aims of the curriculum and its implementation through the science teachers' instructional practices.

2.1 Goals of school education

School education in Botswana is directed by the recommendations of the 1977 National Commissions on Education which was the first Commission to be instituted ten years after Botswana obtained its independence from United Kingdom in 1966 (Botswana, 1977). At independence, Botswana was one of the poorest countries in the world (Bank, 2013) and it had not benefited much from its colonial ties with the United Kingdom in terms of schools, teachers and education officers (Botswana, 1966). Therefore, at the time of independence, the Government took a pragmatic stand to build its school education system in order to develop its human resources including teachers. At the same time there was an expressed need for technically skilled human resource for the economically promising mining industry that was underway; science therefore became a critical school subject for future training of learners in science based field (Botswana, 1966). However, the apparently poor quality of school education led the Government of Botswana to set up the first National Commission on Education in 1977 to give direction on the country's school education system (Botswana, 1977).

The 1977 NCE recommendations became highly pervasive in the subsequent development of school education in which science education is a component. The fundamental recommendation was establishment of universal school education based on four national principles of democracy, development, unity and self-reliance known as *Education for Kagisano.* Kagisano is a Setswana word for social justice (Botswana, 1977). In view of the concentration of schools in towns and large villages at that time, the main concern in the development of universal school education was equitable distribution of schools around the country to cover remote villages. Provision of qualified school teachers with appropriate instructional skills to assist learners of wide ability range that were to be admitted in the schools was also a major concern.

2.1.1 Access to education at primary and junior secondary levels

Universal school education began with nine years of basic education for all learners in 1986 which entailed seven years of primary, two years of junior secondary and three years senior secondary education making up 7-2-3 school system (Botswana, 1993). The development leading to the nine years of basic education involved removal of various constraints to enrolment including free education and automatic promotion to higher education levels. Payment of school fees was abolished in 1980 at primary school and 1989 at secondary school level which gave all children an opportunity to attend school regardless of their socioeconomic background (Botswana, 1993 par. 12.5.6 & 12.5.10). Fee payment was however re-introduced in secondary school level at 5% of the total cost to ensure sustainability of education (Botswana, 2009). Automatic promotion which had been introduced before the 1977 National Commission on Education was maintained to encourage school attendance and reduced possible backlog of repeaters (Botswana, 1977, 1993). However, there was concern with automatic promotion among the educators that it contributed to the poor quality of education.

The development towards nine years of basic education also involved building of schools to accommodate the increase in number of learners due to removal of possible constraints to school attendance. The schools were built such that most children would not have to walk long distances from their homes to school; boarding are provided where people live in scattered settlements (Botswana, 1993, 2006). Learners are provided with standard facilities including textbooks, notebooks and exercise books. The school buildings include at least two fairly equipped science laboratories for junior secondary science education to facilitate the teaching of science (Botswana, 1993; Nganunu, 1988). Consequently, the school enrolment and progression rate increased.

The present record for school enrolment stands around 89.6% for primary schools and 96.9% access to junior secondary schools (Botswana, 2009) with a progression rate of 97% in primary education (Botswana, 2007). Efforts to reach 100% enrolment rate at primary level has been found problematic in remote areas and with children with special needs (Botswana, 2009). The progression rate from junior secondary to senior secondary increased from 49% in the year 1999 to more than 68% in 2008 (Botswana, 2007) and is projected to reach 98% in 2016 (R. o. Botswana, 2005). New secondary schools are built on continual basis to accommodate increasing number of learners (Botswana, 2009). However, progression to senior secondary schools was selective based on Junior Certificate Examinations results and only learners who qualify for admission progress to senior secondary schools (Lewin, 2009). Learners who do not qualify for entry in senior secondary schools either go for vocational training, distance education or world of work (Botswana, 2008). However, junior secondary education qualifications for nine years of basic education and the maturity level of learners were found unsatisfactory for the world of work. Therefore, the second National Commission on Education made recommendations to change the school education system to 7-3-2, seven years of primary, three years of junior secondary and two years of senior secondary education, and to increase transition rate from junior to senior secondary school (Botswana, 1993).

2.1.2 Access to education at senior secondary level

In preparation for the increase in transition from junior to senior secondary schools (see Table 1), the 27 existing senior secondary schools were expanded from 21 to 42 classes to double enrolment of learners. In addition, a plan was made to build five senior secondary schools in the north-west, central, southern and south central regions of the country by the end of the financial year 2007/8 (Botswana, 2006). The locations for the new schools were in line with the equitable distribution of resources to make school education accessible and to avoid exposing learners to new environments away from home which may negatively impact on their learning (Botswana, 1977, 1993). However, only two schools were completed by 2012 due to financial constraints. To keep up with the demand for senior secondary education in the phase of economic slow-down, a strategy typical of the efficiency reform for primary schooling in Zimbabwe in the early 1980s was used (Lewin, 1987). The official class size was increased from 35 to 45 and a double shift system introduced in five senior secondary schools that are located in areas with a high number of primary and junior secondary school completers. The double shift entailed increasing access by having two groups of learners so that one group attend classes in the morning and another group in the afternoon compared to one group of learners in a normal school arrangement (Botswana, 1993, 1994). The current projections to increase transition rate from junior to senior secondary school are reflected in Table 1.

Table 1: Transition rate from junior to senior secondary school

Baseline/2008	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
66.1 %	67.1 %	76.1 %	80.4 %	89.3 %	89.8 %	95.2 %	100 %

Botswana (2009)

2.2 Science Curriculum for ten years of basic education

The development of science curriculum for basic education involved aspects that were not only important for science education but also for science teachers' instructional practices. The curriculum was designed to take into account the experiences from the learners' lives (Nganunu, 1988; Ogunniyi, 1995). The science content was drawn from topics that were critical to Botswana such as water conservation, mining, health, wildlife and transportation. It also included problems encountered in communities in towns and villages such as water shortage, fuel shortage, dehydration, and overgrazing.

The curriculum provided opportunity for teachers to develop instructional activities around learners' lives (Nganunu, 1988) which would create a continuum between school science and out-of-school life. It included instructional material designed to guide teachers on the content and expected instructional methods. The curriculum was closely aligned to the recommendation of 1977 National Commission on Education that instruction should help learners (Botswana, 1977): to be familiar with the local Botswana context - country's achievements and problems and how the problems are tackled (Item 2.29) and to make own observations, use reference material and make inquiries at home and in the community (Item 2.23); and have a voice and manage their own affairs (Item 2.10). The instructional material for the nine-year basic education in the form of textbooks, worksheets and teachers' guides were relevant to Botswana in this regard. For instance, the worksheets were intended to engage learners in specific science ways of thinking and studying their environment (Prophet & Rowell, 1990). In addition, the textbooks were aligned to the competency levels in the language of instruction at different school levels; as Ogunniyi (1995) noted, books 1-4 were written in Setswana while books 5-7 were written in English. The reason was "because in grades 1-4 Setswana is the medium of instruction while in grades 5-7 English is the medium of instruction" (Ogunniyi, 1995 p.104).

The science curriculum for nine years of basic education was expanded in 1996 when the school system changed from 7-2-3 to the present 7-3-2 (see section 2.1.1) by adding topics such as Environmental Education, Population and Family Life Education, HIV-AIDS and The World of Work (Botswana, 2003; M. o. Education, 1995). The topics reinforced the syllabus alignment towards the lives of the learners. However, research studies showed weaknesses in the teachers' instructional practices as discussed next.

2.2.1 Junior secondary school teachers' instructional practices

Research studies on teachers' instructional practices showed weaknesses in providing opportunity for learners to make observations of their own environment as afforded by the science syllabus and the associated teaching material. Prophet and Rowell (1990) in a study that involved classroom observations in five junior secondary schools found the instructional interactions predominantly authoritarian and teacher-centred which encouraged passive learning. This observation was made despite the provision of instructional material designed to actively engage learners in the science content. Prophet and Rowell (1990) made the following observation.

> Worksheet 16B suggests that students observe the features of a housefly and then draw a leg of the fly. I have watched this lesson presented by three different teachers, and in each case the teacher drew a diagram of the fly on the board so that students can copy the labels, and then a more detailed diagram of the leg. No flies were actually examined. (Prophet & Rowell, 1990 p.26)

The junior secondary teachers' instructional practices were also found inadequate in linking school science content to learners' lives. For instance, Koosimile (2004) in a case study which involved 26 junior secondary schools found that science teachers lacked pedagogical skills to effectively engage learners in out-of-school experiences in science. In particular, teachers "could not easily create links between the learners' out-of-school experiences and science" (p. 488). The inclusion of out-of-school experiences in school science was part of the science curriculum for the 10 years of basic education which presented school science in the context of learners' lives. It was therefore critical that teachers implemented the curriculum in that respect.

The research studies conducted by Koosimile (2005) revealed weaknesses in the continuity of instructional content between primary and junior secondary science instruction. In a study of science teachers' instructional practices in inducting primary school leavers in junior secondary science it was found that teachers did not have a clear direction in initiating learners to more cognitively demanding junior secondary science (Koosimile, 2005). Koosimile (2005) described the teachers' instructional practices as characterised in the following.

- Authoritarian and teacher-centred environments;
- Acquisition of knowledge by pupils through rote learning;
- Emphasis and priority on content coverage rather than on science processes and understanding;
- Weakly defined role of practical work in science teaching and learning;
- Pupils viewed as (and increasingly becoming) passive recipients of information, with no acknowledgement by science teachers of pupils' backgrounds and experiences from primary school science.

(Koosimile, 2005 p.45)

The findings showed the teachers' instructional practices' divergence from intended curriculum. They indicate low level of learner participation in instructional activities at junior secondary level which has a bearing on science teachers' practices at senior secondary school. This is based on Mullis et al. (2009) assertion that "teachers' success in implementing the curriculum and contributing to student learning is influenced by the prerequisites that students themselves bring to the educational enterprise as well as their attitudes toward learning" (p.95).

2.3 Botswana General Certificate for School Education

The senior secondary schools followed Cambridge Overseas School Certificate (COSC) science syllabuses during the development of the science curriculum for the 10 years of basic education. COSC was found necessary for monitoring the quality of education because of its international profile for gauging learner performance with that of other countries (Botswana, 1993). However, there was need to accommodate the increasing number of learners from junior secondary school in senior secondary schools (Botswana, 1977) and COSC syllabuses posed limitations in that regard because they could not accommodate learners of wide ability range. Therefore, there was an expressed need to develop a national curriculum that would cater for a wide range of learner abilities. The curriculum was specifically intended to offer "children a range of educational experiences that would enable them to discover and develop their interests and inherent talents and skills" (Botswana, 1993 par. 4.7.6(e)).

The design of the national senior secondary school curriculum named Botswana General Certificate for School Education (BGCSE) largely reflects its intention to cater for a wide range of learners' interests. This is shown in the curriculum blueprint in which learners are expected to take at least eight subjects (M. o. Education, 1998b). The subjects are grouped into core and options. The core group consists of mathematics, Setswana and English language. Science fall under optional groups and consist of four subjects namely Single Award, Double Award, Pure Sciences and General Science. General science is meant for private candidates who would not have access to laboratory activities. The single Award was meant for learners who would want to follow careers that are not science-based. Double Award and Pure sciences were meant for learners who would want to follow science-based careers to different degrees. The pure science grouping consists of separate biology, chemistry, and physics syllabuses, while Double Science and Single Science Awards are combined syllabuses which in principle constitute 2/3 and 1/3 of the pure science content respectively. The weightings are reflected by the minimum time allocation of lesson periods for the three science options as shown in Table 2.

Table 2: BGCSE Science options weighting by time and credit allocation

Subject	*minimum periods per week*	*Credits*
Single Science	4	1
Double Science	4 + 4	2
Pure Science(Triple Science)	4 (biology) + 4 (chemistry) + 4(physics)	3

(M. o. Education, 1998b p.11)

The minimum periods per week in the COSC pure science syllabuses were 6+6+6 which meant that the number of periods was reduced by 2 for each science subject. The reduction in number of periods allowed for more subjects in the timetable through which learners could be exposed to basic concepts in a wide range of career fields.

However, the implementation of the BGCSE science curriculum fell short of catering for the wide abilities of learners. For instance, the syllabus has core objectives expected to be achieved by all learners in the respective syllabus options and extended objectives which are meant for able learners. But, the way the instructional activities for extended objectives were to be conducted in a large class of wide ability learners was not articulated for implementation by teachers (Koosimile, 2005). This left the actual implementation of core and extended syllabus objectives to teachers' discretion. In this regard Koosimile (2005) noted that "any innovation gap that may prevail in the adoption of the syllabus is largely due to contradictions, misinformation and ambiguities in official policy statements vital for guiding its adoption, interpretation and implementation" (p218).

According to Koosimile (2001) the development of the BGCSE science syllabuses was characterized by the notion that science was universal which implied that science syllabuses could be developed and therefore effectively implemented using foreign context. A universal view of science has been viewed with scepticism for not meeting the development and learners' needs in non-Western cultures. For instance, Ogunniyi (1986) in his review of science education in Africa stated the following.

> There is a great need for relevance. Although by nature science is universal, the needs of the different cultures and economies are not the same. Certainly, topics that relate to mechanized farming, control of malaria and many tropical diseases, ecological balance, provision of good drinkable water, production of food, development of good roads, drought, small agro-based industries, etc., are more relevant to the African setting than such topics as computers in the schools… (Ogunniyi, 1986 p.119)

Mutegi (2011) on performance of non-Western learners asserted that the difficulties the learners faced in learning western-science emanate from differences in cultural perspectives which form part of the learners' knowledge. Making western-science relevant to Batswana learners is rooted in the 1977 National Commission on Education statement that education "must relate to and reflect the values of the society of which it is a part" (Botswana, 1977: par 2.04 p.23). Therefore, it was important to have senior secondary school science content presented in the context of the learners' lives. This would also help in developing a continuous context of science with the junior secondary school science which was developed to take into account learners' lives as well as making science more accessible to learners (see section 2.2).

Nevertheless, the instructional experiences recommended by the BGCSE science curriculum were to be learner-centred (M. o. Education, 1998c). The concept of learner-centredness originates from John Dewey that school children should be encouraged to communicate, inquire and construct knowledge (Noddings, 1998) as opposed to lecturing them on knowledge. For school education in Botswana, learner-centred approaches seek to develop the individual learner qualities and skills (Botswana, 1977) by increasing the participation and performance of learners of different abilities, learners with special needs, girls and boys

(Botswana, 1993). The BGCSE physics syllabus elaborates on learner-centred approaches as follows.

- Laying emphasis on science process skills, problem-solving skills, and the acquisition of hands-on experience which should increase the participation and performance of all groups e.g. groups of different abilities, learners with special needs, girls and boys.

- Presenting science in an interesting and challenging way that should popularise it and encourage learners to opt to pursue Science and Science-related fields for careers.

(M. o. Education, 1998c p.iv)

Learner-centred approaches are not elaborated upon beyond these statements for instruction in classes of wide ability learners.

However, the domains of knowledge to be taught were elaborate. The BGCSE physics syllabus were to be achieved through learning experiences in the following domains: knowledge and understanding; handling information; application and problem solving; investigation and experimental skills; and attitude in physics and science in general (M. o. Education, 1998c). The criteria for the domains are

1. Knowledge and understanding of concepts, laws, theories and principles of physics, scientific vocabulary, terminology, convention (including symbols, quantities and units), application of science and of their technological economical environmental ethical and social implications.
2. Handling information, application, and solving problems, to solve problems as they relate to day to day situations including some of a quantitative nature, use of information to identify patterns, report trends, draw inferences, make predictions and propose hypothesis, manipulate numerical and other data.
3. Investigation and experimental skills. Follow a sequence of instructions, use appropriate techniques, apparatus and materials, handle instruments, apparatus and materials safely, make and record observations, measurements and estimates, interpret and evaluate observations and data; plan investigation and/or evaluate methods and suggest possible improvements
4. Attitudes in science: Open-mindedness, inventiveness, concern for accuracy and precision, objectivity, integrity and initiative towards scientific skills; Respect for life; awareness and appreciation for the environment; promotion of indigenous science and technology; recognition of the usefulness of science, and limitations of scientific method; promotion of awareness that the applications of science may be both beneficial and detrimental to the individual, the community and the environment.

(M. o. Education, 1998c p. iv-v)

The domains serve to guide instructional practice together with the assessment weightings where knowledge and understanding constitute 50% of the instructional experiences (M. o. Education, 1998a). The other 50% is for handling information, application, solving problems, and investigation and experimental skills as shown in Table 3.

Table 3: Assessment weightings of knowledge domains

Knowledge domains	*weightings*
Knowledge and understanding	50%
Handling information, application, and solving problems	30%
Investigation and experimental skills	20%

(M. o. Education, 1998a p.4)

The domains were elaborated further in the science textbooks which are loaned to learners and teachers (see section 2.7.1). However, the content expressed through each of the domains were found cognitively demanding for Double and Single Science groups as they did not match their cognitive abilities (Prophet & Vlaadingerbroek, 2003). This meant that the recommended learner-centred approaches and intention to make school science accessible to all learners would not be easily achieved at instructional level particularly because science teachers found the syllabuses too congested (Koosimile, 2001; Prophet & Vlaadingerbroek, 2003).

2.3.1 Senior secondary school teachers' instructional practices

Prior to the implementation of BGCSE physics syllabus which began in 1998, the teachers' instructional practices were found to be characterized by excessive use of chalkboard (Botswana, 1993). The 1993 National Commission on Education observed that:

> …notwithstanding the ample supply of laboratories and equipment, some teachers do not use them adequately for instructional purposes. There is a tendency amongst teachers to give blackboard tuition even in Science topics that have a strong practical basis. (Botswana, 1993 par 5.10.21 p.177)

Excessive use of blackboard encourages copious note-taking which does not ensure cognitive engagement of learners in what is taught (Driver & Oldham, 1986). Therefore, it was not a desired approach for instruction in science. Instead, experiments and other hands-on activities which actively involved learners were found to offer alternative methods for which laboratories are instituted (Hodson, 2009). However, experiments and other hands-on activities require the support of qualified laboratory technicians who were not available in schools (Botswana, 1993) and were still not available during this study.

The senior secondary school science teachers' practices have changed little after the implementation of BGCSE curriculum. For instance, Tawana (2009) found that teachers still had some way to go to reach the ideals of the BGCSE curriculum which was studied using a scale devised by Rogan and Grayson (2003). Rogan and Grayson (2003) developed constructs for curriculum implementation at school level which include profiles of capacity to support reform for developing countries using South African Curriculum 2005 as an illustration. Tawana (2009) found that areas that needed improvement at individual teacher level in Botswana included:

- The need to polish levels at which teachers were already operating. There were still some concerns over issues teachers took for granted and considered them as unimportant such as balancing teaching across all streams
- Attempt to help all teachers at relatively lower operational levels to raise to higher levels already attained by colleagues
- Attempt to move to new levels which basically means trying new things, teachers have never attempted such as classroom interactions, practical work and science and society at level four

(Tawana, 2009, p.268)

The low teaching experience of the science teachers might also have had an influence on their low operational level (Tawana, 2009). Rivkin et al. (2005) found that teachers who have 25 years of experience in teaching are more effective in supporting learners compared to less experienced teachers. While there are no official records of teaching experience of senior secondary science teachers, small studies indicate that they have relatively low teaching experience. For instance, 2008 Needs Assessment for professional development of senior secondary science teachers showed that 38 out of 50 physics teachers had teaching experience between 0 -10 years which is about 76% and 15 of the teachers with an experience of 0-5 years which is 30%. The number of physics teachers at the time of the study was about 220 (Motswiri, Ramatlapana, & Rammiki, 2010).The next section discusses the professional development of science teachers.

2.4 Professional Development

Ogunniyi (1986) advanced that the "new science curricula demand teachers who are capable of using instructional procedures that are supportive of the new emphasis" elaborating through Akintola's words that:

> Our educational needs have grown beyond the competence and know-how of most of our teachers. It is therefore essential that organized teacher in-service education become an inseparable aspect of curriculum development activities. For success in this very crucial endeavour, teachers need help which must be provided at instructional,

state and national levels in an organized and coordinated manner (Ogunniyi, 1986 p.120)

The 1977 National Commission on Education highlighted the importance of professional development program in curriculum reform as "to inform serving teachers and headmasters of new development in their subject field…to disseminate information on curriculum and syllabus changes" (Botswana, 1977 par 6.103 p.160). The large part of professional development has been on in-service training (Botswana, 1993) which is considered largely successful in upgrading teachers' content knowledge (Craig, Kraft, & Plessis, 1998). The teachers' professional development at instructional level which this section is focused on has not been equally successful particularly when viewed in a broad context of development of school science education curriculum as highlighted by Ogunniyi (1986) quoted at the opening of this section.

The professional development programs for teachers started as a joint venture with other developed countries mainly due to shortage of local expertise. For instance, the professional development program for junior secondary science known as Botswana In-service Project (BIP) was a partnership between Botswana and Overseas Development Administration (ODA) based in the United Kingdom from 1986 to 1994 (Meyer, Nagel, & Snyder Jr., 1993; Monyatsi, 2005). The professional development activities for junior secondary science have not been prominent since the departure of the ODA experts until the recent establishment of SMASSE (). Presently, there are no published documents on the on-going SMASSE program. The available information is an undated working paper which outlines its aims and program strategies. However, Ishihara (2011) presents SMASSE as a Japanese-based in-service program aimed to promote activity-based instruction and learner participation. It was initially a joined venture between Kenya and Japan but now it is widely used in Africa including Botswana. It is noteworthy that the program has already been found ineffective in influencing the teachers' instructional practices in Kenya (Sifuna & Kaime, 2007).

The professional development for senior secondary science teachers began as a partnership between Botswana and Netherlands (U. o. Botswana, 1997) under the name UB-INSET. UB-INSET was institutionalised in 1999 into the Department of Mathematics and Science Education in the University of Botswana and renamed DMSE-INSET, Department of Mathematics and Science Education In-service Training. DMSE-INSET faced a major task of supporting teachers with the implementation of the BGCSE science curriculum with limited funding (U. o. Botswana, 1997). It used a departmental oriented in-service training program to get information to teachers through the school administrative and leadership structures. The program was based on the premise that the curriculum changes can be implemented when they are supported and carried out by a department as a whole and when the responsibility rests with the school as noted in In-service Education and Training programme for Science and Mathematics teachers INSET III (1997) that:

> Heads of schools and heads of departments are given responsibility to set up school-based INSET programs. It signifies the importance of schools refining their own INSET needs. Heads of Department therefore, play an important role as educational leaders, who apart from being members of the school facilitative management team, are expected to act as organisational curricular and supervisory leaders. (U. o. Botswana, 1997 p.7)

The teachers were trained through annual workshops which were run during school holidays for one week and through follow-up school visits. The teachers were expected to implement what they learned from the workshops in their classrooms and to share it with other teachers through workshops or informal collaboration. However, DMSE-INSET workshops and school visits reports indicate that teachers faced some difficulties in implementing what they learned from workshops. For instance, DMSE-INSET School Visit Report of 2008 stated a number of reasons which biology, chemistry and physics teachers raised for failing to implement DMSE-INSET workshop outcomes including the following.

- The information is normally not well disseminated to the rest of the staff to be implemented.
- Resources for implementation are limited.
- The time for workshops is short for internalising the ideas.
- The follow-up visits come too late when teachers have already abandoned the ideas due to difficulties they face in the implementation process.

(D. o. M. a. S. Education, 2008 p.3)

Although teachers have a greater impact on students' performance than the curriculum (Hawley & Rosenholtz, 1984), their preparation through professional development programmes have been criticised for failing to bring desired changes in teaching and student performance (Guskey, 1986; Smiley, 1989). The major criticism was that they were not firmly based on classroom situations (Darling-Hammond & McLaughlin, 1995). DMSE-INSET faced similar criticism that its training programme does not impact on the teaching of science and mathematics in schools (Koosimile, 2007). The success of professional development in recent programs which has been attributed to the quantity and intensity of training activities (Borko, 2004; Supovitz & Turner, 2000) is lacking in the professional development activities of DMSE-INSET. Regardless, some science teachers successfully use their own professional knowledge to help learners to access the subject content.

It is noteworthy that this study was rationalised from a DMSE-INSET baseline study conducted during school visits (D. o. M. a. S. Education, 2008). The baseline study used lesson observation and short after-lesson interviews to provide information on how teachers taught in large wide ability classes in seven, out of twenty-eight senior secondary schools. The teachers observed were selected by the senior teachers who are responsible for the development and implementation of the subject curriculum at school level. The teachers' instructional practices were viewed in the light of BGCSE science curriculum recommendation for learner-centred instructional approaches. Therefore, the apparent lack of engagement of learners in the instructional activities was a concern which motivated the research problem for this study.

2.5 Science Teacher Education

The pre-service education provides the basic training on which the teachers' learning continues during practice as noted by Craig et al. (1998) that "Teacher development must be seen as a continuum of learning, with teachers located at various places along the continuum" (p.1). Botswana has established institutions for pre-service education which prepare school science teachers for teaching at primary, junior and senior secondary school level.

The primary school pre-service teacher education is done in four colleges of education which offer a three year Diploma in Primary Education. The junior secondary school pre-service science teacher education is done in two colleges of education which offer three year Diploma in Secondary Education and the senior secondary school pre-service science teacher education is done at the university level which offers Bachelor of Education (Science). The minimum entry requirement for all teacher training institutions is a senior secondary school certificate. The other pre-service course offered at University of Botswana is a one year Post Graduate Diploma in Education course for students who have completed a Bachelor of Science program. The degrees offered at each institution for pre-service teacher education are based on the minimum qualifications required for teaching at the respective school levels. Although, there are some unqualified teachers in schools, they are employed on temporary terms for relief purposes (Botswana, 2008).

The Bachelor of Education (Science) offered at the University of Botswana, where most of the teachers are trained, is a four year course (U. o. Botswana, 2005). The first year course is a common Level 1 Bachelor of Science program and the education courses begin in second year while the science courses continue in the Faculty of Science for the rest of the course duration at a ratio of about 1:2.6 (education : science content) (Chakalisa, Garegae, Setlhare, & Kaino, 2007). The ratio differs from that of Diploma in Secondary Education courses which is about 1:1.2 (education : science content). However, science teachers are generally found to show unsatisfactory instructional practices at both levels (see sections 2.2.1 & 2.3.1).

Teaching practice is one of the education courses offered which prepares student teachers for classroom instruction at pre-service teacher education. But, the research studies indicate some discrepancies between school curriculum expectations and preparation of student teachers through teaching practice particularly on learner-centred instructional approaches. For instance, Vlaadingerbroek (1998) found that the pre-service teachers at the University of Botswana could pass their Teaching Practice well without having demonstrated pedagogic skills. He reported that,

> To excel in TP, a student needs to do his/her 'bookwork', dress smartly and exercise what are often natural control and communication abilities over his/her charges without having to pay a great deal of attention to improving on his/her teaching performance (Vlaardingerbroek, 1998 p.49)

Tafa (2001) stated that use of teacher-centred approaches still characterize the teaching practice programs at Teacher Colleges of Education. He argued that pedagogical change from teacher-centred to learner-centred is a paradigm shift which requires a comprehensive campaign to effect change, in the following words.

> There is need for the Ministry of Education to unpack the 1977 learner-centred education slogan (*Education for Kagisano*) which has remained largely ignored, … Top-down bureaucratic innovations (however well-meaning) that do not take on board teachers' implicit theories of teaching/learning and the context in which they work are likely to come to nothing. (Tafa, 2001 p.22)

The foregoing shows discrepancies between curriculum intensions and the teacher education with respect to learner-centred instructional approaches. Another important factor in the teachers' instruction is language which is discussed next.

2.6 Language of instruction

The language of instruction (English) is the second or third language for Batswana students and teachers (Nyati-Ramahobo, 1998). The communication of science content has been very close to textbook language with constrained expansion by teachers to avoid confusion or ambiguity in the course of discussion. Prophet (1990) noted that:

> Language is not merely an incidental way of communicating, or solving problems, or reflecting. Rather, in our rational reconstruction of reality, language acts as the mediator and supporter in the continuous matching and fitting that takes place between 'things as they are' and 'things as we know them. (p.112)

Prophet and Towse (1999) compared the understanding of common English words that are used in science instruction by learners in United Kingdom whose first language is English with learners who spoke different languages at home and Batswana learners in Botswana. The findings showed a large difference in understanding of these words between the two groups of learners. For instance, they found that 82% of learners whose first language is English understood the word ‘dehydrate’ compared to 32% of learners who spoke different languages at home including Batswana learners. Oyoo (2007) argued that difficulty in classroom language is not only rooted in the language of instruction (English) but also in the science culture noting that even students who are proficient in English do face difficulties understanding science instruction in English.

Basic proficiency is however a pre-requisite to all learning otherwise language of instruction can throw learners into deeper confusion and misunderstanding. For instance, Wagner (2006) in a multiple case study on San perceptions of access to education notes the confusion that some learners had having to use different languages at home and at school.

2.7 Instructional material

2.7.1 Textbooks for BGCSE

Science textbooks define the depth and the scope of the curriculum and they serve as a tool and tutor, guidebook and gauge for instruction (Kuhm, Roseman, & Treistman, 2002). However, the textbooks that are recommended and used for BGCSE science curriculum are authored in the United Kingdom for different curricula which means they can only provide limited support for instruction. For instance, Emereole and Rammiki (2004) in a study that evaluated four commonly used textbooks in twelve out of twenty-seven senior secondary schools found the physics textbooks inadequate in supporting learner participation and learner-centred approaches recommended by the BGCSE syllabus. The findings concurred with Baiyelo’s (2002) research findings that the physics textbooks used in West African Certificate Examination Physics Syllabus provided inadequate learning activities. The findings were also congruent with Lubben et al. (2003) who found low frequency of textbook in senior secondary school science in Namibia. It follows that textbooks are not supportive of learner-centred approaches to instruction.

Notwithstanding, textbooks have generally been found inadequate as instructional material. For instance, the American Association for Advancement of Science (AAAS) found that the textbooks ignored or obscured important ideas, inadequately explained diagrams and gave very little guidance in interpreting experimental results (Budiansky, 2002).

2.7.2 Computers

Information technology is a recent major development in school education that has a potential to form part of available instructional tools or teaching aids for teachers (Botswana, 2009). The University of Botswana, Teacher Colleges of Education and secondary schools are equipped with computer laboratories installed with education data network and connected to internet (Botswana, 2003). Every junior and senior secondary school has at least one computer laboratory equipped with at least twenty computers to provide computer awareness courses for learners (Botswana, 2006, 2009; Monngakgotla, 2012).

Most schools in addition have computers solely for teachers’ use. In some schools the computers for teachers have however been donated by private companies or parents and teachers’ association in line with the 1993 National Commission on Education recommendation for financing costs of education development (D. o. M. a. S. Education, 2010). The commission recommended that the,

> … communities should be required through voluntary contributions or levies imposed on students by the Board of Governors, to provide other ancillary facilities such as additional equipment (Botswana, 1993 par.12.5.20 (b)).

While the computers for teachers are generally used for preparation of tests and instructional material such as class exercises, they have not penetrated teachers’ instruction to a degree where they are used in instructional interaction possibly because of their limited number and lack of other accessories such as projectors.

2.8 Learner performance

The learners' performance in primary and junior secondary science in Botswana is lower than in most subjects as reflected in the analysis of the 2010 national examination results (Council, 2010a). The 2010 Primary School Leaving Examination (PSLE) results show 53% credit pass rate in integrated science with the highest being a grade D. Compared to English and Setswana subjects, the performance is marginally lower in science and mathematics. The difference in performance between English, Setswana and Mathematics on one hand and integrated science on the other can be attributed to the difference in the length of instruction. Primary integrated science is taught for three years while the three subjects are taught for 6 to 7 years.

The students' performance in senior secondary school BGCSE science examinations is low particularly in Single and Double Sciences. The 2013 BGCSE Science examination credit pass rate is shown in Table 4 to depict the credit pass rate in percentages.

Table 4: BGCSE Science Examination Credit Pass Rate in percentages

Year	Single Science	Double Science	Chemistry	Physics	Biology
2013	3.8	14	83.03	71.27	66.28
2012	4.11	19.46	78.18	70.92	69.07
2011	9.95	21.36	80.28	76.29	69.75
2010	9.93	24.22	82.64	78.33	73.72
2009	6.66	26.01	79.21	74.47	60.64

(Council, 2013 p.9)

Table 4 shows 3.8% and 14% credit pass rate in the 2013 BGCSE examinations in Single and Double Science respectively. Single and Double Science are done by around 80% of the learners. The BGCSE examination results in 2009, 2010, 2011, 2012 and 2013 show relatively low results for learners in these two options and a steady decline of credit pass rate from 2010 to 2013 which was attributed to the opening of five new senior secondary schools between 2009 and 2012 (Council, 2013). Although the BGCSE credit pass rate in Physics is normally higher than in Biology, the school-based examination results generally show a lower credit pass in physics than in Biology and Chemistry, across schools.

2.8.1 Learner performance by location

Learner performance in schools located in cities and towns has been better than those in rural areas and large villages in PSLE, JCE and BGCSE Examinations. Learners in primary schools in two small mining towns, Jwaneng and Selibe Phikwe, were the best in the country (Council, 2012). Possibly, the environment in cities and towns is more supportive of the school performance than in villages. As found by Marope (1996) that traditional socioeconomic privileges in Botswana such as possessing cattle and lands do not support learner achievement. Notably, communities in the western part of the country in which learner performance is low are involved in cattle and crop farming. However, Botswana students' performance in 2003 TIMSS found that student attitude and values in addition to home possessions, such as a refrigerator and television, had a major impact on the students' achievement (Chepete, 2003).

2.8.2 Learner performance by gender

Botswana primary and junior secondary school girls perform better than boys in national examinations in all subjects; this pattern was seen in the Trends in International Mathematics Science Studies (Gonzales et al., 2008). The fact that girls perform better than boys seems to indicate a change in what Duncan (1989) had earlier observed in her study on *Engendering school learning: science attitude and achievement among girls and boys in Botswana* that gender-typing of school science in Botswana was more salient in achievement process for girls than for boys. But, a close scrutiny of the analysis of 2010 JCE examinations credit passes, show that girls performed best in Setswana, English and Moral Education but least in integrated science, mathematics and agriculture. Instead, boys performed best in agriculture and integrated science (Council, 2010a) showing agreement with Duncan's (1989) findings. According to Duncan (1989) school science in Botswana was perceived as a masculine subject and that girls who favoured divided family roles had less positive attitude towards school science.

At the school level, Dunne (2007) found that gender relations and boundaries were part of daily school life through which feminine and masculine identities were constructed and reinforced. For instance, she found that class participation in Botswana and Ghana schools was used to marginalize, embarrass and degrade girls by boys and male teachers while repeated questioning was used to harangue or indicate favour from the male teacher. It is a fact that in Botswana male teachers are in majority in school physics than in other science subjects. It is also a fact that school physics content, is situated in male dominated fields as in mechanical and electrical engineering, and nuclear physics. Therefore, going by Dunne

(2007) and Duncan (1989) findings, girls would find it difficult to follow physics and physics related fields even though their performance is better than boys'.

Internationally, Batswana learners have performed poorly in the Trends in International Mathematics and Science Studies (TIMSS). TIMSS assess understanding of science concepts (Mullis et al., 2009). The relative extent to which learners demonstrate understanding of science concepts point to the opportunities provided during instruction in specific topic areas (Thomson & Buckley, 2009). Batswana learners' understanding of science concepts is below a 400 benchmark which means that they are unable to recognise some basic concepts with average scores of 365 and 355 compared to TIMSS average of 473 and 500 respectively (Gonzales et al., 2008). The in-country, 2003 and 2007 TIMSS analysis showed lowest learner achievement in physics.

This section has shown the need for teachers' instructional practice to positively influence learners' performance in science and physics in particular. This is argued on the premise that learner performance is influenced by the teachers' instructional practices (Neumann et al., 2012; O'Sullivan, 2006; Seidel, Rimmele, & Prenzel, 2005).

2.9 Chapter Summary

This chapter has reviewed the success in the structural and school curriculum development for school access to basic education. It has shown successes and limitations in the school curriculum development for senior secondary education. The teachers' instructional practices in science for example can be characterised as not encouraging learner participation and lacking in pedagogical content knowledge, hence negatively affects the quality of instructional interactions in supporting learners' access of subject content. The teachers' instructional practices suggest a need for support for teachers' instructional practice through professional development. As so far argued in this chapter, such professional development would be successful if it drew from local exemplary practices of teachers – it is such exceptional teachers that are referred to in this study as exemplary teachers.

CHAPTER 3

Exemplary Teachers' Instructional Practice

3.0 Introduction

This chapter provides a review of literature on effective instruction in school science with a focus on physics teachers' instructional practice. The reason for basing the review on school science is two-fold. Firstly, physics is a science discipline which can be offered as a separate subject or in an integrated or combined form with other science subjects specifically biology and chemistry. Therefore, research studies on effective teaching of school science include physics unless specified otherwise. Secondly, there is more published research information on school science than on school physics. However, there is substantial literature on school physics based on relatively unsatisfactory learner performance and low enrolment rates in the subject.

The review is guided by this study's research questions (see section 1.3).

1. What characterises exemplary teachers' instructional practices in school physics?
2. How do the exemplary teachers' instructional practices support learners in accessing school physics content?
3. Why do the exemplary teachers' instructional practices in school physics support learners in accessing school physics content?

The review is organised in three main sections. The first section, *Research on exemplary teachers' instructional practice in school physics* focuses on characteristics and practices of exemplary teachers. The second section, *Issues in school physics,* presents literature on issues in school physics which may have an influence on exemplary physics teachers' instruction. The third section, titled *Explaining the sociocultural process of exemplary practice and support for learners,* presents the sociocultural theory adopted in this study. The fourth section, *Why focus on local examples of exemplary teachers' practice*, presents an argument for a focus on local exemplary physics teachers. The fifth section, *Analytical framework - the zone of proximal development,* presents analytical framework for the study. The sixth section, *Learner involvement in the study*, presents a justification for involvement of learners in the study. The seventh and last section is the Chapter Summary.

3.1 Research on exemplary teachers' instructional practice in school physics

Research on exemplary teachers' instructional practice falls within effective teaching research domain (Creemers, 1994; Darling-Hammond & Baratz-Snowden, 2005) which is characterised by a search for teaching effects that influence learner achievement (Stronge, Ward, & Grant, 2011). It is based on a process-product model by which teaching processes are linked to learner achievement (Brophy & Good, 1986; Seidel & Shavelson, 2007). Teaching processes are teacher's instructional actions such as elaborating on a concept to help learners in understanding it (Shuell, 1988), whereby the resulting learners' understandings form the product. Research on exemplary teachers' instructional practice falls within effective teaching research domain (Creemers, 1994; Darling-Hammond & Baratz-Snowden, 2005) and is characterised by a search for teaching effects that influence learner achievement (Stronge et al., 2011).

The importance of viewing teacher's practice as goal-oriented is to enable exploration of teachers' actions and interactions with regard to their purpose of helping learners' understanding the subject content. This view is in line with Zimmerlin and Nelson (2000) findings that teacher's instructional practice is structured on multiple goals comprising major and local goals directed towards learners' understanding. The major goals include lesson objectives related to the content and social interactions, while the local goals were related to lesson activities. The multiplicity of the goals of the teachers' instructional practice reflects the complexity the practice. For instance, Schoenfeld et al. (2000) used the goal model to characterise the practice of an exemplary teacher, Minstrell, and found it complex and non-linear with respect to learner achievement. The complexity of the practice had earlier been disentangled into a number of characteristics including a way of questioning referred to as reflective tosses which is a form of formative assessment the teacher used to evaluate and direct learners' understandings (van Zee & Minstrell, 1997a).

The studies reviewed on effective school physics instruction based on the aforementioned views fall within two main categories: large-scale surveys; and real classrooms observations. The large scale surveys use learner assessment outcomes in examinations, tests or international studies such as TIMSS (TIMSS, 2003). The surveys use statistical analyses to relate learner achievement to teacher characteristics (Rivkin et al., 2005) by controlling extraneous factors such as learner abilities, family background and school effect and by using random selection procedures (Nye, Konstantopoulos, & Hedges, 2004) to obtain valid outcomes. The characteristics of effective teachers found through this type of studies include years of experience and certification (Clotfelter, Ladd, & Vigdor 2007; Laczko-Kerr & Berliner, 2002; Rivkin et al., 2005) and can also be specific to teachers' instructional practices. For instance, Stronge et al. (2011) found characteristics of effective teachers that are related to instruction such as instructional clarity, instructional complexity, expectations for student learning and use of technology. Seidel et al. (2005) found characteristics related to teachers' support for learners' development such as support of competence, autonomy, relevance and instructional quality. Other characteristics were related to assessment, classroom management and personal qualities (discussed in the next subsection titled *issues in school physics*).

However, the characteristics of teacher effectiveness from large scale surveys have been considered distal due to statistical processes that entail control of variables (Seidel & Shavelson, 2007). For instance, the studies are found to have low effect sizes on learning achievement (Nye et al., 2004). In addition, the complexity of teachers' instructional practice makes it difficult to be explained by learner achievement scores. This was evidenced by Cottaar (2012) in high school physics who, as a result, suggested non-linear correlation between teacher characteristics and learner achievement. Other studies have combined statistical processes with surveys of learners and observations of teaching practices to strengthen the link between teacher characteristics and learner achievement. For example, Seidel et al. (2005) carried out surveys of learners' perceptions of supportive learning conditions specifically on clarity and coherence of lessons in physics and found significant correlation between the two. Regardless, the studies do not provide details on teacher characteristics to guide instructional practice.

Research on effective teachers based on classroom observations, that is observation of interactions in real classrooms, is considered important in providing detailed information for improving teachers' practice (Tytler, 2003). Effective teachers found through this type of research are well known as exemplary teachers. A pioneer study on exemplary science teachers practice conducted under a project titled *Search for Excellence* (Penick & Yager, 1983b) was a survey of instructional programs that matched the desired state of school science education in the United States of America. The findings consisted of a list of features of exemplary programs which included, "Being models of active inquiry; Using societal issues as a focus; Asking questions leading to a synthesis of ideas; Stressing science literacy;

Wanting students to apply knowledge; and Seeking excellence" (Yager & Penick, 1984, p.149). This particular study was used together with surveys of learning environments that used standardised questionnaires on learner perceptions to substantiate and perhaps elaborate on the concept of exemplary teachers (Fraser & Tobin, 1989b; Yager & Penick, 1984). However, studies which used classroom observations to provide detailed information for guiding other teachers' instructional practices were considered more informative (Tobin & Fraser, 1990). These studies include experimental or quasi-experimental and Classroom observation studies which are discussed next.

Experimental and quasi-experimental studies involve development of pre-determined models of instructional practice that are considered potentially effective in real classrooms (Keeves, 1998). The models are studied and refined in practice and compared with ordinary instructional practices through pre-tests and post-tests (Gay & Airasian, 2000). However, these studies have focused more on science learning than teachers' instruction (Millar, Leach, & Osborne, 2000). Exceptions include studies on instructional design in physics by Tiberghein (2000) and Tiberghein (1994). In contrast, classroom observation studies on exemplary science teachers provide information on instructional practice in real classrooms. They are comparative studies between expert and novice or non-expert teachers (Fraser & Tobin, 1989a; Tobin & Garnett, 1993; Tsui, 2009), even though the comparison may not be explicit (Ladson-Billings, 1995). The studies on classroom observation of exemplary teachers focus on a wide range of teacher characteristics based on instructional activities, knowledge processes employed, and language of instruction. These are discussed in the following section.

Exemplary teachers use activities that provide opportunity for learners to participate in instruction. For instance, exemplary teachers use laboratory activities as noted by Treagust (1991) that "laboratory activities had a central role" (p.341) in exemplary teachers' practice. Exemplary teachers view laboratory activities useful for making science concepts meaningful and accessible to learners with limited prior knowledge (Xu, Coats & Davidson, 2011). They also considered them important for developing inquiry skills. For instance, they can encourage learners to develop curiosity and critical thinking (Hofstein, Ben-Zvi, & Carmeli, 1990), interest to question, explain and justify their reasoning and to draw inferences (van Zee & Minstrell, 1997b). This is in agreement with Chin and Osborne (2008) that learners questions can help them "to monitor their own learning, explore and scaffold their ideas, steer thinking in certain directions and advance their understanding of scientific concepts and phenomena" (p.34). Laboratory activities are also found important for helping exemplary teachers attend to high cognitive skills such as making inferences (Tobin & Garnett, 1993).

Exemplary teachers also use strategies that encourage discussions in instructional activities. Class discussions offer learners opportunity to construct new ways of understanding by collaborative negotiation of their meanings (Alexopoulou & Driver, 1997). Alexander (2008) found that instructional approaches that focus on purposeful 'dialogic' (p.106) classroom interactions engage learners in thinking and reasoning about science concepts. Erduran and Dagher (2007) found that exemplary physics teachers used argumentation skills to conduct class discussion as they viewed "the ability to conduct and coordinate group discussions as a significant skill (p411)" an indication of possible difficulties in conducting class discussions. Exemplary science teachers also use a variety of questioning techniques (Wahyudi & Treagust, 2004) that involve more learners in the instructional activities and build on previous questions such as recycling of questions, use of turn-taking procedures and series of related questions (Chin, 2006; Rowell, 1990).

Exemplary teachers use strategies that enable learners to process knowledge. For instance, research indicates that they use learners' prior knowledge to contextualise science concepts. Prior knowledge can be based on real life situations, analogies and models (Brown, 2004; Clement, 1993; Treagust, Harrison, & Venville, 1998). Ladson-Billings (1995) found how one of her good teachers used outstanding events from the community in which learners lived to make the instructional content relevant. Events in learners' lives are found to facilitate their reasoning and thinking. Mercer, Dawes, Wegerif, and Sams (2004) and Simon and Maloney (2007) used situations which are familiar to learners to develop their thinking and reasoning skills. This findings agree with research in educational psychology showing prior knowledge as beneficial to learners' learning and achievement (Dochy, Segers, & Buehl, 1999). For instance, Pressley et al. (1992) McNamara, Kintsch, Songer, and Kintsch (1996).

Research also indicates various strategies in appropriate use of the language of instruction to make science concepts accessible to learners, an attribute which exemplary teachers are expected to possess. For instance, Oyoo (2012) found that more than novice teachers, experienced science teachers were able to explain non-technical English words in their instructional interactions and could in the process also use concrete examples from learners' lives. Prophet and Badede (2009) found that simplifying sentence structure such as reducing its length, replacing difficult words with simpler ones, changing of tense from past to present, and simplifying the grammatical structure improved learner performance in Botswana. Brown and Ryoo (2008) separated the conceptual and linguistic components of science by teaching science concepts in learners' everyday words to clarify the meaning of technical terms. Exemplary teachers are known to possess such strategies (Wellington & Osborne, 2001).

Physics teachers' instructional practices captured through the foregoing research studies is explained by a number of fields of knowledge including the curriculum, assessment and teacher's knowledge. The next section provides a discussion on these fields with a focus on physics teachers' instructional practices.

3.2 Issues in school physics

Physics teachers' instruction (Shulman, 1987) is guided by school physics curriculum which came to the fore in the nineteen fifties during curriculum reforms following the launching of the Sputnik - the first flight to the moon by the Soviet Union (Matthews, 1994). The importance of the Sputnik is that it brought about curriculum reforms in subjects that were considered important for defence after the World War II and school physics was one of the target subjects (Ornstein & Hunkins, 1998). The curriculum reforms in school physics were led by the Harvard Project Physics Course which developed instructional material (Bevilacqua & Giannetto, 1998; Matthews, 1994) that emphasised conceptual knowledge which was to be taught through experiments and hands-on activities (Holton, 1967). The emphasis on conceptual knowledge characterised western science which was accepted as universal in most countries including Botswana (Jegede, 1988; Koosimile, 2001; Ogunniyi, 1986).

However, the focus on conceptual knowledge in school physics was not welcomed by all physicists. There was a group of physicists who argued against splitting of theoretical and experimental physics and advocated for the teaching of physics content through its history and philosophy (Bevilacqua & Giannetto, 1998). For instance, Bevilacqua and Giannetto (1998) argued that the use of experiments to confirm conceptual knowledge was not representative of physicists research work which they described as "an open game in which the player has a considerable degree of autonomy" (p.1016). The argument was to make history and philosophy of science central to physics curriculum by contextualising it on the way physicists made discoveries (Matthews, 1994; Stinner & Williams, 1998). The assumption underlying history and philosophy of science has become important in wake of research on learners' difficulties in understanding science concepts and practical work (Bevilacqua & Giannetto, 1998). The next section provides a discussion on learners' difficulties in understanding science concepts and practical work.

Learner difficulties

Research on learners' difficulties in school physics is dominated by research on misconceptions (Duit, 2002). The research findings in this area show that learners used intuitive ideas about the physical world to conceptualise science ideas across subject topics (Driver, Asoko, Leach, Scott, & Mortimor, 1994; Driver & Easley, 1978). It is noteworthy that one of the earliest studies which related learners' misconceptions to intuitive ideas was in physics on Newton's laws of motion (Viennot, 1979). This led to studies on other topics including thermal physics and light. For instance, on thermal physics topic Erickson (1979) found a number of misconceptions which included learners' inability to differentiate between heat and temperature. On the topic of light, Guesne (1985) found that learners assumed that they saw things because those things were in the light which made the idea of virtual images difficult for them. Common to these studies was that teachers' instruction was not effective in addressing learners' difficulties with physics concepts within the defined curriculum.

Research related learners' difficulties to differences between school science and school physics concepts and learners' social and cultural lives. Leach and Scott (1995) described the difference between school science and learners' everyday lives in terms of conceptual knowledge, epistemology and ontology as a learning demand which learners faced. Smith, diSessa, and Roschelle (1993) attributed the differences to learners' and physics experts' ways of explaining their experiences which were found detailed for physics experts. The differences were also attributed to learners' cultural background and social background relative to western science (Arons, 1983; Mutegi, 2011) and language of instruction, English (Prophet & Towse, 1999). Gallagher and Tobin (1987) found that if the cognitive demand is too high for learners to make meaning of instructional activities they demonstrated task avoidance behaviours which reduce their chances of interacting with the content. The findings indicated the importance of social experiences in learning physics concepts which has serious implication on the effectiveness of the teachers' instructional practice in non-western cultures considering the western origins of the curriculum.

Practical work

Practical work is an important aspect of school science content through which teachers provide instruction on conceptual knowledge and practical skills for experiments and investigations (Hodson, 2009). Research on practical work indicates a need to define its syllabus objectives in a way that guides teachers' instructional practice (Abrahams, Reiss, & Sharpe, 2013). For instance, learners were found to follow instructions without making sense of the practical activities in science (Tasker & Freyberg, 1994) and that their actual learning processes in practical activities were found inconsistent with those intended (Tiberghein, 1994). This showed that learners' actions and thinking on the intended scientific ideas were not effectively guided by teachers' instruction (Abrahams & Millar, 2008). The need for learners' guidance by the teacher was reflected in earlier studies by Neidderer, Aufschnaiter, Tiberghein, Buty, Haller, Hucke, Sander and Fischer (2002). However, as noted at the beginning of this paragraph, teachers also needed guidance. Abrahams, Reiss & Sharpe (2013) found that teachers' instruction on practical skills in different countries was based on assessment objectives for national examinations which did not provide adequate guidance for developing learners' knowledge. They stated,

> the current dominance … within summative assessment of practical work in science in some countries means that the focus has been directed on to what students know about practical work and how it should, in principle, be undertaken rather than on their competency in terms of actually being able to do practical work themselves. (Abrahams, Reiss & Sharpe, 2013, p.245)

Summative assessment in school science, as part of teachers' instruction, is discussed next.

Assessment in school science

Assessment is an integral part of teachers' instructional practice which provides information on learners' achievement and progress (Fairbrother, 1993; Tamir, 1998). There are two types of assessment, summative and formative. Summative assessment is normally conducted at the end of a program for grading and placement of learners in classes according to their achievement (Tamir, 1998). It is also used for teachers' accountability for guiding learners to educational authorities, parents and learners and to each other (Patterson & Walker, 1993). As a consequence, summative assessment may put pressure on the teachers' instructional practice to meet the requirement for good grades at the expense of learners' understanding (Abrahams, Reiss & Sharpe, 2013). Formative assessment differs from summative assessment in that it provides information on learners' progress in the course of instruction which the teacher can use to modify instruction (Black & Wiliam 1998; Wiliam & Thompson, 2007). For instance, the teacher can guide learners' thinking and actions, and negotiate ideas with learners to help their understanding (Furtak, 2012b; van Zee & Minstrell, 1997a). Therefore, formative assessment is a useful tool for teachers' instructional practice.

However, the opportunity provided by formative assessment is stifled by the tension imposed by summative assessment in science (Black, 1998). Black (1998) argued that the tension needed to be resolved for teachers to fully exploit the opportunity afforded by formative assessment. In that regard, Lomask, Baron, and Greig (1998) reported on an assessment project in which same assessment structure for formative (class-embedded) and summative (on-demand) assessment were used. And, Erickson and Meyer (1998) provided a framework for assessment that takes into account learners' knowledge from everyday life, knowledge of science and cognitive abilities which aligns assessment to instructional practices in science. These efforts show how assessment can be used to improve instructional practice.

The exemplary physics teachers' instructional practice is situated within the issues discussed above. However, it is dependent on the teachers' pedagogical content knowledge which is discussed next.

Pedagogical content knowledge

Pedagogical content knowledge (PCK) is the teacher's knowledge of teaching specific subject content which was introduced by Shulman (1986) as "the dimension of subject matter knowledge for teaching" (p. 9). Berry, Loughran, and van Driel (2008) and (Loughran, Mulhall, & Berry, 2004) interpreted PCK as "the amalgam of a teacher's pedagogy and understanding of content such that it influences their teaching in ways that will best engender students' learning for understanding" (p.1272). The interpretation reflects teachers' knowledge, an amalgam of pedagogy and content, as an essential component of their instructional practice in that the knowledge is related to learners' understanding.

PCK grows with years of teachers' experience (Gess-Newsome, 1999) and therefore varies according to phases of teacher's professional development (Steffy, 1989; Steffy et al., 2000). Steffy et al. (2000) identified six phases of development of a career teacher by years of experience in terms of the teachers' pedagogical knowledge. Among the six phases of development of a teacher, novice phase which is in the first two years of practice and expert which is the last before exit phase have attracted the attention of researchers. The novice teacher is described as creative and open to new ideas which they sometimes fail to put into context, while expert teachers are in control and dependable but at the same time continuously developing their instructional skills. Exemplary teachers are in expert stage and are found more knowledgeable than novice teachers (Berliner, 1986).

The foregoing review shows science and physics teachers' instructional practice as a complex activity which is characterised by a wide range of teaching effects and explained by different factors. It is noteworthy that only a few studies specifically on effective and exemplary instruction in school physics were found, none on exemplary physics teachers, which reflects the scarcity of research in that area. Most of these studies were based on large scale surveys that employ statistical analysis on student achievement, for some the surveys were coupled with classroom observations and surveys of learner perceptions. Two of the studies van Zee and Minstrell (1997a) and Seidel, Rimmele and Prenzel (2005) were exceptions. This study was a contribution to existing research on exemplary physics teachers' instructional practice.

What is common among the reviewed research studies is that they are based on constructivist theory in which knowledge construction is assumed to be an individual process (Driver & Oldham, 1986). The social interactions are considered only necessary for contributing towards individual constructions of knowledge as noted by Glasersfeld (1989) that "introducing the notion of social interaction raises a problem for constructivists" (P.126). This study views exemplary teachers' instructional practice as situated in a particular sociocultural context. Therefore, exemplary teachers are teachers who process knowledge in relation to the social and cultural context in which the learners are situated to enable individual learners' constructions of the knowledge. The next section provides an explanation of sociocultural process of exemplary teachers' practice which forms a framework for this study.

3.3 Explaining the sociocultural process of exemplary practice

Vygotsky's sociocultural theory explains phenomena in terms of processes and interactions (Vygotsky, 1978; Wertsch, 1991). Firstly, the theory presents knowledge as a social construct which is developed through interactions among people. This is reflected in Vygotsky's statement on internal reconstruction of external operations that,

> An interpersonal process is transformed into intrapersonal one. Every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level; first, between people (interpsychological) and then inside the child

> (intrapsychological). This applies equally to …logical memory and to the formation of concepts. (Vygotsky, 1978, p.57)

In addition to the interpersonal interactions referred to in the above quotation, Wertsch (1991) stated that "When action (interaction) is given analytical priority human beings are viewed as coming into contact with themselves and their surroundings, creating themselves and their surroundings through the actions in which they engage" (p.8). For this study, the surroundings include the instructional material and laboratories. Social interaction, according to the theory and as specified in the above quotation, is important for cognitive development such as logical memory and formation of concepts at a personal or intra-psychological level. Hence, exemplary teachers' instructional practice should exhibit highly interactive activities such as practical activities, discussions and questions reflect high level of interaction between the teacher and learners, and among learners for development of logical memory and formation of concepts.

According to the theory, logical memory and formation of concepts results from ways of thinking that develop from the social interactions. Vygotsky (2012) stated that "In our conception, the true direction of the development of thinking is not from the individual to the social, but from the social to the individual" (p.32). The review in section 3.1 indicates two ways of thinking that are found in school physics instruction, learners' intuitive thinking and the teachers' way of thinking represented by physics concept and the activities through which the concepts are taught such as practical work. It follows that exemplary teachers' interactive activities should be structured to support learners on developing ways of thinking consistent with formation of concepts in physics. This is in accord with Vygotsky's view of instruction as a necessary factor for bringing about intellectual processes for the learners' development quoted by Hedegaard (2000) as follows.

> … instruction cannot be identified as development, but properly organised instruction will result in the child's intellectual development, will bring into being an entire series of such developmental processes, which were not at all possible without instruction. Thus instruction is a necessary and general factor in the child's process of development – not of the natural but of the historical traits of man. (p.172)

The above quotation, is consistent with sociocultural assumption that the teacher is a more knowledgeable participant in the social interactions (Vygotsky, 1978) who designs and enact instruction (Shulman, 1987). It also explains the search for exemplary teachers according to the features of their instructional programs (Yager & Penick, 1984). The importance of social interactions in directing learners' thinking through instruction agrees with Vygotsky's concept of learning as a function of interpersonal interactions as follows.

> … an essential feature of learning is that it creates the zone of proximal development; that is, learning awakens a variety of developmental processes that are able to interact only when the child is interacting with people in his environment and in collaboration with his peers" (Vygotsky, 1978, p. 90)

The view expressed above underlines essential features of exemplary physics teachers' instructional practice such as practical activities which involve a wide range of skills and associated learning processes, and guiding them in linking actions with ideas embedded in these activities (Hedegaard, 2000).

Social interactions including those that are instructional occur through language and other semiotic mechanisms. Vygotsky (1978) attributed high mental functions, which differentiates human behaviour from animal behaviour, to complex modes of communication through language and other semiotic mechanisms described as psychological tools. Vygotsky, quoted by Daniels (2000), distinguished psychological tools from technical tools as follows.

> The most essential feature distinguishing the psychological tools from the technical tool is that it directs the mind and behavior whereas the technical tool, which is also inserted as an intermediate link between human activity and the external object, is directed towards producing one or other sets of changes in the object itself (Daniels 2000, p.7).

Communication strategies such as reflective discourse (van Zee & Minstrell, 1997a) and other semiotic mechanisms such as visuals (Gilbert, 2007), are psychological tools the teacher can use to direct learners' thinking and behavior in social interactions. According to Wertsch and Smolka (1993) the incorporation of talk and other semiotic representations into human action, or interaction, results in qualitative transformation of behavior which can lead to deeper understanding. Wertsch and Smolka (1993) quoted Bakhtin that "…for each word of utterance we are in the process of understanding, we, as it were, lay down a set of our own answering words. The greater their number and weight, the deeper and more substantial our understanding will be" (p.74). With respect to exemplary instructional practice, examples would include the questioning techniques which the teachers employ such as turn-taking procedures and asking a series of related questions (Chin, 2006; Rowell, 1990). Such techniques would result in a large number of contributions from learners which the teacher can use to understand learners' thinking, or to facilitate learner understanding of concepts in physics (Scott, 1998).

Language and other semiotic mechanisms are also important for contributing to the act of developing meaning through dialogues. Scott (1998) defined the function of a dialogue in instructional interactions by quoting Bakhtin as follows:

> Its (dialogue) creativity and productiveness consists precisely in the fact that such a word awakens new and independent words, that it organises masses of our words from within, and does not remain in an isolated static condition…the semantic structure of an internally persuasive discourse is open…. this discourse is able to reveal ever new ways to mean. (Scott, 1998, p.63)

The dialogic function defines teacher-learner and learner-learner verbal interactions that are expected to lead to understanding of new experiences and ideas. This agrees with Zinchenko (2007) assertion that words are related to thought, or sense making. From Vygotsky's idea of 'thought and word' which also reflects construction of ideas, he states the following. "Thought, regardless of truth or falseness, is manifested sometimes in word, sometimes in an image, sometimes in an action or deed, sometimes in all of these as well as something else or something elusive or mysterious (p.213)". And, "The thought itself is not born from another thought, but from the motivational sphere of our consciousness which encompasses our drive and mind, our needs, our interests and intensions, our affections and emotions" (Zinchenko, 2007, p.214). Exemplary teachers' practice with regard to use of group discussions and encouragement of talk in physics practical activities is consistent with formation of physics concepts by learners.

The foregoing explains exemplary teachers' instructional practice as an organized process that brings about learners' developmental processes for construction of knowledge through interactions. The interactions through language and other semiotic mechanisms are considered beneficial for directing learners' thoughts and behavior.

3.4 Why focus on local examples of exemplary teachers' practice

Sections 3.1 provided a review of literature on exemplary teachers' instructional practice mainly from developed countries to inform the study. However, the focus of this study was on exemplary physics teachers' instructional practice in a local context of two schools in Botswana, a developing country. This section therefore provides an argument for local examples of exemplary teachers' instructional practice based on Vygotsky's sociocultural theory.

Vygotsky defined sociocultural setting in broad terms of social, cultural, historical and institutional establishments (Wertsch, 1991). Stigler and Hiebert (1999) in TIMSS video studies found differences in instructional approaches between countries which were explained in terms of the cultures of those countries. It follows that the teachers' instructional practice is informed by a broader context in which it is situated including the curriculum, assessment and teachers' pedagogical content knowledge.

To define context and situation in sociocultural terms, Cobb and Bowers' (1999) interpretation through the common statement that *"My situation at work is pretty good at the moment"* (p.5) is particularly drawn from. To elaborate on Cobb and Bowers' (1999) statement, the *work* is the context of activities and *situation* is the position of the worker in terms of social affairs. The implication is that situation defines the worker's qualities in relation to the work. The situatedness of exemplary teachers' practice is perhaps explained best in Ladson-Billings (1995) findings on good teachers in African American communities. The good teachers were found to address the fundamental issues in the education of African American learners such as academic success, cultural competence, and critical consciousness which were distinctive characteristics for that community (see also section 3.1).

The teacher's pedagogical content knowledge also explains the situatedness of teachers' practice. According to Kozulin (2003) general orientation of the sociocultural theory is that subject knowledge is a social and cultural phenomenon. It represents particular historical human cognition. Science content in particular represents human cognitive mechanisms and the systematic reasoning reflected in science concepts and knowledge which differs from everyday ways of thinking (Leach & Scott, 1995; Leach & Scott, 2002). The teachers' knowledge of learners, as an aspect of teachers' pedagogical content knowledge, explains the situatedness of the teacher's practice. The learners' abilities and competencies relative to the subject content may vary according to their social and cultural background which direct teachers' practice as implied by Driver, Squires, Rushworth, and Wood-Robinson (1994) that: "Science ideas which are constructed and transmitted through the culture and social institutions of science will not be discovered by individual learners through their own empirical inquiry: learning science involves being initiated into the culture of science." (p.6)

The situatedness of the teacher's instructional practice with respect to learners lies in its mediational dimension. The term mediation was used in contrast to approaches that deal with the learner as a passive recipient of information (Kozulin, 2003). According to Kozulin (2003)

Vygotsky found it "…meaningless to assert that individuals 'have' a sign or have mastered it, without addressing the ways in which they do or do not use it to mediate their own actions or those of others." (p.29**).** Wertsch, del Rio, and Alvarez (1995) interpreted mediation as *a* process involving the unique use of cultural tools with regard to directing and shaping action. The concept of mediation provides a basis for support in the instructional actions in the form of teacher's strategies. To illustrate, I draw from Vygotsky's study titled dual stimulation described by Wertsch (1991). In dual stimulation, patients with Parkinson's disease were instructed to walk through a given distance using verbal language only. It was found that they could not walk through the distance due to their symptoms of uncontrollable body tremors. Then foot path markings were stuck on the floor along the distance they had to walk and the patients were given the same verbal instruction. The participants were found to successfully walk through the given distance when the verbal instruction was coupled with foot-path markings. The verbal language instruction alone, and verbal language and foot-path markings together, mediated the patients' action but the foot-path markings and verbal language together were more supportive. This defines a way in which exemplary teachers may support learners in accessing topic content through their instructional practice.

The situatedness of teachers' practice can also be explained in terms of school timescales such as the lesson period, number of periods per cycle (Tiberghein & Buty, 2007). The school timescales have a bearing on the management of instructional activities (Ausubel, 1968) for development of deep understanding of subject content and continuity of knowledge (Scott, Mortimer, & Ametller, 2011). Development of deep understanding of subject content would involve building connections to learners' prior knowledge by activating relevant cognitive functions and integrating new knowledge to establish coherence (Seidel et al., 2005) through instructional mediation.

Therefore, exemplary teachers' instructional practice is expected to have characteristics that are unique to the context in which it is situated. (See section 4.1.4.1 for philosophical perspectives)

3.5 Analytical framework - the zone of proximal development

Zone of proximal development (ZPD) is a sociocultural concept which puts focus on cognitive development of learners. Vygotsky defined zone of proximal development as: "the distance between the actual development as determined by independent problem solving and the potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (p. 86). According to Chaiklin (2003) zone of proximal development was developed for two purposes, to identify the child's psychological functions and to identify the associated interactions needed for cognitive growth. The current state of the learner's psychological functions and the associated interactions define his/her *actual development.* These are functions in which the child or learner has matured and is competent in carrying out activities independently (Vygotsky, 1978). *Potential development* involves psychological functions which have not matured and need the teacher's guidance and support to develop. The teacher provides the guidance by processing knowledge (Shulman, 1987) and managing activities (Ausubel, 1968) that mediate learners' actions (Wertsch, 1985) in a supportive way.

Analytical scheme

An analytical scheme was used guide the exploration of the exemplary teachers' instructional practices. The scheme helped to focus the analysis so that it does not turn out to be descriptions of the activities and to avoid possible researchers' biases (Bednarz and Garrison, 1998). Tiberghein and Buty (2007) analytic approach for studying science teaching practices was found appropriate. The approach provided a scheme for the researcher's constructions and representation of the knowledge staged in the classroom by the teachers and their learners during instructional interactions referred to as *taught knowledge*. The taught knowledge differs from the *knowledge to be taught* which refers to the knowledge prescribed by the syllabus and elaborated by other curriculum material, which in the case of Botswana General Certificate of Secondary Education (BGCSE) is the physics curriculum and textbooks.

For analysis, the taught knowledge was specified by dividing it into units. Each unit had an introduction and conclusion which took about 10 minutes. The interactions that took place in a unit were related to each other by a theme. To enable deep analysis, each theme was specified into the following categories of knowledge: elements of institutionalised new knowledge which the learners are expected to learn; re-use of elements of knowledge covered in previous units, which for this study was extended to knowledge covered in prior instructional activities because that was used in the interactions; processing of knowledge from the epistemological perspective of the interactions, how knowledge was staged, for example in a practical activity, discussion, demonstration, or teacher presentation. The analytic scheme enabled in-depth analysis of individual units in a series of lessons and allowed for formation of patterns which were used to characterise exemplary teachers' instructional practice on the topics taught.

The scheme was applicable for the analytic framework in that it accounted for use of prior knowledge, hence learners' abilities to learn the new concepts. It also took into account how associated interactions for each element of new knowledge were staged, and how the teacher processed the knowledge in the interactions. The importance of how the knowledge was staged and processed is that it showed how the teacher supported learners in making sense of the new concepts within the learners' potential development. Hence, learners' involvement in the study was important as discussed in the next section.

3.6 Learner involvement in the study

Interactions in a sociocultural setting are systems where people's actions and the surroundings in which they act are viewed as related moments (Wertsch, 1991; Wertsch et al., 1995). Therefore, learners' actions in the instructional interactions are important in understanding the teachers' practice. The involvement of learners was also in accord with the social constructivism philosophical viewpoint that meaning is constructed through the world of experience as it is lived, felt and undergone by people acting in social interactions (Schwandt, 2001). From instructional viewpoint, learners are an important part of the teachers' instructional practice in that their characteristics are assumed to inform practice (Shulman, 1986) and to define its exemplariness (Fraser & Tobin, 1989b; Yager & Penick, 1984). Therefore, they are key constituents of exemplary instructional interactions.

3.7 Chapter Summary

In this chapter a review of exemplary teachers' characteristics with respect to facilitating learner understanding of school physics have been presented. The exemplary teachers' characteristics viewed in terms of instructional practice as a process of making science content accessible to learners has been gleaned from research on effective instruction. Sociocultural theory has been presented as appropriate perspective for the study due to its inclination towards processes and interactions in the context of particular educational settings.

CHAPTER 4

Research Perspectives, Design and Planning Issues

4.0 Introduction

This chapter presents the methodological approach employed in the study based on the sociocultural theory described in section 3.2. It is divided into seven sections: Introduction, Philosophical viewpoints; Research design; Research method; Data collection methods; analytical scheme; and Summary. The purpose of this chapter is to provide a theoretical background for the procedures used in the actual collection of data as will be detailed in chapter 5.

4.1 The philosophical viewpoints

The importance of philosophical viewpoints in research is that the decisions that are made during the planning and actual research process are informed by beliefs or assumption held by the researcher (Janoff-Bulman, 1992; Ruthven, 1979). Such beliefs and assumptions form part of the epistemological basis of the research process (Howe, 2001); they underpin the procedural decisions of the research process (Biesta, 2010). The plans and procedures for research "span decisions from broad assumptions to detailed methods of data collection and analysis." (Creswell, 2009, p.3) In this section philosophical viewpoints shared by researchers are outlined to clarify the line of thought pursued. In particular, assumptions attributed by various authors to social constructionist and positivistic/post-positivist are considered. In addition, the philosophical viewpoints held for this study are declared to ensure consistency in the decisions that are made during the planning and actual research process. The plans and procedures concerned with turning research questions into projects are included in research designs (Robson, 2011).

4.1.1 Positivistic and Post-positivistic viewpoints

The positivist and post-positivist philosophical viewpoints are outlined here with regard to knowledge and research process as provided by various authors to reveal that the basic assumptions shared by both positivist and post-positivists are related. The positivists and post-positivists share the assumption that knowledge is objective (Creswell, 2009). That is, knowledge assumed to be based on pre-established criteria which makes it universal (Phillips & Burbules, 2000). In line with the objective view of knowledge, positivist and post-positivist views are based on search for factual knowledge about the world with a basic aim of identifying and assessing causes that influence outcomes (Miller, 2000). The studies are well known as those seeking to establish cause-effect relationship. One example of such a research study is experimental in which cause-effect relationships are established by manipulating at least one variable, controlling other variables and observing the effect on dependent variables (Phillips & Burbules, 2000). Other examples include correlational research which determines a relationship between two or more quantifiable variables and causal-comparative research which determines cause for differences between entities. Generally, the studies explain phenomenon by determining connections between variables. The explanations are related to general scientific theory. A theory by its nature shows interrelationship among a set of variables (Kerlinger & Lee, 2000).

Objectivity is an essential aspect of the research studies based on positivist and post-positivist viewpoints (Creswell, 2009). To achieve a level of objectivity, standard research procedures that control extraneous factors and personal and cultural values are used. The research process involves making claims and then refining or abandoning some of them for other claims that are more strongly justified. It seeks to develop relevant, true statements that can serve to explain situations or describe the causal relationships in the best possible way according to Miller (2000). Research methods and conclusions are examined to reduce possible bias to establish reliability and validity. The research procedures have built-in checks that are used to control and verify activities and conclusions to attain dependable knowledge (Kerlinger & Lee, 2000). Data is largely in a quantitative form which is derived from use of instruments that are tested to provide some level of their validity and reliability. The checks are anchored on reality lying outside the scientist's personal beliefs, perceptions, biases, values, attitudes and emotions.

The difference between post-positivists' and positivists' viewpoints is that positivists view knowledge as absolute truth while the post-positivists' claim that knowledge cannot be taken as absolute truth when studying the behavior and actions of humans (Phillips & Burbules, 2000). They assume that human behavior and actions are subjective, they are influenced by what is valued at individual and collective level.

4.1.2 Social Constructionist viewpoints

Social constructionism presents reality about the world on the basis of cultural and historical establishments of the human community (Robson, 2011). It differs from positivist and post-positivist in that instead, knowledge is viewed as constructions of the human community and therefore subjective. Social constructionism is therefore concerned with how individuals make sense of the world as represented by human community. Making sense of the world involves individuals developing meanings of new experiences which they encounter as they engage with the world or human community (Tuffin, 2005).

Although meanings are constructed at a personal level, the constructions occur through social interaction with the human community (Crotty, 1998) and with the representation of knowledge that is socially constructed. According to Schwandt (2001) constructionist approaches emphasize the world of experience as it is lived, felt and undergone by people acting in social interactions. Hence, the task of the researcher is to understand multiple social constructions of meaning and knowledge held by the people participating in social interaction and to construct personal meanings of the phenomena by engaging with the social world. The research problems are concerned with social issues and the phenomena of interest lies in the fluid social constructions (Robson, 2011). Researchers use interviews and observation to acquire multiple perspectives about the phenomenon. The participants are seen as helping to construct reality about the world with the researcher. The researchers base their interpretations on historical and social perspectives (Crotty, 1998) as well as on contemporary actions.

Meanings constructed from social interactions are in addition related to the context of the interaction such as goals and objectives of the particular social events (Burr, 2003). In other words, meanings are context bound. Borrowing from Schwandt (2001) illustration, the meaning of a raised hand by a student in a classroom or by someone hailing a taxi cab or a witness testifying in court, differs according to the context in which it occurs. Therefore, the way to make sense of the hand raising act, if not already aware, is to talk to the individual in order to understand the context in which it is used. The next Section 4.1.3 discusses a philosophical standpoint which takes a middle ground known as pragmatism.

4.1.3 Pragmatism

Pragmatism takes middle ground relative to positivist/post-positivist and social constructivism philosophical standpoints. Pragmatic standpoint is a practical-oriented philosophical position (Johnson & Onwuegbuzie, 2004). Knowledge is viewed as both constructed in social interactions as in social constructivism and based on objective reality of the world as post-positivism. Theories constituting knowledge become true depending on how well they can be applied in solving problems or predicting outcomes (Robson, 2011). Pragmatic worldview, according to Creswell (2009) arises out of situations and consequences rather than antecedent conditions. Hence, research studies are based on approaches that can best provide the answer to the question rather than being based on one particular approach. Different or conflicting perspectives can be used, such as observable experience from the participants' perspective and objective valuation through experiments or other objective processes. The rationale for a pragmatic standpoint is the use of both positivist/post-positivist and social constructivism philosophical positions and multiple perspectives to find solutions to day-to-day problems. In that sense, it disputes the assumption of incommensurability of positivist/post-positivist and social constructivism but is not clearly positioned as a philosophical viewpoint detached from the two viewpoints (Greene & Hall, 2010).

It can take social constructivist and positivist viewpoint as outlined in the above sections depending on how best they can provide for a solution to a particular problem. It can determine objective knowledge and explore meaning of real-life experiences in search of consequences of particular actions. Hence, its view about knowledge is problem-centered rather than philosophic in the sense that it can take any philosophical standpoint depending on the problem hence could result in multiple perspectives and mixed methods approaches (Creswell, 2009). As already alluded to in Section 3.4, the present study was based on a social constructivism philosophical standpoint - its use in science education is now discussed.

4.1.4 Social constructionism in science education

As apparent in the discussions that now follow, the viewpoints posed by philosophers such as Karl Popper and Thomas Kuhn may have been motivated by the need for scientific methods that address epistemological issues in science education.

Karl Popper's interest lay in characterizing a theory formation in a scientific process, which he referred to as a problem of demarcation (Popper, 1963). His focus was on the process of induction which leads to the formation of a theory. He considered the formation of a theory to be a rational process and not logical. He illustrated his point with an example of a dog that sniffed cigarrete smoke from which it reacted badly and consequently ran off each time it saw a rolled white paper. He argued that induction is an outcome of human background knowledge and perceptions and cannot be logically justified by repeated tests as posed by scientific method.

The argument for induction as a rational process was directed against representations posed by positivists in science method which reflected observation as a basis for induction. In the positivist scientific method, inferences leading to the formation of a theory are said to be based on repeated tests which present theory formation as a logical process. Popper's argument was that a theory should be accepted based on the empirical tests that seek to nullify it rather than on those that formulate and confirm it. The view formed the basis for falsification of a theory. In falsification, the repeated tests are done on the basis of testing a theory rather than formulating or confirming it. In his words he notes the following.

> The principle of empiricism which asserts that on science, only observations and experiments may decide upon the acceptance or rejection of scientific statements, including laws and theories, can be fully preserved, since the fate of a theory: its acceptance or rejection is decided by observations and experiments - by the results of tests, so long as a theory stands up to several tests we can design it is accepted, if it is not it is rejected. But it is never inferred from empirical evidence. (Popper, 1963. p.54)

The implication of the rationalism is that inferences made from observations of a particular event can form a theory on the basis of human background knowledge which does necessarily require repeated tests or observations. Together with the concept of rationalism, falsification provides for validation of a theory in a tentative way which opens research process for theory formation. This view is in line with Feyerabend (1975) who considered the scientific method to be too rigid, basing his argument on the common violations in research studies. He posed his argument as follows.

> The idea of a method that it contains firm, unchanging, and absolutely binding principles for conducting the business of science meets considerable difficulty when confronted with the results of historical research. We find then that there is not a single rule, however plausible and however firmly grounded on epistemology that is not violated at some time or other. It becomes evident that such violations are not accidental events, they are not results of insufficient knowledge or inattention which might have been avoided. On the contrary we see that they are necessary for progress. (Feyerabend, 1975, p.23)

Feyerabend (1975) argued that science is epistemologically anarchic and proposes a theory in which "The only principle that doesn't inhibit progress is: Anything goes" (p.29). Although, Feyerabend (1975) based his theory on issues of scientific method, the theory does not provide for a consensus which is essential for validating information that builds on knowledge.

Kuhn (1970) found the accumulation of anomalies in scientific method as a precursor to a change in the normal scientific approaches. Unlike Feyerabend (1975) who was perturbed by violations of the scientific method and proposed an open approach in which anything goes, Kuhn interpreted accumulation of anomalies in scientific method as a sign for impending crisis in the normal science leading to a revolution. A revolution in Kuhn‘s terms is a scientific development in which the successes of old approaches are maintained and the problems which led to the crisis are solved. Kuhn (1970) explained the anomalies as part of cyclic pattern consisting of normal science, crisis and revolution. He used the term 'normal' to refer to established rules and regulations of conducting scientific research. It is when the shared beliefs and techniques of the community fail to address irregularities or fail to provide solutions to emanating issues within the community that crisis may occur. Crisis becomes obvious when the majority of the scientific community members agree that there is a need for a solution to the problems signaled by the accumulation of anomalies.

To support his idea of a revolution, Kuhn (1970) used examples of scientific discoveries as evidence which Bird (2000) refers to as 'exemplars'. Bird (2000) did highlight the use of exemplars in Kuhn's revolution as the essence of the particular, within the overarching influence of a paradigm. Kuhn (1970) elaborated a paradigm as a global and particular commitment among members of the scientific community which Bird (2000) interprets as a "socially reinforced, trained way of thinking" (p.66). A paradigm has great influence on the way scientists think for which Kuhn gives examples they would choose to apply to particular findings and ignore others which are equally applicable. Kuhn (1970) described the global aspect of a paradigm as the "very broad notion, encompassing the entire constellation of beliefs, values, techniques and so on shared by members of a given community" (p.175). The particular commitment is elaborated by the exemplary instances of discoveries as puzzle-solutions in that established rules of scientific research were applied to provide a clear understanding of the discoveries that led to new ways of thinking, what is referred to as a paradigm shift. The idea of exemplary instances provided a basis for the way that the teachers who participated in this study were sampled.

4.1.4.1 Philosophical standpoint on adoption of social construction for this study

In section 3.3, some discussion has already been presented on why local expertise was the focus in this study. A philosophical instigation is now reviewed why social constructionist viewpoint was found useful in guiding the study and in answering the research questions. The study embraced Kuhn’s (1970) concept of exemplars in studying exceptional teachers’ instructional practice that could support learner engagement in the school physics content. By that way, this study took a social constructionist philosophical viewpoint which is concerned with making sense of the world as it is lived and experienced by people who live in it in a particular context.

The teacher’s instructional practice entails activities that are prescribed by the school physics curriculum which includes the syllabus, teaching and learning material, and the timetable as well as the constructivist approaches to instruction. In this regard, school instruction is a part of social and cultural establishment which makes social construction an appropriate viewpoint to study school instructional practice. This is in contrast with developing understanding by determining cause-effect relationships that are established by manipulating and controlling external factors, and observing the effect on dependent variables (see section 4.1.1) which would ignore the sociocultural context.

In terms of classroom research, the social constructionist viewpoint allows the teacher’s instructional practice to be understood from the teacher-learner and learner-learner interactions through observation and interviews. The viewpoint is highlighted by Burr (2003) that social constructionist ways of understanding the world is derived from “the daily interactions between people in the course of social life that our versions of knowledge become fabricated.” (p.4) Therefore, it allows access to practice-based knowledge that would not be accessible by employing or adapting philosophical standpoints that detach social context from the study (Oser & Baeriswyl, 2001). It requires the research process to respect and value the actors’ viewpoints rather than to discredit them as they reflect their construction about life which we seek to understand as asserted by Pring (2006)that,

> …the social construction of the personal and social world presupposes the independent existence of objects (persons) which can be described in terms of consciousness, rationality, intentionality, responsibility and feeling. The very ‘negotiation’ of meanings can be conducted only within a framework of shared meanings, which meanings (in their most general state) are not open to negotiation (p.53).

The respect lies in the act of questioning, for instance, posing questions in a non-judgemental way, in a manner that may not cause misunderstanding (Peräkylä, 2005). The researcher's prior knowledge about practice is also important in establishing a respectful and ethical environment during the observations of instructional interactions (Angrosino & Perez, 2000). Instructional interactions involve verbal and non-verbal communication and the researcher's background knowledge plays an important part in interpreting both forms of communication (Gay & Airasian, 2000).

In taking Kuhn's concept of exemplars, the interest in this study was not to make sense of the practice for its own sake but as a possible solution to learner engagement in the subject content. The study assumed scarcity of instructional skills for engaging diverse learners in the school physics content particularly in a context of limited and local context based empirical resources.

4.2 Research Design

4.2.1 An overview of Research Design

Qualitative and quantitative research designs are two basic types of research designs used in educational research with a general aim of developing an understanding of educational processes and practices (Robson, 2011). The two designs share similar structural elements or features. For instance, different authors show that a research design is a model that has a purpose/goal, methods, a conceptual or theoretical framework, sampling strategy and validity (Creswell, 2009; Hakim, 2000; Maxwell, 2005; Robson, 2011). They agree that a research design provides a specific direction for the research project (Creswell, 2009) that ensures dependable and valid answers to the research questions (Kerlinger & Lee, 2000). Hakim (2000) for example describes a research designs as follows.

> Design deals primarily with aims, purposes, intensions and plans within the practical constraints of location, time, money and availability of staff. It is also very much about style, the architect's own preferences and ideas (whether innovative or solidly traditional) and the stylistic preferences of those who pay for the work and to live with the final result. (p.1)

Hakims' (2000) description of a research design captures major factors that influence a research design such as money, time and location. These factors prove to be critical on the initial plans of the study. As Creswell (2009) stated "Research designs are plans and the procedures for research that span decisions from broad assumptions to detailed methods of data collection and analysis (p.3)". Decisions may have to be taken to alter data collection plan due as a consequence of limited funds, distance and time constraint.

In the following section, quantitative design, qualitative design and the mixed method research design which draws from qualitative and quantitative designs are discussed to highlight the attributes of each and inform why only one design was deemed suitable for this study.

4.2.2 Quantitative Research Design

Quantitative research is characterized by control of variables to determine the relations among phenomena (Kerlinger & Lee, 2000). The control of variables is reflected in the statement of the research problem, the sampling and measurement procedures which require variables to be identified prior to carrying out the study so that they can be controlled. For example, Linn (1986) assert that a "comparison of alternative conditions is fundamental in making causal inferences" (p.93). One of the variables controlled in quantitative design is the social context, specifically the personal and cultural values (Gorard, 2001). The control of variables narrows the understanding of phenomena to a few well defined variables as well as defined knowledge bases.

Variables are constructs that can take two or more values or scores (Gay & Airasian, 2000). They are represented in measurement scales such as nominal scales which categorize participants into groups say, male or female. Categorical variables provide qualitative information on differences in constructs. Another measurement scale is ordinal which classify and rank variables. It provides quantitative variables on a continuum that ranges from high to low such as the height of participants.

The quantitative research problem is stated in the form of a hypothesis, a tentative proposition about the relation between two or more variables (Kerlinger & Lee, 2000). It states the researcher's expectations concerning the relationship between variables in the research problem. The researcher then collects data to determine whether the hypothesis is supported or not supported by the data. It is formulated from a theory and it logically follows the theory because it is based on implication of the theory. Therefore it leads one to expect certain relationships (Gay & Airasian, 2000).

The quantitative research procedure involves the testing of hypotheses by manipulation of independent variables which can cause changes in the dependent variables. The changes in the dependent variables are reliably related to the manipulation of independent variables because of the control over other variables. The control and manipulation of variables, provides reliable and objective outcomes. The data for quantitative research design provide numerical data (Gay & Airasian, 2000). It employs statistical data analysis methods and uses large samples of participants to provide meaningful results. The data collection instruments include questionnaires, checklists, scale ratings.

The quantitative process also involves sampling based on proportional selection of a sample of individuals so that the results of the study can be applicable to the population from which the individuals are chosen (Gay & Airasian, 2000). Examples of the types of sampling include random sampling to select desired number of samples. Stratified random sampling in which the population is divided into separate levels such as age, working experience, or class level and each level is then randomly sampled. Cluster sampling is a random selection of groups, rather than individuals, from a population. In any type of sampling in quantitative research design, the sample size needs to be representative of the population in order to provide results that can be generalized to the population.

4.2.3 Qualitative Research Design

Qualitative research design is a model for exploring and understanding the meaning held by participants to a social or human problem (Creswell, 2009). The design allows the researcher to make sense of the interaction between people including the tools they use in their sociocultural settings (Robson, 2011). It is a reflexive process which emphasizes the interactive nature of the design decisions involving interconnections and interactions among the different components of the design (Maxwell, 2005). Maxwell (2005) states that "Design in qualitative research is an ongoing process that involves 'tacking' back and forth between the different components of the design assessing the implications of goals, theories, research questions, methods and validity threads for one another" (p.3).

Gay and Airasian (2000) ascribe the participants' perspective as central to making sense of the phenomenon. They state that in qualitative research, the "central focus is to provide an understanding of a social setting and events from the perspective of the research participants" (p.204). In that way, the main purpose of making sense of the phenomenon in respect with participants' understanding and way of life can be achieved. This makes the real life situations the main source of data for qualitative research design as stated by Denzin and Lincoln (2005) that “Qualitative research is a situated activity that locates the observer in the world.” (p.3) The implication is that the researcher should be physically present at the research setting where the real-life events are taking place to observe the participants’ actions and to capture their views about their specific actions and the event as a whole (Tracy, 2010). The direct observation of people’s action is essential in understanding how they make sense of the events in which they are involved. It enables the researcher to obtain the participants’ views and perceptions about the activities they carry out in a real-life context (Opie, 2004). It also deepens the researcher’s understanding of the events in a tacit way. This sets a basis for multiple data collection methods such as interviews, further observation and documents to capture events as they occur in natural setting or real life context. (See also sections 4.4.2 & 4.4.3)

The process of developing understanding requires the researcher to be immersed in the details and specifics of the events (Woodside, 2010). Therefore, recordings of interviews and observation need to be detailed to provide information on which the researcher can make sense of the setting, participants and their interaction in their activities. The details lie in the on-going and constantly changing actions which characterize an event as well as in the multiple perspectives held by the participants (Creswell, 2009).

An understanding that develops from what the researcher hears and sees in activities takes time (Maxwell, 2005). It requires the researcher to spend time at the research setting to allow feelings and initial interpretations about the ongoing activities to be modified, replaced or refined by subsequent activities (Woodside, 2010). For instance, the activities in instructional practice are sequential and integrated, current activities can be based on the previous ones and set some foundation for the subsequent activities (Tiberghein & Buty, 2007). Hence, the feelings and initial interpretations can go through a process of validation (Kerlinger & Lee, 2000) with time spent in observing a sequence of instructional activities.

Developing an understanding of the phenomenon from qualitative data requires the data to be analyzed inductively (McMillan & Schumacher, 2006). Inductive analysis involves building patterns, categories and themes from the data by organizing it into abstract units of information (Gall et al., 2007). It involves identifying emerging factors and sketching a pattern out of them. The researcher does not impose an organizing structure. Generalization is reached from multiple specific instances observed (Hesse-Biber & Leavy, 2011). The researcher's personal experiences and insights are an important part of making sense of data.

A qualitative research approach offers a variety of research methods such as ethnographic study, grounded theory, and case study (see section 4.3.1). Gay and Airasian (2000) point out that the difference between these methods lie in the research questions. If a research question seeks to determine cultural patterns and perspective of a group of people in its natural setting, then ethnography provides the best method for the study (Gay & Airasian, 2000; Robson, 2011). If the central aim of a research questions is to generate theory from data then grounded theory provides the best method. Grounded theory is particularly useful in areas where there is lack of theory and concepts to describe what is going on. Data collection, analysis and theory development are interspersed throughout the study. It involves systematic but flexible strategies which provide detailed descriptions and data analysis (Bryant & Charmaz, 2007; Charmaz, 2006). In a similar sense, if a research question seeks to determine the characteristics of a particular phenomenon or entity the case study is employed. A case study involves development of detailed and intensive knowledge about a case or small number of related cases (Yin, 2009); it features selection of a single case, the study of the case in its context, and use of a range of data collection techniques.

4.2.4 Mixed Method Research Design

Mixed method research design employs a combination of qualitative and quantitative research designs to broaden and deepen understanding (Leech, 2010). Creswell (2009) describes procedural approaches employed in combining quantitative and qualitative research approaches according to timing and relative weight of each approach and the extent of merging them for which he uses the term 'mixing' (p.207).

On timing the quantitative and qualitative approaches can be combined sequentially by collecting quantitative and qualitative data one after the other. For example, data collection can start with qualitative data to develop understanding followed by quantitative data to generalize findings on large representative sample (Bryman, 2006). Alternatively, qualitative and quantitative data collection can be done concurrently with the similar intent of developing understanding and generalizing findings (Hesse-Biber & Leavy, 2011).

In weighing, priority can be more on quantitative than qualitative data or vice versa as the need may be in understanding the phenomena (Greene, Caracelli, & Graham, 1989). Mixing refers to the extent of merging qualitative and quantitative data by connecting, integrating and embedding one approach to another (Creswell, 2009). In connecting, the data analysis in one approach, say qualitative, can be used to inform data collection in the other approach which would be quantitative. In integrating, the data from one approach is interpreted in terms of the other (Greene, 2001). As may be necessary the constructs developed from interpreting qualitative data can be counted and compared with description in findings in quantitative data or vice versa. Embedding of qualitative or quantitative approaches involves utilizing information from one approach in a secondary form to support the study (Bryman, 2006).

Mixed method design is commonly associated with the pragmatic philosophical viewpoint that research methods are not intrinsically linked to specific philosophical positions hence paradigmatic differences are ignored (Maxwell & Mittapalli, 2010). It is based on their practical utility in answering research questions. It can take a value-laden approach dependent on cultural values as well as value-free approach independent of people's perceptions and constructions as elaborated in qualitative and quantitative research designs respectively (see section 4.2.2 and 4.2.3).

In line with the social constructivist perspective adopted as the theoretical framework (Section 3.2) together with the philosophical viewpoint (section 4.1.5) the study took a qualitative research design to access teachers' actions in exploring the way they support learners during classroom instruction (Robson, 2011). The design was chosen with an understanding that research questions need be aligned to a particular type of research design based on the relevant philosophical viewpoint taken for the study.

4.3 Qualitative Research Design for Teacher's Instructional Practice

The teacher's instructional practice is complex hence qualitative research design was found a suitable approach for exploring the teacher's instructional practice (Hamilton & McWilliam, 2001). Teacher's instructional practice serves multiple goals and objectives in developing learners' cognitive abilities (such as subject content understanding) (Howe, 2001). And, such goals are constrained by the curriculum expectations, the available facilities, and the teachers' perceptions of the learners' needs at instructional practice level (Shulman, 1986). Therefore, to characterize and understand how teacher's instructional practice supports learners in this study teachers were studied as they work with learners in the contexts of the schools where they worked.

Central to qualitative research design is its purpose to provide an understanding of the phenomenon from the perspective of the research participants (Gay & Airasian, 2000). The phenomenon is embedded in participants' actions and interactions in real life context which for this study were to be instructional activities in real classrooms, in what Carter (1990) calls practical knowledge. The design makes provision for capturing of the teacher's and learners' actions and interactions (Gay & Airasian, 2000; Robson, 2011) through multiple data collection methods such as observation and interviews. The methods were to have a complementary effect so as to enable the instructional practice to be viewed from different data capturing modes to offer information from varying perspectives (McMillan & Schumacher, 2006). A qualitative design could also offer ways in which the information could be inductively analyzed relative to the research questions (Atkinson & Delamont, 2005). Inductive analysis allows the researcher to explore data by using the existing body of knowledge on instructional interactions to make sense of the interaction from the teachers' and learners' position as facilitators and learners respectively (Patton, 2002). It also allows the researcher to use own experience and knowledge of instructional interaction as a teacher and a learner (Labaree, 1998). The qualitative design would also provide ways of triangulating the information from various sources (Seale, 1999). Since the study was to focus on few exceptional teachers, a case study approach within qualitative design was appropriate. This is now discussed.

4.3.1 Case study method in education

4.3.1.1 Historical background

The historical background of a Case study is discussed in this section to provide a context for the present study. The context provides a basis for understanding the influencing factors for selecting a Case study approach. The context also helps to highlight the kind of problems best solved through a Case study approach (Simons, 2009); this is a means to establishing the relevancy of a Case study in answering the research questions in the current study.

Different authors indicate that Case study research has its origins in methodologies used in medicine and law. Some of the first recorded Case studies in medicine were done by Sigmund Freud during his medical career as a physician (Rothgeb, 1973). The studies involved collection of data on the behaviour of patients in their everyday life which could not be adequately observed in the science laboratory. The data were used to develop an understanding of behaviour of patients and their underlying thoughts hence it had to be detailed and holistic to provide information on which valid inferences could be drawn about the Case. Examples of Case studies carried by Sigmund Freud include a Case of hysteria suffered by a girl named Dora and a case of phobia studied in Little Hans. The reports indicate that data collected included medical history of family members, the relation between the patients and their family members, and how patients react to their environment. The inferences drawn about the cases led to possible diagnosis of the problem, followed by laboratory based treatment.

Case study was adapted as a holistic research approach in social contexts perhaps as a way to address methodological anomalies expressed by social constructivists in the likes of Karl Popper (1963) and Kuhn (1970) in science education (see section 4.1.4). Yin's (2009) defines a Case study as "an empirical inquiry that investigates a contemporary phenomenon within its real-life context especially when the boundaries between phenomenon and context are not clearly evident" (p.18). The definition shows that a Case study retained its original characteristic of studying behaviour and perceptions in real life situations when it was adopted as a research approach. The definition provides the purpose of a Case study as that of investigating contemporary, as opposed to historical, phenomenon in its real-life context which reflects its original purpose. In addition, the definition points to the complexity of the context in which the phenomenon is embedded, especially lack of clarity of evidence as a setting in which a Case study is rooted. Yin's (2009) definition gives a Case study an empirical status.

In education, the use of a Case study as a research approach is marked by the 1972 and 1975 conferences held in United Kingdom (Simons, 1980) about two decades before the definition by Yin (1994). The conferences sought research approaches that could evaluate innovative education programs to inform decision-making processes and improve social and educational actions (Simons, 1980, 2009). They needed research approaches that were:

- responsive to the needs and perspectives of differing audiences;
- illuminative of the complex organizational, teaching and learning processes at issue;
- relevant to the public and professional decision forthcoming; and
- reported in language which is accessible to their audiences.

(Simons, 1980, p.5)

The Case study method was identified as a research approach that could address those needs. The 1975 conference in particular was aimed at articulating procedures for a case study project: the data collection methods such as interviews and observation; data control and processing; formulating a code of practice. Although, the aim was not achieved, the conference proceedings perhaps opened the practice of case study to other areas of education beyond evaluation of educational programs. Bassey (1999) provided various types of Case studies given by authors according to their interest, including exploratory, descriptive and explanatory types of Case study which according to Yin (2009) is characteristic of general research approach typology. Bassey (1999) also included Stenhouse's (1985) three broad categories of Case studies in education: evaluative, educational and action research which reflect the wide application of Case studies in education. For instance, Bassey (1999) quotes Stenhouse's description of educational Case study as,

> [… where] many researchers … are concerned neither with social theory nor with evaluative judgment, but rather with the understanding of educational action…They are concerned to enrich the thinking and discourse of educators either by the development of educational theory or by refinement of prudence through the systematic and reflective documentation of evidence. (p.28)

According to Merriam (1998) a Case study has educative effects in that it allows for confirmation of what is known and provision of insights into the Case. In this way, it can bring about discovery of new meanings and extend the readers' experience of the Case. It can also be expected to reveal previously unknown relationships and variables.

4.3.1.2 Case study in science education

Published research studies indicate that Case study method in science education has been and continues be used for a variety of purposes including evaluation of science programs, learning, and instructional practice including science teacher education programs.

Stake and Easley (1978) used a Case study method as part of the National Science Foundation (NSF) research project for evaluating school science program in the United States of America. The aim of the project was to provide a portrayal of the conditions of science classrooms to help make the NSF's program of support for science education. A Case study was used to obtain in-depth information to make inferences and descriptions that would be useful not only to NSF but also to the teachers, educators and policy makers. As an inherent nature of Case studies in education particularly the ethnographic ones, issues of data on which inferences are drawn, sampling and controlling bias were significant part of the study (Merriam, 2009; Patton, 2002).

The team used their knowledge and experience of the status of science education to identify key issues which shaped their questions. Stratified purposive sampling was used to get people who would provide relevant *information* that supported their views about status of science education in their country. The sampling allowed researchers to spend a long time at the site collecting data as they did not rely on structured interviews, observations and formal testing. Biases were controlled by the competency of the researchers engaged in the project to produce a balanced and unclouded account of teaching at their schools. Some of the challenges faced with the method were that the planning did not allow sufficient time for field workers to complete their work, and the coordination of findings from several sites was not productive enough. However, Stake and Easley (1978) found the quality of their work improved by the way they handled complexity and particularity of each science classroom.

On learning, Case studies have been used to investigate learning processes. Givry and Tiberghein (2011) used a Case study to identify learning processes based on the ideas expressed by two school learners. They used video data and written worksheets of the two learners at the upper-secondary school level during a teaching sequence about "gas". The results of their study revealed that the learners developed a network of volume, pressure and temperature about gases based on a network of two ideas which learners expressed in previous discussions. The results had implications for teaching a network of ideas. Aufschnaiter, Erduran, Osborne, and Simon (2007) used a Case study to investigate how learners incorporate their content specific knowledge in lessons and develop their science understanding in those lessons based on argumentation.

On instructional practice, for instance, Furtak (2012a) used a Case study to investigate how teachers used learning progression to support formative assessment. They used interviews and videotapes of six high school biology teachers leading assessment conversations as sources of data. The results indicate that teachers made inferences about student ideas during assessment but did not use the ideas to develop their instructional practice. De Jong and Van der Valk (2007) used a Case study of seven experienced science teachers participating in a school-based in-service course aimed at guiding teachers to scaffold students on inquiry learning. The findings indicate teachers' ability to scaffold learners by giving them a well-balanced combination of 'space' for own contributions at one moment and 'direction' at another moment. The studies were informed by research on learning for instructional practice in two different ways: learning on the job and professional development using learners' learning progression (Putman & Borko, 2000).

On teacher learning, Henze, van Driel, and Verloop (2009) investigated the informal learning of a small number of experienced science teachers in their first few years of teaching a new science syllabus in secondary education in the Netherlands. They reported two forms of learning, the revolutionary course of development in a teacher's engagement and evolutionary development in a teacher's participation in both individual and collaborative activities. The findings also have implications for teacher education programs.

On teacher education, Loughran, Mulhall, and Berry (2008) in exploring the use of the idea of pedagogical content knowledge (PCK) in pre-service science teacher education employed a Case study to develop insights into how a teacher educator taught his science student-teachers to help them develop knowledge and practice of teaching science. They found that the student-teachers applied a more sophisticated view of learning about teaching in their own practice that appeared to help them challenge the more traditional science teaching. In the same area, Tobin, Roth, and Zimmermann (2001) had earlier developed a co-teaching model for teacher preparation based on Case studies.

Case study method in science teacher education is used to produce cases for teaching. Case-based teaching is believed to bridge the theory-practice gap by involving student teachers in active examination and reflection of problematic situations in real world teaching practice (Shulman, 1987).

4.3.1.3 Case Study of Exemplary Teacher's Instructional Practice

A Case study, as a study of the particular, would enable exploration of the exemplary teachers' instructional practice; Schön (1987) has termed teachers' instructional practice as the "swampy zone of practice" (p.3) where such zones have been referred to as

> Those indeterminate zones of practice – uncertainty, uniqueness and value conflict – escape the canons of technical rationality. When problematic situation is uncertain, technical problem-solving depends on prior construction of a well-formed problem – which in itself is not a technical task. (Schön, 1987 p.6)

In particular, this study has drawn from Merriam (1998) definition of a Case study as "particularistic" and "descriptive" (see pp. 29-31). According to Merriam (1998) by being particularistic, a Case study focuses on particular situations or phenomenon. The importance of the particularistic feature of a Case study implies a focus on the events which may include uncovering the interactions between factors within a case (Stake, 2005). This is expressed in Merriam (1998 p.29) quoting Shaw as follows:

> (Case studies) concentrate attention on the way particular groups of people confront specific problems, taking a holistic view of the situation. They are problem-centered, small scale, entrepreneurial endeavors.

The particularistic feature is understood in the sense of embracing the complexity of real-life events through which the discrepancies of viewpoints held by participants can be represented and supported (Adelman et al., 1980). For example, detailed and specific information on the activities employed by the teacher to guide learners' understanding of a specific concept can be used to develop understanding of the activities (Svensson & Doumas, 2013). The point is supported by Bassey (1999) that large amount of data is necessary for exploring features of a case in its real-life setting.

> An essential feature of a case study is that sufficient data are collected for researchers to be able to explore significant features of the case and to put forward interpretations for what is observed. Another essential feature is that it is conducted in its natural context. A case study of playground behavior would require observation of the playgrounds: interpretation with teachers about playground behavior would be insufficient, for it would be difficult to test for the trustworthiness of the data without triangulating them with observational data.
>
> (Bassey, 1999 p.47)

The descriptive feature reflects the many factors obtained from different sources which contribute to the complexities of a situation in which a phenomenon exists (Merriam, 1998). The descriptions allow for subsequent reinterpretation bearing in mind the complexity of events in educational context which may require multiple interpretations according to the purpose of the study (Adelman et al., 1980). The particularistic and descriptive features of a Case study make the approach particularly appropriate and suitable for exploring the teachers' practices towards finding answers to the research questions in this study.

The first research question 'What characterizes the teacher's instructional practice' was to be an exploration of the enacted instruction with the intention of identifying broad features or patterns of the practice. According to Yin (2009), the "what" type of question has two possible meanings. The first meaning is a form of "how many" and "how much" (p.9) kind of inquiry. The first meaning is appropriate for situations where there is insufficient information such as the existing concepts to describe the phenomenon. However, the theories of instruction provide adequate concepts for describing instructional practice. The second meaning is a form of "what can be learned from…" (p.9). Therefore, the second meaning 'what can be learned from a particular event or phenomenon' is what the research question was to investigate. This informs on why the question required a particularistic approach to study the instructional activities a feature of the Case in the study (Merriam, 1998). The question forms a conceptual basis for the second and third questions.

The second research question ‘How does the teacher’s practice support learners in accessing school physics content’ is a ‘how’ question. This question sought details of the instructional activities that the teachers used to guide the learners in making sense of the content. According to Yin (2009), the ‘how’ question is a type of question that seeks to explain phenomenon. It aims to establish relations between a phenomenon and the specific event which for this study would be specific instructional activities implemented in the support for learners.

The third research question ‘Why does the teacher’s practice support learners’ in the way it does?’ was aimed at establishing a link between the support provided for learners and the motivating factors underlying the support. Similar to the second research question, the third question required establishment of relations between teacher’s practice and support for learners. The three questions required interpretative approaches (F. Erickson, 1986) or a particularistic orientation which could be employed through a Case study in order to merge with the descriptions of the participant teachers instructional practices. Exploration of the practice required detailed and in-depth information from real classroom interactions to deeply understand the practice, to make plausible interpretations and construct a worthwhile argument (Spillane & Zeuli, 1999). Stebbins’ (2001) elaboration of the possible scripts of adopting an exploratory perspective in research is captured by the following statement.

> There is a playfulness of mind back of such combining as well as a truly fierce drive to make sense of the world, which the technician as such usually lacks. Perhaps he is too well trained, too precisely trained. Since one can be trained only in what is already known, training sometimes incapacitates one from learning new ways; it makes one to rebel against what is bound to be at first loose and even sloppy”. (Stebbins, 2001 p. 23)

The descriptive feature of a Case study would provide a rationale for collecting information (Bassey, 1999) that would enable a full understanding of the particular. It may now have become apparent why the three research questions required a particularistic orientation which would lead to descriptive account of the various factors that would be indicative and illustrative of the teacher’s practice in supporting learners. It is a possibility with a Case study approach that made it most appropriate for exploring the research questions in this study.

4.4.0 Data Collection Methods

4.4.1. Introduction

In line with the particularistic and descriptive features of the case study method, methods of data collection employed were observation and interviews (see also section 4.2.3). The observation method was used as a primary source of data and interviews were used to complement the observations. This decision was based on Gaskell (2000) view that compared to observations, interviews have limitations. Examples relevant to this study include the interviewee omitting important details by taking them for granted or by not being able to express them in words (Loughran et al., 2004). In observation, the researcher has a "greater breadth and depth of information and is able to triangulate different impressions and observations" (Gaskell, 2000, p.44) which are relevant to the research questions. However, the two methods were considered suitable to capture detailed data and at the same time provide a holistic view of the teacher's practice (Jick, 1979) to enable the uniqueness of practice to be explored (Stake, 2005). In addition to the interviews, learning material and learners' work were also to be used in cross-checking the interpretations and inferences from observations. The methods are discussed in the following sections to provide ways in which they could enable detailed and holistic data to be captured, to inform on their suitability for this study.

4.4.2 Observation

Observation as a method of data collection is situation-specific in that they provide a view of the phenomenon under study (Evertson & Green, 1989). Adler and Adler (1994) define observation as a way of gathering impressions of the surrounding world through senses of sight, touch, smell, hearing and tasting. The use of multiple senses in observation enables understanding and at the same time provides opportunity to refine understanding of what is observed (Jick, 1979). Observation therefore enhances validity of information. There are various approaches to systematic observation reflecting how the data is obtained. Each approach has inherent sources of error which need to be considered when collecting and analysing observational data. In this section approaches to systematic observation, sources of error and ways of validation are discussed.

Opie (2004) describes two main types of systematic observation namely structured and unstructured observations. He defines structured observation as one in which the criterion for observation is predetermined in a way that the observer can use a checklist to collect data. An example of structured observation in which a checklist is used is the Flanders interaction analysis tool (Flanders, 1978). It consists of categories of teacher's talk during instructional interaction which includes teacher's initiation of ideas, response to learners' actions, and questions. Each of the categories is divided further into sub-categories. For instance, teacher's response is categorized into teacher accepting learners' feelings or expressions, praising learners or using learners' ideas. The categories are used to record observations on the teacher's interaction with the learners during the lesson. The process of observation is also pre-determined. For instance, it can be decided that the activities be recorded every time five minutes of the lesson (Foster, 2006).

Unstructured observations are open-ended they do not use predetermined criteria for observations. The purpose of unstructured observations is to record and study interactions which cannot be predetermined as they occur normally in natural settings (Gall et al., 2007). They allow the researcher to make sense of the interaction in the way that they occur which requires the observer to immerse into the events (McMillan & Schumacher, 2006). It is in the immersion that "…the phenomenological complexity of the world where connections, correlations and causes can be witnessed as and how they unfold" (Adler & Adler, 1994 p.378).

Observation method is also defined by the role the observer takes in the activities being observed. The importance of roles taken by observers is the depth of observations afforded and the effect they have on the natural occurrence of events being observed (Angrosino & Perez, 2000). When the researcher participates in the observed activities s/he takes the role of a participant observer and a non-participant observer when s/he does not participate in the activities. The role of a non-participant observer can be associated with the structured type of observation where predetermined criteria are used to observe activities (Foster, 2006). In this role, the observer can make observations without physically interacting with the participant. This can take the form of an observation being made from video recorded activities or from a one-way window (Loizos, 2000). It is believed that the advantage of a non-participant observation is that the researcher has less effect on the unfolding of the activities than does in participant observation (Gay & Airasian, 2000). However, Angrosino and Perez (2000) note that the ethical requirements for informed consent, in which the research participant has to agree to be observed or decide to withdraw, the advantage of a non-participant observer role is idealistic. Participant observer is a researcher who enters a setting for the purpose of collecting data but interacts casually or indirectly with research participants while collecting observational data (Adler & Adler, 1994). Adler and Adler (1994) however note that participant observer roles in naturalistic social science (like educational research) have moved into membership role. They identify three types of membership roles: complete-member-researcher, active-member-researcher and peripheral-member-researcher (p.380). The complete-member-researcher is one who collects observational data in a setting where s/he is member of the group. The active-member-researcher is a researcher who becomes involved in the central activities of the setting without fully committing to the members' values and goals. The peripheral-member-researcher observes and interacts closely with the group members for the purpose of establishing insider's perspective without participating in the central activities of the group (DeWalt & DeWalt, 2011). The peripheral-member-researcher describes the type of observer role taken by the researcher for this study.

Observer effect

The presence of an observer can affect the natural way in which the activities occur (McMillan & Schumacher, 2006). In the presence of an observer, participants can change their natural behavior to present their actions in a particular way for the observer. In that way, what is observed is not exactly the way a participant would naturally behave (Angrosino & Perez, 2000). This means that the presence of an observer, whether in participant or non-participant role, affects the natural interactions in a natural setting (Foster, 2006). Exception is made of a covert observer role in which the participants are not aware of the presence observer. This is not recommended under general ethical regulations (Gay & Airasian, 2000) even though its use in particularly private areas can be informative (Adler & Adler, 1994). The observer effect can be reduced by the researcher taking an unassuming position when entering the field by being as cordial as possible and non-threatening when asking questions (Gay & Airasian, 2000). For instance, the researcher should not sound judgemental when seeking information that is meant to clarify her/his understanding of participant's actions.

Observer bias

The observer's own knowledge, experience and assumptions about the activities being observed are useful in understanding and interpreting observational data (Adler & Adler, 1994). But, the knowledge can bias interpretations in favour of the researcher, for example the researcher may have a preference for an instructional strategy which differs with the one the participant uses (Kerlinger & Lee, 2000). The researcher may therefore fail to interrogate the strategy fairly which could result in findings that do not project the phenomenon as it exists in relation to other areas of the strategy (Foster, 2006). In that way, the interpretation cannot be valid as noted by Gay and Airasian (2000) that the nature of data collected and the personal interpretive role of the researcher introduce bias and invalidity in a study.

Observer effect can be reduced by the researcher recording his/her feelings, thoughts and reaction about activities observed and using the record to review his/her position objectively (Gay & Airasian, 2000). It is important that the researcher makes an effort to obtain trust and comfort by providing detailed and honest information (Kothari, 2004). Adler and Adler (1994) in view of the absence of the participants in the analyses and interpretations of the observational data suggest the use of quotations from raw data to enrich and confirm researcher's analyses which can also be used by readers to check the validity of the statements. The use of analytic inductive methodology in which negative cases play an important role in generating statements that are likely to be perceived as grounded or universal is recommended (Merriam, 2009).

Authors involved in qualitative observational studies suggest minimizing observer bias to strengthen the validity of observations from the point of entry to the field to reporting of findings.

4.4.3 Interviews

As already mentioned in this thesis, the interviews were used to cross-check interpretations and inferences from observations with the teacher, and to focus observations for consistency and reliability (Jick, 1979). Therefore, the interviews were focused on specific situations and actions in teachers' instructional interactions with learners to develop understanding of the support provided (King, 2004). Fontana and Frey (2005) define interviews as "active interactions between two (or more) people leading to negotiated, contextually based results." (p.698) As negotiated, interviews have potential to develop a joint construction of meaning between the researcher and the participant and not just a construction of the participant (Gay & Airasian, 2000). As contextually based, an interview can produce a situated understanding of specific interactional episodes (Fontana & Frey, 2000; Kerlinger & Lee, 2000). The type of interview employed in a study determines the extent to which meaning and understanding can be jointly constructed.

There are two main types of interviews structured and unstructured interviews (Fontana & Frey, 2000; Gaskell, 2000). Structured interviews consist of pre-established questions with a set of response categories which allow limited variation of responses. The conduct of the interview is also important. The interview conducted in a structured way requires the interview questions to be sequenced in a particular way and all the participants are asked the same questions in the same order (Foddy, 1993). There can be alternatives for each question so that phrasing of responses is structured. Questions are self-coding with each alternative answer pre-assigned a code (Wilson & Sapsford, 2006). Structured interviews aim to capture data in a manner that can be coded to explain behaviour through pre-established categories. The structured interviews are generally used for survey while unstructured interviews are used for in-depth studies (King, 2004).

Unstructured interviews also known as in-depth interviews are made up of exploratory open-response questions. They are used to examine attitude, concerns and values more easily than in observations. Interviewer can explore and probe participants' responses to end up with in-depth information about their experiences and feelings of research participants (McMillan & Schumacher, 2006). Unstructured interviews as in-depth interview can vary according to the type of questions. McMillan and Schumacher (2006) provide three types of in-depth interviews: informal conversation and standardized open-ended interviews which are also known as unstructured; partially structured; and semi-structured (Gay & Airasian, 2000). Informal conversation interviews use open-response questions which may become structured during unarranged conversations (Foddy, 1993). The interviewer can formulate and sequence questions without pre-established order (Fontana & Frey, 1994). In an informal conversation, questions emerge from immediate context, there are no predetermined topics and wording as the interviewee actively participates in the conversation (King, 2004). They are also useful for discussions immediately after the lesson when the teacher's information and feelings about the lesson are still fresh (Bishop & Denley, 2003). Interview guide are used for more formal conversations to explore and probe information after researchers' reflections on observation and field notes (Gay & Airasian, 2000). In interview guide, topics are outlined and questions are formulated in advance but the researcher decides on the sequence and wording and may add or modify questions during the interview. In standardized open-ended interview the exact wording and sequence of questions are predetermined but the questions are open-ended (Fontana & Frey, 2000).

Group interview is a technique of collecting data by systematic questioning of several individuals at the same time in a group (Fontana & Frey, 2000; Hesse-Biber & Leavy, 2011). Group interviews can be structured or unstructured interviews. Unstructured interviews can be in the form brainstorming session and structured interviews are directive in terms of questions and answers (Fontana & Frey, 1994). The interviewer can be very formal and directive, guiding discussions and permitting digression from the topic or can be non-directive approach to establish a range of meaning and interpretation of the topic. Group interviews can be exploratory (Vaughn, Schumm, & Sinagub, 1996). Exploratory interviews are designed to establish familiarity with the topic and to refine findings. The interviewer can be directive but the questions can be unstructured and open-ended where the intent is to tap meaning with depth and diversity. They can be used for aiding respondents to recall specific events and to stimulate descriptions of events (Gaskell, 2000). They can also be used for triangulation purposes in conjunction with other data gathering techniques, for studying phenomena and for verifying interpretations (Vaughn et al., 1996). Group interviews can also be used as a stand-alone technique (Hesse-Biber & Leavy, 2004)

Sources of error

According to Fontana and Frey (2000) quoting Scheurich (1995) stated that interviewing is "persistently slippery, unstable and ambiguous from person to person, from situation to situation from time to time" (p.654). This makes interviewing not easy to conduct and susceptible to errors. The information through words uttered by participants are limited by participants knowledge, memory, ability to convey information clearly and accurately and being affected by how they wish to be perceived by outsiders (Gall et al., 2007). Some of the errors noted by Fontana and Frey (2000) are that the respondent may deliberately hide information from the interviewer, may provide socially desirable responses, or may not remember details of activities. The interview questions might not be sequenced in a way that assists the respondent to provide required information. The interviewer's wording may not communicate questions clearly to the respondent (Foddy, 1993). The language and culture of the respondents can also cause some errors if not understood by the researcher. For instance, the learners may talk in a particular way and use words that are not standard which may not be easily accessible to the researcher. To reduce interviewer effect, Fontana and Frey (2000) emphasise the importance interviewing skills by quoting Raymond Gorden that interviewing "…involve high-order combination of observation, empathy, sensitivity, and intellectual judgement" (p.651). In this regard Gay and Airasian (2000, p.223) provide the following guideline:

- Listen more talk less
- Follow up what participants say and ask questions when you don't understand
- Avoid leading questions, ask open ended questions
- Keep participants focused and ask for concrete details
- Don't be judgemental
- Don't debate with participants

Foddy (1993) suggested that questions must be based on theoretical framework and research approaches and both the researcher and interviewees must be clear about the nature of information required and encode the information in their requests or responses. Fontana and Frey (2000) also point out the importance of gaining trust of the participants and establishing rapport by attempting to see the situation from the viewpoint of the participants.

The next section presents analytical scheme - an approach adopted towards analyzing observational data as the main type of data on instructional practice.

4.5 Analysis

Analytical scheme

Larochelle and Bednarz (1998) argue for an analytical schema to guide constructions so that they do not turn out to be descriptions of instructional activities or driven by the researchers' biases. In this sense, the study employed Tiberghein and Buty's (2007) analytic approach to *studying science teaching practices in relation to learning.* The approach is used to view instructional interactions based on knowledge prescribed by the syllabus, and the evolution of instructional activities. This study adopted two terms from the approach: *knowledge to be taught* which refers to the knowledge prescribed by the syllabus and *taught knowledge* which refers to the researcher's constructs of the conversational productions of interactions. This is in accord with Larochelle and Bednarz (1998) statement that "representation of knowledge is as much a function of the immediate context of interaction as of the surrounding representations and beliefs which serve to define what is happening within an event" (p.10).

The *knowledge to be taught* is prescribed by the syllabus and elaborated in other curriculum documents, which in the case of Botswana General Certificate of Secondary Education (BGCSE) physics curriculum are textbooks (see sections 2.7.1). The *taught knowledge* corresponds to the mediated knowledge in the instructional interactions. The critical aspect of taught knowledge in this study is the progression of activities in developing new knowledge during instructional interactions which is addressed through concept of *didactical time*. Didactical time refers to the pace of introduction of new knowledge in instructional interactions *and determined by* dividing taught knowledge into units which have structure, thematic coherence, and introduction and conclusion. The times interval for each units is about 10 minutes. The cognitive processes involved and the support provided through units can then be explored.

4.6.0 Chapter Summary

This chapter has attempted to provide a methodological approach taken to conduct the study with some theoretical basis of the method employed. The approach was based on the social constructivist philosophical viewpoints for its concern on how individuals make sense of the social world of which they are part and how they conduct their activities in that world. Making sense of the world involves individuals developing meaning of new experiences which they encounter as they engage with the world. It included a description of the qualitative research design which was used to capture instructional practice in real classrooms, the data collection aimed at collecting detailed information and the analytical scheme for teachers' instructional practice. It also included an argument for a case study approach as particularistic and descriptive. In the next chapter Sampling issues and how the study was implemented are discussed.

CHAPTER 5

Sampling Issues, Data Collection and Approach to Data Analysis

5.0 Introduction

While Chapter 4 provided the theoretical background of methods for this study, this chapter now provides a description of the sample and sampling process, actual process of data collection, data processing and analysis employed for the study. Details of the ethical procedures, validity and rigour in the process of gathering and analyzing data are also provided in this chapter. The data collection, processing, and analysis were aimed at addressing the research questions this study sought to answer; these are reproduced below:

1. What characterises exemplary teachers' instructional practices in school physics?
2. How does the exemplary teachers' instructional practice support learners in accessing school physics content?
3. Why does the exemplary teachers' instructional practice in school physics support learners in accessing school physics content?

First presented are the details of the sampling process and of the participants/sample used in the study.

5.1 Sampling of exemplary physics teachers

The definition of sampling adopted in this study is the one provided by Strauss and Corbin (1990) who describe sampling as the selection of "those persons, places, situations that will provide the greatest opportunity to gather the most relevant data about phenomenon under investigation" (p.181). Sampling in this study was intended to select physics teachers whose instructional practices had a potential to support learners on the subject content.

The two main types of sampling that can be used for selection of participants in educational Case study are purposive and non-purposive sampling (Merriam, 2009) or what can be called non-probability and probability sampling within a quantitative design perspective (Henry, 1998). A non-purposive sampling involves proportional selection of individuals to the population (Gay & Airasian, 2000; Merriam, 2009) and it has an inherent purpose of generalizing results from the participants to the population in which participants belong (Gorard, 2001) which are important factors in quantitative research (also see section 4.2.1). Hence, non-purposive sampling is generally associated with quantitative research design.

Purposive sampling is associated with qualitative research design (Merriam, 2009; Patton, 2002) which offers the researcher the reflexivity to study phenomenon of interest in a real life setting (Maxwell, 2005). Such reflexivity may include purposely selecting a setting where the phenomenon is intense in order to understand it from the participants' actions (F. Erickson, 1986; Shaw, 2010). It is for this reason that purposive type of sampling was found appropriate in this study. The next section provides further details on purposive sampling.

5.1.1 Purposive sampling

Gay and Airasian (2000) describe purposive sampling as judgment based on researcher's knowledge of the group to be sampled. The rationale for purposive sampling for this study was on the fact that purposeful sampling allows for the selection of "information-rich" (Patton, 2002, p.230) cases for an in-depth study. Patton (2002) described information-rich cases as "those from which one can learn a great deal about issues of central importance to the purpose of inquiry" (p.230).

Purposive sampling has categories that reflect the distribution of the population with respect to a particular phenomenon (Gall, Gall & Borg 2007; Merriam, 2009; Patton, 2002). For instance, in a normal population distribution, learners' performance can be average, below or above average, and extremely low or high. Similarly, the purposive sampling categories reflect relative intensity of the phenomenon which provides a basis for sampling criteria for the study. These categories include extreme or deviant, intensity, typical, maximum variation, stratified, homogeneous and snowball sampling (Merriam, 2009; Patton, 2002). In addition, there is convenience sampling which is not based on the characteristic of the population with regard to the phenomenon but on the convenience of the researcher in accessing participants (Marshall, 1996). The following is a brief description of each category which would help in describing the selection of the participant teachers in this study.

Extreme or deviant sampling involves selection of members of the population who display extremely high or extremely low characteristics with respect to the phenomenon of interest (Gall et al., 2007). The purpose for selection of the sample is that it would be easier to detect the phenomenon of interest due to the extreme and possibly frequent prevalence of the phenomenon with the sample relative to other groups. That is, the sample is information-rich and can easily illuminate the uniqueness of the sample (Patton, 2002; Merriam, 2009). The possible disadvantage of the extreme or deviant sampling is that the information might be highly unusual and not be easily applicable to other members of the population.

Intensity sampling involves selection of the members of the population who exhibit the phenomenon of interest intensely, that is, above average but not extremely. The purpose of the selection of members would be that the phenomenon can be easily explored because it is intensely manifested. Similar to the extreme sampling, it can be information-rich, but the findings from intensity sampling could be more applicable to other groups than in extreme sampling. This is argued because more members of the population are likely to identify with the way the phenomenon is displayed (Gall et al., 2007).

Typical sampling involves selection of members of the population who display an average level of the phenomenon. The sampling is typical because members selected from the portion of the population in which the phenomenon is neither high nor low. The characteristic of the phenomenon found in this group could be reflected across the population in varying levels. Merriam (2009) states that typical sampling is chosen because it reflects average instances of the phenomenon of interest as opposed to extreme or intensely unusual instances. The sampling targets the majority of the population (Gall et al., 2007) in that the findings from this group can provide a reference for the improvement of practice or program. An example would be exploring common teachers' instructional practices.

Maximum variation sampling involves selecting members of the population who illustrate variation in the phenomena to be studied. The samples would exhibit a wide variety of instances of phenomenon (Merriam, 2009). It could be made up of members from various groups of the population or could be a sample through which various instances of the phenomenon could be exhibited and explored (Patton, 2002). The purpose of maximum variation sampling is to document the range of variation and determine common themes, patterns and outcomes across variation (Gall et al., 2007).

Stratified purposive sampling differs slightly from maximum variation sampling. It involves selection of members of the population at defined points of variation such as average, above and below average performers (Merriam, 2009; Patton, 2002). It helps in gaining insights in the way the phenomenon manifests at each level of performance. It differs from maximum variation sampling in that it can provide sufficient information that could be used in showing variations between defined points of variation. However, the common features in defined points of variation are not excluded as they form an important aspect of the analysis (Gay & Airasian, 2000).

Homogenous sampling involves selection of members of the population who have similar characteristics of the phenomenon (Merriam, 2009; Patton, 2002). In contrast with the maximum variation and stratified purposive sampling, the sample does not exhibit variation of the phenomenon. Its purpose is to capture the characteristics of a particular group in the population in detail. The characteristics of homogenous sample need not be typical to the population from which it is drawn.

Snowball or chain sampling involves selecting a few members of the population who meet the established criteria for participation in a study and in the process ask the participants to suggest other participants who meet the same criteria (Merriam, 2009). It may involve asking well-situated people to recommend those with similar characteristics for the study. As the process continues, the researcher might discover an increasing number of individuals who could be included in the sample (Patton, 2002).

Convenience sampling involves selection of members of the population based on convenience such as availability of funds, time and distance from where the researcher resides. Merriam (2009) suggested that selection based on convenience alone is likely to produce information-poor rather than information-rich cases, and is a strategy that is not necessarily purposeful (Patton, 2002).

Intensity purposive sampling as already described in this section was used for the selection of teachers. This sampling approach fitted the aim of the study that was to explore the exemplary teachers' instructional practices. The sampling process for achieving the aim of the study required exemplary teachers to be identified followed by selecting those who would participate in the study.

5.1.2 Issues on selection of exemplary teachers

Perhaps the question that would arise in science education in Botswana is the validity of selecting local non-physics specialists examples of exemplary teachers of physics. The question would arise due to scarcity of research studies on the local characteristics of exemplary science teachers' instructional practice (see Chapter 2) which could be used to inform the selection. It could also arise because of general dissatisfaction with classroom interactions from learners, teachers and head-teachers (Prophet & Rowell, 1990). This study therefore, takes a bold stance of making a selection of local teachers as examples of exemplary teachers based on their instructional practice (see Section 3.3). Hence, a literature review of selection of exemplary teachers is considered critical as a basis for the selection method used in this study.

The two studies on exemplary teachers conducted in Botswana employed alternative methods for selection of teachers. Ramorogo (1997) randomly selected schools and used purposive sampling validated by the head-teacher and senior teacher to select exemplary teachers in Botswana. Rowell (1990) stated that teachers, learners and administrators in Botswana junior secondary schools "rarely indicated dissatisfaction with the quality of classroom interaction" (p.88). The statement was based on Prophet and Rowell (1990) who had concluded that the major issue in the classroom interactions in junior secondary science in Botswana was the "acquisition of limited skills associated with the specific responses required for success on the terminal examinations" (p.27). Based on the foregoing views, the selection of exemplary teachers by teachers, learners and administrators would be biased by the general inclinations towards examination results (Prophet & Rowell, 1990).

The criterion for selection of exemplary teachers in this study is also informed by findings from Rowell (1990) and Prophet and Rowell (1993) that examination results were the only criterion by which teachers' instructional effectiveness was assessed. For instance a participant teacher is quoted to have said that "rote memorisation they use here is OK because that is all they have to do on the exam" (Rowell, 1990 p.103). The general inclination on examination results for assessing teacher effectiveness by school administrators was also prevalent in the senior secondary schools that participated in this study (see section 5.2.2). This was so despite the fact that Double science and Single Science Syllabus in Botswana have biology, chemistry and physics components which are taught by three subject specialist teachers but examined in a combined form (M. o. Education, 1998a). Research on teacher effectiveness elsewhere indicates that the use of examination results alone for selecting effective teachers is not valid. For instance, Clotfelter et al. (2007) state that evaluation of teacher effectiveness in terms of learner achievement in examinations require control of factors such as learners' ability, prior knowledge, sociocultural background, and school effect.

The methods for selecting exemplary teachers in developed countries are generally based on nominations made by teachers, head-teachers and other school administrators. Penick and Yager (1983a) based their selection on nominations made by the teachers, head-teachers and other school administrators. Fraser and Tobin (1989a) in Australia used teachers, Ministry of

Education advisory staff and tertiary institution staff to nominate outstanding teachers and the selection was based on the frequency of nominations. Ladson-Billings (1995) in the African American communities used a similar method that was used by Fraser and Tobin (1989a) but with teachers, head teachers and parents nominating outstanding teachers. The selection was based on frequency of nominations. It is noteworthy that nominations are not always perfect. For instance, Tobin (1998) after selection of exemplary teachers nominated by education officers, teachers and administrators found that one of the teachers' instructional practices did not support learners on high cognitive skills.

Some research studies show variation in selecting exemplary teachers which does not put much emphasis on nominations. Hofstein et al. (1990) used student evaluations in addition to supervisors' recommendations to select exemplary chemistry teachers. Alsop et al. (2005) used nominations from education officers and school administrators and selected exemplary lessons chosen by the nominated teachers.

Teaching experience

Lunenberg and Korthagen (2009) define teaching experience as the knowledge that one gains from operating in the real world which includes the good or wrong ways of doing things. Teaching experience is a major characteristic of exemplary teachers which is indicative of the time committed to refining and perfecting the instructional practice to the status of an exemplar. This view is consistent with Penick and Yager (1983b) findings that exemplary teachers had 11 years on average teaching in the same school in which they developed their programs and an average age difference of 10 years between them and other science teachers. This sharply contrasts with the high rate of movement of science teachers from one school to another in Botswana (Botswana, 2008) and the relatively low teaching experience (see section 2.3.1). The advantage of teaching experience, however, was found among primary school teachers by Mwamwenda and Mwamwenda (1989). Mwamwenda and Mwamwenda (1989) found that learners taught by teachers with long teaching experience of nine years on average, were superior in academic achievement in comparison with pupils taught by less experienced teachers in science, English and mathematics.

> Teachers in Botswana are convinced that a teacher's experience has a role to play in the improvement of quality of education. It was argued that being a professionally qualified teacher is not enough … This must be complemented by competence, dedication and most important of all a considerable amount of teaching experience.
>
> Mwamwenda & Mwamwenda (1989 p.39)

The importance of teaching experience as a quality for exemplary teachers concurs with Berliner (1986) that expert teachers have many years of teaching experience. It also agrees with Steffy et al. (2000) that it takes time before a teacher reaches expert phase. Lee and Luft (2008) found that experienced secondary science teachers' knowledge included the following: learners' different ability levels, needs, interests, prior knowledge, learning difficulties, misconceptions; curriculum organisation that enabled making connections between lessons and units, organising lessons in specific order, making decisions about what to teach; skills for students' discussion and questioning, immediate feedback; knowledge of resources including materials, activities, multimedia, local facilities (p.1352).

Unlike was the case with Penick and Yager (1983b), age and teaching experience were not included in the criteria for selecting exemplary teachers in this study. The selected teachers, details of whom are provided later in this section, were both left with two years before they reached the official retirement age which is 65 years; both also had gathered more than thirty years of teaching experience in Botswana. It is noteworthy that teaching experience is not a criterion for selection of exemplary teachers but it is a characteristic which can be used to substantiate the validity of their selection.

However, Tsui (2009) studied expert teachers and equally experienced non-expert teachers and found that they differed on a number of factors. The expert teacher's practice was characterised by integration of knowledge in response to the context of their work which enabled them to improvise and make changes on initial strategies these were not observed in the non-expert teachers' practice. Bereiter and Scardamalia (1993) define expertise as a process rather than a state. They assert that "when people work at the edge of their competence to tackle increasingly difficult problems to extend their competence, they develop expertise" (Beireter & Scardamelia, 1993 p.34).

Learner perceptions of ideal teachers have been used to select exemplary teachers. Fraser and Tobin (1989b) found that learners taught by exemplary teachers perceived their classroom learning environment as more favourable than those taught by non-exemplary teachers in biology, chemistry and physics. Waldrip and Fisher (2003) used a questionnaires on teacher interactions which were completed by learners and validated through learner interviews to select exemplary teachers. Gentry, Steenbergen-Hu, and Choi (2011) used similar method and in addition used teacher interviews to select exemplary teachers. The studies reported high agreement between actual perception of learners in exemplary classes and the standard preferred for learning environment. Although learners were not involved in the selection of exemplary teachers in this study their responses to their teachers' instruction were expected to reflect a positive perception of their teachers.

5.1.3 Details of the participant teachers, their schools and the participant learners

Based on the foregoing, the selection of exemplary teachers from a baseline study conducted by DMSE-INSET, a professional development unit in the University of Botswana for mathematics and science teachers was found appropriate. The approach of selection was similar to the one used by Rowell (1990) where the exemplary teachers were selected from a study conducted by Prophet and Rowell (1990) in which most teachers' classroom practices were found authoritative. The approach in this study was also found appropriate because of high teacher turnover due to transfers from one school to another and promotions to administrative posts. In most cases, the promotions take expert teachers away from the classroom. There is also high rate of attrition as physics teachers leave teaching for more lucrative jobs which makes the involvement of community of practice in the selection relatively unreliable.

The teachers were identified from the participants in a baseline study conducted by DMSE-INSET, a professional development unit responsible for developing professional secondary school mathematics and science teachers. The teachers who participated in the baseline study had been selected from the physics teachers in their schools by the senior teachers whose responsibility involved implementation of the subject curriculum at the schools but the criteria for their selection for participation in the DMSE-INSET study was not communicated. The teachers who participated in the baseline study could have been selected by their Senior Teachers for reasons not related to their effectiveness. From this group of teachers, two teachers whose practice showed exceptional skills in engaging learners were selected out of eleven teachers observed. The two teachers are referred to as Teacher A and Teacher B in this report to keep their anonymity. They taught in separate schools which necessitated consideration of the school effect. The schools location has been found to have an effect on learner performance in national examinations in Botswana (also see section 2.8.1). The distance from the schools to the place where the researcher resided was considered to reduce travel and accommodation costs. Teacher A taught in School A located in a town and Teacher B taught in School B located in a village. The names of the schools are not their real names, they are synonyms used in this report for ethical reasons.

Background details about Teacher A and Teacher B, the schools in which they taught as well as their respective learners who participated in this study are provided next.

Teacher A and School A

Teacher A is of African origin. He came to work in the country as an expatriate teacher on contract terms as part of the country's effort to meet teacher shortages. He majored in Chemistry Education at university but due to shortage of physics teachers in Botswana he became a physics teacher. At the time the study was conducted he had taught in several different schools across the country for more than thirty years. He taught physics under the COSC curriculum and BGCSE curriculum. He participated in different professional development workshops including those organised by the DMSE-INSET. At the time the study was conducted he had two years left before he reached official retirement age which made him one of the most experienced science teachers at senior secondary school level. English is his second language. He also speaks Setswana well despite his foreign nationality which he used to emphasise points in his lessons.

Teacher A taught in School A which is situated in a small town along the main road to the capital city, Gaborone. The town features some prominent Government buildings such as the High Court, Botswana Meat Commission, the Home of the ECCO Beef, the country's largest Psychiatric Centre and the Geological Surveys laboratories. School A was opened in 1972. The school has two distinct sets of buildings. One set of buildings consists of blocks of classrooms clustered in one area. The buildings were painted light-green which matched the green color of the female uniform. Another set of buildings consisted of large blocks of science, home economics, design and technology laboratories, and administration. This set of buildings featured red face-brick walls which indicated the recent expansion of the school to accommodate more learners.

The school has a history of high performing learners. One of its marks for high performing learners was a technical wing which offered subjects such as technical drawing, electronics, metalwork and woodwork before they were introduced in other schools. The subjects were used to prepare learners who wanted to follow engineering careers at university and other tertiary institutions. Learners who performed exceptionally well at junior secondary school particularly in mathematics and science and wanted to follow engineering careers were admitted in this school. At the time of this study, School A was one of the top performing school in the country and the top in the Southern region in BGCSE examinations. This school was not selected based on its performance in BGCSE examinations; its rating in BGCSE however serves as an indication of the kind of learners who form the population at this school and from which the student sample for this study was drawn.

Teacher B and School B

Teacher B is of European origin. He came to teach in Botswana as an expatriate teacher on contract terms more than thirty years ago. He majored in Biology Education but due to shortage of physics teachers in Botswana, physics became his teaching subject. At the time of this study he had taught physics in different schools in the Southern Region for several years under both the COSC and BGCSE curricula. He participated in organising annual regional science fairs for many years as a physics teacher. He had held the position of head of science department which involved coordinating the implementation of the curriculum at classroom level. He participated in different professional development workshops including those organised by the DMSE-INSET. At the time of this study, he had two years left before he reached official retirement age which also made him one of the most experienced teachers in school science at senior secondary school level. He speaks English as his main language. He also speaks some Setswana which he used to get learner's attention during instruction. Teacher B taught in School B.

School B is situated in a village 20 km off the main road that joins major towns along the eastern part of the country. The village is a center for Local Government administration and Tribal Administration for a sub-district in the southern part of the country. The sub-district is well known for its potential for commercial crop and small stock farming which is generally done at a subsistence level. School B was one of the five new schools built to accommodate more learners at senior secondary school level. Although the school physical plan is probably the best in the country, School B did not have some facilities in place. For instance, the science departments had not been supplied with laboratory equipment. It depended on small contingencies that were secured from extra funds for the school and the annual departmental votes.

The school teaching staff had some experienced mathematics and science teachers, including Teachers B, who could be classified as experts. It also had one of the best School-head from junior secondary schools. To a large extent, the staff served to ensure admission of this new group of learners from junior secondary schools into the senior secondary school curriculum and instructional practices which were established on high performing learners.

The opening of School B, and other new schools, introduced a new group of learners in senior secondary schools whose needs needed adjustment of instructional approaches to support their learning. For instance, it happened that the school was opened for its first group of learners during the course of 2008 school calendar. As a consequence of this late opening, most of its learners had not qualified for admission in the existing Government schools because of their low pass rate in junior certificate examinations. While there was general need to cater for diverse learners in schools (Motswiri et al., 2010), School B therefore had this new group of diverse learners whose needs were different from those in other schools, but had to be catered for. The teachers at this school had to adjust their instructional practices to support learners and Teacher B was one of them.

As already alluded to in Chapter 2 section 2.4, 2009 DMSE-INSET report for instance, indicates that teachers had to make an extra effort to bring the learners' performance to a level that would enable them to access the subject content. For example, in mathematics, the teachers worked with the school administration to organize workshops for junior certificate mathematics teachers in the sub-district to discuss possible gaps between the syllabus prescriptions and issues that the teachers may have experienced when teaching the subject. In science subject, the efforts made were visible in Teacher B observed instructional practices during the DMSE-INSET school visits.

Learner Participants at School A and School B

The participant learners in both schools were those taught by the participant teachers in their normal classes to avoid possible inconveniences the study could have otherwise caused their teaching considering that it was going to cover a sequence of lessons on specific topics. The level selected for the study was Form 5 (Grade 12) and learners at this level were going to sit for their BGCSE examinations at the end of the year. From now onwards, the tone changes from that of planning to that of doing; in other words, the next section till the end is about this study.

5.2. The Actual Study

5.2.1 Gaining Entry to the Field

> *The case's activities are expected to be influenced by context, so contexts need to be studied and described, whether or not evidence of influence is found (Stake, 2006 p.27).*

Negotiation of access was done in steps. First step was to obtain clearance with the University of Witwatersrand Human Research Ethics Committee. This was because part of the University's responsibility is to ensure that research on human participants is safe, ethical, soundly based, and respects the right of individuals. Permission for conducting research was therefore sought from the Human Research Ethics Committee as a University requirement, to make sure that the set ethical standards had been provided for in the study plan. After a review of the application, I was granted clearance to conduct the research project (see appendix 1). This would be a warrant to seek permission from other relevant authorities and potential participants to carry out the study. Since the study would be conducted in Botswana senior secondary schools, the first point of entry to securing local permission was the Department of Planning and Research Services. For completeness, I now describe in detail the process I underwent to obtain the research clearance.

My visit to the Department of Planning and Research Services started early in the morning to ensure that I meet the officers in case they had to attend meetings on that day. When I got to the Ministry of Education Building, the security office at the ground floor was busy. I decided to go to the Department of Secondary Education at 6th floor where a security person directed me to 7th floor. At the 7th floor, I entered the first office, where I was told to go to office number 242. There was no one in the office 242 but the door was left opened. Within a few minutes, the research officer came and asked if I needed help. I introduced myself and I gave her a copy of my application letter which s/he read.

After reading the application letter, the research officer gave me a copy of the application form and a document of guidelines for conducting research in the country such as providing a copy of the research report at the end of the study. I was expected to name the schools where I wanted to carry out the study. It was the beginning of the year when teachers are normally transferred. So, I had to confirm the schools where the Teacher A and Teacher B were teaching to update the information on the application letter if necessary. I was able to locate Teacher B and I decided to use the name of the school near to where I resided for Teacher A. I submitted the documents to the research officer the following morning. S/he checked the documents, told me to take them to their Records office at 2nd floor for registration and to be back for the outcome after ten working days. I took the application to the records office where I met a cheerful young officer who was however not sure whether the documents were for his Department or the Secondary Department. When I insisted that I had been sent to his office by the research officer, he said he would take care of the forms. He gave me his name, which I wrote down and recorded the date and the time.

After ten days, when I went to the research office to check for the outcome of my application for the research permit, I learnt that the outcome of my application had not reached the office; the records office also had no record of the application. I did not have the file where I had written the record officer's name so I had to go there the following day to provide evidence that I had submitted the forms ten days earlier. The record officer was then able to trace the application which he had taken to the Department of Teacher Training and Development where it was then passed to Secondary Department. The application was attended to and I got the copy of the permit the same day (see Appendix 2). According to Department of Planning and Research Services there was no requirement from the Department to seek permission from parents possibly because parents were represented in the school system through Government and parent-teacher association. This allowed me to conduct research in schools through the permission of the school authorities and the participating teachers. With this permit/clearance from the Department, I was able to approach the school principals where Teacher A and Teacher B taught for their permission to use their schools.

5.2.2 Gaining access to the research sites: the Schools

This section provides an outline of my first visits to two senior secondary schools to seek permission from school authorities to conduct the study in the schools, request the participation and gain consent the teachers and learners to participate in this study.

Requesting Permission and Informed Consent at School A

The school reception office had a welcoming person who was ready to help. After I introduced myself, she said the school-head was not in the office and then went into the deputy school-head office for a few seconds and ushered me in the office as she came out.

I had met the deputy school-head before in another school where he worked as a senior teacher and later the deputy school-head while I was a professional development lecturer. I introduced myself as a PhD student and that I had come to seek for permission to conduct my study in their school. I presented application letter and the statement for the informed consent. The deputy school-head was relatively new in the school, so he phoned the physics department to confirm the presence of Teacher A in the department and to introduce me to the senior teacher grade 1 – physics, who also acted on behalf of the head of the department.

After about 30 minutes the senior teacher entered the office. I introduced myself as I did with the deputy. The senior teacher wanted to know how I selected teacher A. I told him I based the selection on a DMSE-INSET study but I was somehow startled by the question. I later learned that the teachers' promotions were a responsibility of the school heads which involves the senior management team of which senior teacher - grade 1s are members. The senior teacher communicated with Teacher A who had gone for lunch by phone. I decided to wait for Teacher A at the bench outside the reception office. I had worked in School A as a physics teacher for about five years and within those years I was a science department coordinator. So, I spent lunch time with non-teaching staff who I worked with at the time. Teacher A arrived more than two hours later.

I briefed Teacher A why I had come to see him. He decided that we should go to the science workroom where there was an air conditioner because it was hot. After a few minutes in the workroom three teachers entered so we moved to a physics preparation room which was equally comfortable even though it did not have an air conditioner. I told him about the research project and that I had sampled him for participation in the project based on the DMSE-INSET lesson observation studies that he had participated in. I then requested him to be a participant. When he agreed to be a participant, I elaborated that the study aimed to explore his practice in a positive way and not to judge it and gave him the informed consent document. He read through the copies of informed consent documents and signed the informed consent forms (see Appendix 3, 4, & 5).

He said he liked what the study intended because that was what he strived for in his teaching. He gave me the timetable for the class which he had selected to be observed teaching. Table 5 shows the dates and times of lessons for the class on which Teacher A would be observed on while teaching.

Table 5: Class A Time-Table

Day 2	*Day 4*	*Day 5*
Period 5&6 (11:20 – 12:40)	*Period 5&6 (11:20 – 12:40)*	*Period 7 (13:45 – 14:25)*
19 Jan (Thur)	*23 Jan (Mon)*	*16 Jan (Mon)*
27 Jan ()	*23 Jan()*	*24 Jan ()*
06 Feb (Mon)	*31 Jan (Tue)*	*01Feb (Wed)*
14 Feb (Tue)	*8 Feb (Wed)*	*9 Feb (Thur)*

After we agreed on the lessons on which he would be observed on, he invited me to observe his lesson that very afternoon to also meet the learners. I did not have the video camera and the audio recorder with me but I took notes. Teacher A greeted the learners and introduced me to the class. He informed the learners about my visit and that I would be with them for a long time. The learners welcomed me. I inquired if there were any learners who were 16 years or below so that I can seek for a special informed consent for them from the teacher and he said their age ranged between were 17 and 18 years old. One learner signed the informed consent form on behalf of the whole class (see Appendix 6). In this way informed consent for Teacher A's learners was obtained.

Requesting Permission and Informed Consent at School B

I had made a phone call to School B to find out whether the school-head was available before starting my journey to seek permission to carry out my study in the school. The receptionist told me that the School-head was attending a staff meeting which had started at 09:00 am. I arrived at School B at around 12:00 noon. I introduced myself to the receptionist who told me the meeting was still on and I waited at the reception.

The school-head walked into his office after 14:00 hrs. I did not want to be the first to see him after his chairing such a long staff meeting, so I let three teachers who had also come to see him, to go into the office before me. When my turn came the school-head was on his way out of the office. I greeted him in Setswana and introduced myself and told him I had come to request for permission to conduct research in his school with Teacher B who I had sampled for the study. He said he didn't have a problem with science people because they do not deal with sensational issues. He however asked me if I was a friend to Teacher B which indicated some reservation about my sample which he later revealed (see last paragraph in this section). I told him that I had sampled him from DMSE-INSET study which I felt did not answer his question. However, he wanted the research permit first before which I could even talk to

Teacher B; this was like in School A where permit was asked for before I could be granted permission. I drove back to where I resided 135 km away from the school.

I had the research permit, I went back to see the school-head. The School-head then introduced me to the Career Guidance Head of Department - and we talked about the sampling for the study. They felt that the sampling should have prioritized on the examination pass rate record of teachers. They gave me an analysis of the 2011 examination results and recommended some of the teachers who they felt produced good results because they were concerned with the school overall Double Science results. Unfortunately, some of the teachers they recommended were not observed in 2009 DMSE-INSET study on which the sample was based. But it was difficult for me to see differences in physics teachers' performance from the examination results for two reasons. Firstly, Double Science class was taught by two other teachers – a Biology teacher and a Chemistry teacher, therefore learners' performance in examinations could not be attributed to only the physics teacher. Secondly, there wasn't enough information to attribute the difference in learners' performance in examinations to the teachers since learners' ability and background knowledge have an effect on their examination pass rate (Clotfelter et al., 2007). The Career Guidance Head of Department who was working in the school during the 2009 DMSE-INSET study commented that things were really difficult for them that year which in a way validated the sample because they showed resilience in that difficult time.

The Career Guidance Head of Department was asked by the school head to introduce me to the Mathematics and Science Head of Department who was to facilitate my meeting with Teacher B.

Meeting with Teacher B

When I met Teacher B, I briefed him about the research project and that I had sampled him for the project based on the DMSE-INSET lesson observation studies. He agreed to be a participant upon which I handed him the participant information sheet which he read, and the informed consent forms which he promptly signed (see Appendix 3, 4, & 5).

Teacher B then gave me the timetable for the class he had chosen for this study. Table 6 reflects the dates of lessons that we agreed would be observed.

Table 6: Class B time-table

Day 3	***Day 6***
Period 1&2 (06:45– 07:55)	*Period 1&2 (06:45– 07:55)*
8 Feb (Wed)	
16 Feb	
20 Feb (Mon)	*23 Feb (Thur)*
28 Feb (Tue)	*01 March (Fri)*
Period 3&4	*Period 3&4*
06 March (Tues)	*14 March (Wed)*
19 March (Mon)	*22 March (thurs)*

The teacher then introduced me to the class and the learners welcomed me. Like in School A, I was able to brief the learners and request their participation. They agreed and one signed the consent form on behalf of the whole class (see Appendix 6).

5.2.3. Selection of the topics on which the participant teachers' practices were explored

The physics topics on which the exemplary teachers' instructional practices were studied were those which the teachers taught at the time the study was conducted. This was in accord with the social constructionist perspective of understanding phenomenon from real life situations with minimal disruptions on the way the phenomena is expressed in day to day activities. Alternative approach would have been to select a topic and request the teachers to teach that topic during the study which might disrupt their plans. This was particularly important because the learners were to sit for their final examinations at the end of that year. Alternatively, the researcher would have selected a topic and then wait for the time the topic was taught according to teachers' plans which would be costly for the researcher to postpone data collection to a time that coincides with the teachers' plans for teaching a selected topic. On the whole, it was assumed that since the teachers were exemplary their practice would offer insights on learner support in any topic.

Teacher B’s practice was studied on thermal physics topic and Teacher A’s practice was studied on waves and light topics. Table 7 provides the syllabus objectives on each topic.

Table 7: Physics syllabus objectives on thermal physics, and waves and light

Topic	**General objectives**
Thermal expansion of matter	Understand the concept of expansion of matter:
General wave Properties	Acquire basic knowledge about wave motion Recognize the difference between transverse and longitudinal waves Use water waves to show reflection and refraction
Light	Demonstrate understanding of reflection of light by plane Demonstrate understanding of refraction of light total internal reflection and refractive index. Understand the action of a thin lens on a beam of light.

5.2.4 Actual Data Collection

This section describes the collection of data through observation and interviews of Teacher A and Teacher B and their learners in schools A and B. As stated in chapter 4 section (4.5.1) observational data was the main form of data for exploring the teacher’s instructional practice. Additional data through interviews were to obtain the participants’ voice with regard to observed interactions. This was in accord with Gumbrium and Holstein (2001) that participants’ voice points the researcher to their “operating standpoint” which is important in substantiating or validating the observations (Fontana & Frey, 2000). First presented is a description of how the observations were conducted.

5.2.4.1 Observations

The initial plan was to observe ten lessons for each teacher. But, for various reasons only seven of Teacher A’s lessons and eight of Teacher B’s lessons were observed. For example, in one of Teacher A’s lessons learners had to write a common regional test and in another lesson the classroom was being painted. Other lessons were missed because the researcher had to travel back to the University in Johannesburg for registration. One of Teacher B’s lessons could not be observed because of timetable changes which resulted in one lesson being missed and other lessons were missed because the researcher had to travel to the University in Johannesburg for presentation. It is noteworthy that the recorded lessons appear sequential regardless of the fact that I missed some lessons because the teachers changed their teaching program when I travelled to Johannesburg and resumed the teaching of new topic content when I came back.

Observation of Teacher A and his learners

Teacher A’s lessons were conducted in two physics laboratories. The two laboratories were part of the old buildings that were painted light green which had not been renovated to accommodate increase in learner enrolment. They had five fixed benches and each bench could comfortably accommodate six learners (see pic. 1). But, the space between the benches was too small for the teacher to move along when checking or supervising learners’ work. They also had a side bench fixed along the other side of the laboratory. The space along the side bench was large enough for learners to conduct and observe demonstrations in small groups.

The two laboratories did not have gas supply and electricity although gas taps and electric sockets could be seen on the benches. The teacher used candles and hot water heated elsewhere for the demonstrations. The equipment for demonstrations of thermal expansion, such as ball and ring apparatus and bimetallic strips, was short. But the teacher designed the activities in a way that enabled learners’ opportunity to use the available apparatus in the best way possible. This gave an impression that Teacher A’s instructional practice had contingencies for providing opportunities for active learner participation in situations where there was shortage in resources.

Pic. 1: Physics laboratory during a lesson in School A

Teacher A’s learners displayed a level of responsibility in their learning during lessons. They came for lessons in small groups at different times as they would be coming from different subject options located in different departments. Those who came before others were observed browsing through their notebooks and hand-outs and talking to their neighbours about their work while waiting for the lesson to start. During lessons, learners were observed asking the teacher questions, discussing among themselves without involving the teacher, and actively participating in activities with minimal directions from the teacher.

Observation of Teacher B and his learners

Teacher B's lessons were conducted in two spacious physics laboratories which could accommodate a large class size of about 50 learners (see pic. 2). The laboratories had ten fixed benches and each bench could accommodate a maximum of five learners. The space between the benches was large enough for learners to conduct hands-on activities in small groups. The laboratories had electricity, water and gas and Teacher B was able to involve learners in standard hands-on activities. Teacher B spent considerable lesson time preparing learners for activities including hands-on activities and closely supervised learners' progress in carrying them out. He also facilitated learner participation through use of worksheet or hand-outs which he developed for the topic. This gave the impression that Teacher B's instructional practice considered learners' competencies in participating effectively in the activities.

Pic. 2: A view of the physics laboratory in School B

Teacher B's learners needed elaborate guidance to participate in instructional activities. The learners had shown signs of low motivation in the first lesson observed which was presented through PowerPoint. The learners appeared less concerned about what the teacher was presenting: some learners rested their heads on the benches; some went out of the classroom supposedly to drink water because it was a hot afternoon; others could be seen yawning despite the teacher's attempt to involve them in the presentation. The teacher told me that the PowerPoint presentation should not take the whole lesson for this particular class. He was using the PowerPoint presentation for the first time and was trying to incorporate it in his lessons. But he had intentionally planned to use PowerPoint presentation for the whole lesson as an introduction to the topic.

In subsequent lessons, the teacher used PowerPoint presentation and other methods of presenting content together with learner activities. The learners appeared motivated. They carried out the activities responsibly according to the teacher's expectations and completed them within the allocated time. They made use of the readily available teacher assistance for carrying out their individual and group work. They were observed submitting their work for marking, on their own accord, during the lesson. At the end of the lesson, they were observed handing-in their worksheets or talking to the teacher about their work, on their way out of the laboratory. They also sought each other's assistance and worked together in groups.

What was common in the observations of Teacher A and Teacher B's lessons was the focus to help learners make sense of the key concepts by actively involving in the instructional activities. What was outstanding in the involvement of learners was the minimum copious note taking by learners.

Learners' general response to video recordings

Teacher A and Teacher B's learners did not appear to worry about the recordings when the camera was focused on the teacher. But when the camera was focused on their individual or group work they welcomed it only when they felt they had accomplished intended objectives and were confident about their actions towards the objectives otherwise the learners reacted negatively to the camera. For example, when the camera shifted to the learners in Teacher A's class, the learners censored their talk: they lowered their voices or stopped talking; they talked to the camera when they felt what they were saying was acceptable; they tended to give good speakers space to talk and supported them morally; emotional speakers tended to withdraw from public discussions, in some instances their background comments were captured but were not used in this study for ethical obligations. In a way, the learners solicited a good representation of their interactions.

Learners in Teacher B's class showed off their work or talked to each other for the camera. But in cases where they were not confident or not sure of what they were doing they would hide their work by covering it with their hands or move it away from the camera. If they were talking, they would turn their faces away from the camera and lower their voices. In such cases I would apologetically move away to assure them that it was alright for them hide their work if they wanted to. In that way I kept a good relationship with the learners.

In sum, observations reflected distinct characteristics of Teacher A and Teacher B's instructional practices in engaging learners in the topic content. Tables 8 & 9 show the dates in which the observations were made.

Lessons that were observed are marked with a line through the dates.

Table 8: Dates on which Teacher A's lessons were observed

Day 2	Day 4	Day 5
Period 5&6 (11:20 – 12:40)	Period 5&6 (11:20 – 12:40)	Period 7 (13:45 – 14:25)
~~19~~ Jan (Thur)	~~23~~ Jan (Mon)	~~16~~ Jan (Mon)
~~27 Jan ()~~	~~23 Jan()~~	~~24 Jan ()~~
06 Feb (Mon)	31 Jan (Tue)	01Feb (Wed)
14 Feb (Tue)	~~8 Feb~~ (Wed)	9 Feb (Thur)

Note: The cancelled dates indicate the dates in which observations were made

Table 9: Dates on which Teacher B's lessons were observed

Day 3	Day 6
Period 1&2 (06:45– 07:55)	**Period 1&2** (06:45– 07:55)
~~8 Feb~~ (Wed)	
~~16Feb~~	
~~20 Feb~~ (Mon)	~~23 Feb~~ (Thur)
28 Feb (Tue)	~~01 March~~ (Fri)
Period 3&4	**Period 3&4**
~~06 March~~ (Tues)	~~14 March~~ (Wed)
~~19 March~~ (Mon)	~~22 March~~ (thurs)

Note: The cancelled dates indicate the dates in which observations were made

5.2.4.2 Interviews

The purpose of interviews, as mentioned, was to obtain the participants' views to validate interpretations of observational data. The initial plan was to conduct pre-lesson and post-lesson semi-structured informal interviews and one formal unstructured interview with the teachers and semi-structured interviews with the learners. However, due to technical problems the unstructured interview with Teacher B and interviews with Teacher B's learners could not be conducted. The semi-structured interviews with Teacher B proved useful in substantiating interpretations of observations. Although both the Teacher B's and his learners' interviews would have provided invaluable information, the learners' participation in the instructional activities and the teachers' after lesson interviews provided information which was used to make inferences.

Interviews with teachers

Semi-structured interviews: The pre-lesson interviews were planned to be conducted on the same day that observations were made due to the long distance between the schools and the place where the researcher resided. The plan for pre-lesson interviews was not successful during the actual data collection. The pre-lesson discussions conducted in School A were not very successful as the teacher would be busy preparing for the lesson. In School B, Teacher B had eight periods which covered the whole-day timetable on the days when the observations were conducted. Initially the lesson was timetabled in the first two periods, there was school assembly before the lesson which ended just before the lesson began and it was not possible to have the interviews. The lesson period was later changed to period three and four which ended before tea break which allowed time for post-lesson interviews. The post-lesson interviews were successfully conducted and were relatively informative as the teachers were ready to share their feelings about their instruction and interactions with the learners.

Unstructured interviews: One formal unstructured teacher interview was arranged with Teacher A and Teacher B during the course of the data collection at their respective schools. To assist the teacher to talk about his practice, a video record of one of his lessons was replayed. For Teacher A video record of lesson 2 was replayed. Teacher A watched the video and talked through it. The interview turned into a narrative where Teacher A was allowed to tell his story with little prompting by the researcher. This helped to get information about teacher A's instructional practice from his perspective. He talked about the learners, their abilities and other characteristics, and how he manages them during lessons. He pointed out some of the learners he had included in the selection of the interview. Teacher A also talked about his teaching, how it was influenced by his experience as a student, and the way it promoted learning skills. The interview took 1 hour.

The formal unstructured interview with Teacher B was not as successful as it was with Teacher A. Although Teacher B had said he was ready for the interview, during the interview it became clear that he was not ready to talk through his practice but wanted to be asked specific questions instead. I got the feeling that the day was not the best for the interview with Teacher B. So we agreed that we should have another interview on the day when I would be interviewing the learners. On the new date however it was announced during assembly that the learners would have a career fair. Teacher B sent a message to inform me that the learners would not be available. I still went to school anyway hoping we could have the teacher interview but the teacher was also not available.

I sent a message to request Teacher B to organise a new date for the interview during the second term which he promised to do. Apparently it was not possible for him to secure time for the interview as I spent three weeks trying to have the interviews arranged during the second term but I failed. Therefore, the analysis of data on Teacher B's interviews was based on post-lesson interviews only.

Interviews with Learners

Two sets of semi-structured group interviews were conducted. The learners in School A had a tight schedule and I felt that I was encroaching on their time. The interviews were to be conducted after supervised study at 15:30. For each interview, a group of ten learners were divided into two groups of five males and five females.

I, the researcher, started the first interview by introducing myself to the ten learners to establish a rapport with them by citing some of my classroom experiences as a school physics teacher and a student. This was intended to make my position as a researcher transparent to them (Shaw, 2010) in order to reduce the possible social distance (Duncombe & Jessop, 2012) or power differential (Eder & Fingerson, 2001) that may have existed between the researcher and learners. I then said,

> Physics is not a very easy subject for most learners. I come to your lessons to find out how you learn physics and the way your lessons help you to learn physics. Some things I am able to see and some things I have to hear from you.

The interview questions were intentionally non-leading (King & Horrocks, 2010) to enable the learners to talk freely about their individual experiences and the researcher to get ideas about the learners' views of their instructional experiences in physics to inform the questions for the second interview which was going to be more focused. I wrote the following interview questions on the chalkboard.

1. How do you find your physics lessons?

2. How do your lessons help you learn physics?

The learners were asked to answer the questions by presenting their answers in a conversation (Fontana & Frey, 2000) to the group and not to the researcher. I said "I want you to answer these questions as if you are talking to your very close friend." I informed them that they can use Setswana if they wanted to and that their conversation was going to be recorded but they should not mind the recorder which was placed near the group. The learners were told to each spend two minutes answering each question.

I touched on the confidentiality of the interview to protect their identity (Ginsberg & Mertens, 2009). I told them that their names would not be recorded or used in the report. I stressed that the information discussed during interviews should not be discussed after the interview with anybody. Later, the learners asked me if they were allowed to discuss the information with their teacher. I told them that they may not discuss the details of the interview with their teacher and I assured them that I too was not going discuss the details of the interview with their teacher. This was important for the protection of the individual learners and their relationship with their teacher, in case they found the teachers' practice not as supportive as they would expect.

I sat away from the group to create space for the learners to talk among themselves but I was able to intervene where there was need. This proved to have helped learners to talk about their learning among other members who are not necessarily their friends and to give each other a chance express him/herself for the second session in accord with what Gaskell (2000) called the "forming stage" (p.47). The forming stage is where the members of the group acquaint themselves to each other and establish a group identity. Although the latter was not a problem with the female learners, male learners had to be reminded to let others express their views without having to give counter statements.

The second interview focused on learners' activities. The video record of the activities from Lesson 2 and Lesson 6 was played back during the interview to enable the learners to reflect on their activities during the second session. The questions were open ended,

- Tell me what was going on here?
- What do you think about this activity?
- How did you find it?"

The learners answered these questions one after the other. They expressed their individual views which showed differences in the way activities helped them learn concept on thermal physics. But they also shared common experiences in their efforts to make sense of the activities by expressing similar experiences or adding to what others had said. Thus, the learners expressed a "shared identity" (Gaskell, 2000 p.46) which provided a basis for conceptualizing their individual views about their instructional experiences. For instance, the learners said they found teacher demonstrations and hands-on practical activities helpful in understanding thermal physics concepts and relating them to their everyday experiences.

I thanked the learners at the end of the interviews. The learners requested that some of the experiences be highlighted in the final report to attract the attention of the relevant authorities and I did not respond to their request.

In school B, attempts to have the interview with the learners failed as mentioned earlier in this section. It is noteworthy that Teacher B had earlier volunteered to release the learners during the second half of his lesson when the learners would be working on their worksheets which I did not accept as I assumed it might not be ethical for two reasons. I had observed how the teacher worked relentlessly to prepare learners for the activities and the learners need for his supervision during the activities and felt it would disadvantage learners of the opportunity the activities created for their learning. I also decided that the data might be affected as the interview was expected to take about one hour which accounts to the whole lesson period but the time available for their activities was about half an hour. The decisions were particularly informed by Miller and Bell (2012) on their advice in gaining access to research participants without compromising on the data to be collected and Sieber (2004) assertion for cultural sensitivity and respect for participants.

The interviews with learners in School B would have provided the learners' voices of the support provided by their teacher through instructional activities. While their voices cannot be adequately represented by other learners, the information obtained from learner interview in School A provided pointers for interpreting their responses in instructional activities with respect to learning physics concepts. The pointers include use of demonstrations, hands-on practical activities and relating physics concepts to everyday activities.

The success of the interviews in school A was mainly due to teacher A's practice of giving learners responsibility. Teacher A gave the learners responsibility of organizing time for the interview on the day which we agreed upon. The teacher arranged the venue for the interviews in the science labs where there was very little noise from outside because the building is enclosed. The laboratory assistant was kind enough to stay after hours until the interviews were over to lock the laboratories. Some learners were also kind enough to start their study group meeting late to make time for the interviews.

Data verification

Data was verified in three stages during data collection, transcription and data analysis. Data in the form of informal discussions and field notes were verified during data collection by getting the teacher confirm or expand on the points noted. Part of the data on video recordings was verified during interviews, when the teachers and learners (in School A) were shown some of the lessons to comment on. For the learners' interviews, the lesson recordings in which they were carrying hands-on activities were selected for their comments. The questions used in interviews were semi-structured which allowed them to talk generally about their instructional experiences. The researcher summarized the learners' talk at the end of the interview sessions. The information obtained from the interviews was used to verify observational data. For example, in interviews with learners in School A, the learners pointed out how the demonstrations on convection of liquid and convection of gas in lesson 5 helped them understand discussion on Brownian motion in lesson 3.

Data capturing techniques: some challenges

A camcorder was used to capture the lesson activities for observational data. A single consumer-grade type of camcorder with a rating HD 1920 x 1080 and 40X optical zoom which was able to record much of the activities in the detail which could not be recorded solely through the researcher's observations. But, the complexity of the instructional interactions required the camcorder to shift between teacher and learner activities, following the teacher as he moved about the class and learners during class discussions and dialogues. This introduced discontinuities into the video recording even though the shifting was reduced in an effort to maintain good quality recordings (Derry, 2007; Derry et al., 2010)

The video recordings were mainly done from the back of the class to capture the teacher's activities which mainly took place from the front of the class. Although the learners' non-verbal responses during the teachers' presentations could not be captured in that position, it reduced interference with the learners' activities. The possible interference was indicated by learners' reactions when the camera shifted to them during the activities. The reactions included the learners censoring their talk by: lowering their voices or keeping silent; talking to the camera when they felt they were saying the things they felt were acceptable; some learners withdrawing from public discussions possibly because they were emotional speakers as described in section 5.2.4.1.

The laboratory setting posed an additional challenge on the video recordings of learner activities. The video recordings were restricted to activities near the end of the benches where they could be done without much physical interference. The space between the fixed laboratory benches was not enough to allow for video recordings of learner activities without getting too close for the learners' comfort. I noted that each time the camera was too close the learners tended to stop working to allow for recordings at both schools. With the camcorder used in the study, activities conducted at the other end of the benches attached to the walls of the laboratories could not be captured. The use of two or more camcorders would have prevented or reduced the shifting and thus reduce discontinuities. It would also enable recording of areas that could not be reached with a single camcorder.

Another challenge that I faced when doing video and audio recordings was of the battery running flat and the memory card getting used up in the course of the recordings. These were big inconveniences for data collection of on-going experiences which could not be recovered. This taught me that acquaintance with the use of gadgets that are new to the researcher is important for data collection such as checking the memory card space and battery level and knowing how long they can work. Switching the recorder on and off may seem a simple thing to pay much attention to but on two occasions I thought I switched the audio recorder on only to realize at the end of an interview that nothing was recorded. What saved me was that I made notes of the points discussed although this did not does not provide as rich information as would have been recorded by audio and video recorders.

The digital voice recorder with a built-in memory and 75 mV headphone output was used for recording interviews and quality of recordings was good. But the audibility of the voices was low which made transcribing difficult. It was difficult to use recordings of background voices or some main voices which could have contributed to the understanding of the instructional activities. The sound was not loud enough to be clearly reproduced on Windows Media Audio. For instance, the background voices which could be heard but not clearly due to low volume could not be heard at all on the computer Windows Media Audio. Although the instrument was the best that could be obtained for the study, I learned that it is essential to use high quality sound capturing instruments for instructional activities if possible.

The time to exit the field came when there were no longer any new experiences observed with respect to instructional interactions. In addition, the general impression of what characterize the teacher's practice had been formed to start in-depth analysis. The data collected included video and audio recordings. The participating teachers and learners were thanked for their participation and Heads of the schools were thanked for allowing the research study to be conducted in their schools.

5.3 Data Processing

Data processing is important for organising data and preparing it for analysis (Denscombe, 2010). The data in this study was organised into lesson sequences which were dated and had topic title. The camcorder had recorded the lesson logs automatically. The lesson sequence helped in an overall view of the structure of instruction on the topic and providing access to the details of each lesson which organised data for preliminary analysis.

Transcribing audio and audio-video recordings

The recordings of each lesson were viewed and listened to several times to figure out the main activities and how they were conducted. The lesson recordings were then successively transcribed to re-represent the events recorded in the video to enable exploration of underlying support in the activities (Denscombe, 2010). The transcriptions were done by the researcher which helped to revise impression developed about the lesson activities. The transcription was used to integrate field notes and lesson content logs on what occurred in particular lessons. Through this process, transcripts would become the main data source for the exploration.

But the transcription process was very difficult and time consuming because the recording was inaudible particularly for class discussions. The transcriptions of the recordings were done without ear-phones which required a private place that could only be secured after working hours.

Editing transcripts

The editing of the transcripts was done to make the scripts easier to understand and to enable theoretical judgments about the activities recorded to be made (Derry, 2007).This was done with the awareness that the transcripts did not capture the full complexity of all verbal and non-verbal events and also that they could be open to other people's interpretations. The minimum editing done on learners' discussions was to cut off some of the comments that were not useful for the study particularly for ethical reasons. The major editing involved typographic errors and inaccuracies on teachers' talk which included pauses that came within and between sentences. The editing involved identifying beginning and end of sentences and the placement of commas within sentences. The learners used Setswana when they communicated with each other and in some instances the teachers also used some Setswana which had to be interpreted. Teacher A had a tendency of using metaphors whose interpretation had to be confirmed with other Setswana speaking colleagues. The researcher is competent in Setswana language and was able to interpret the Setswana language, where it was used, to English language.

The processing of data was followed by analysis which is described next.

5.4 Data Analysis Approach

This section describes the preliminary data analysis which was used to describe data and the inductive data analysis.

Inductive analysis

The analysis began with reading each lesson transcript and associated field notes several times (Gall, Gall & Borg, 2007) to understand the contents of the instructional activities, how they were organized and sequenced. This led to preliminary analysis.

Preliminary analysis

The purpose of preliminary analysis was to make sense of the data on instructional activities and to focus on relevant themes in accord with Adler and Adler (1994) that observations start off being unstructured and then become focused. The process involved a description of the main activities in each lesson using Tiberghein and Buty (2007) analytical scheme for "*studying science teaching practices in relation to learning"*. The data on each lesson was constructed as taught knowledge. The taught knowledge formed the researcher's understanding of the knowledge mediated through the activities. The constructions of the taught knowledge were directed by the research questions. The taught knowledge was then divided into units or constructs which had a thematic coherence to the taught knowledge, and a defined structure with an introduction and a conclusion as shown in Table 10.

Table 10: An example of preliminary analysis of learner support from Teacher A Lesson 7

Theme: Writing a scientific report on absorption of heat radiation experiment

Scenery (taught knowledge)	Elements of new knowledge (units of taught knowledge)	Elements of prior knowledge	Knowledge processing
Class discussion of experiments on absorption and emission of heat radiation. The discussion started with three learners presenting experimental results on absorption of radiation carried out in the previous lesson which was not recorded (I had gone to register for the2012 academic year). It was then followed by a discussion of the emission experiment which was being conducted by a group of learners.	*The set-up of the apparatus *Writing experimental procedure *Recording measurements of temperature against time in a table.	Observation of the experiment on absorption of heat radiation by a black and silver painted conical flasks.	Reporting skills

The analysis involved reading the sections from the transcripts related to each unit many times to explore instances of support (Merriam, 2009). The reading was guided by the following questions, "why is this activity done in this way?" "what does this tell me about the way the learner is supported?" or "what does this tell me about this particular practice?"

These questions were modifications of three research questions. The answers to the questions led to development of constructs.

For example support constructs developed from the taught knowledge described in Table 10 is:

Teacher A gave learners opportunity to

- present the results in table from their own knowledge
- write the experimental procedure from their own knowledge

Teacher A then corrected the

- table of results learners had presented from the own knowledge
- experimental procedure learners had written from their own knowledge

The constructs were then linked to each other to form a picture or patterns (Gall, Gall & Borg, 2007). The formations of patterns included the researcher's informed sense about the way the constructs were related to each other in portraying the teacher's practice relative to the research questions. For example the pattern or general construct developed from the above constructs is:

- Teacher B built new knowledge on learners' knowledge

This was substantiated by evidence from interview data that confirmed or provided alternative explanation to the researchers' constructions (Merriam, 2009; Stake, 2006).

5.5 Chapter Summary

This chapter has described the sampling process, data collection, data processing and data analysis approaches employed in this study. The description showed how intensity, stratified, maximum variation sampling were applied in selecting teachers and learners, and the subject topic. The description of data collection included the process of seeking permission, the way the observation and interviews conducted and the exit from the field. The processing and analysis of data were also described. The findings were presented in two parts the descriptions of the lessons and the outcome of the analysis in Chapters 6 for Teacher A's and 7 for Teacher B's instructional practice. The presentation of the analysis in two chapters was important bring out the situatedness of the instructional practices of the two teachers in terms of the schools, learners and school physics topics.

CHAPTER 6

Analysis of Teacher A Instructional practice

6.1 Introduction

The purpose of this chapter is to provide an analysis of Teacher A's instructional practice. The profile of Teacher A has been provided in Section 5.1.3. The analysis is based on the data obtained through observation of seven lessons and interviews of the teacher and learners (how these were conducted have been described in section 5.4). The approaches to the analysis have been provided in section 5.4. This chapter presents reviews of the instances of teacher support, kinds of teacher support and how learners responded to the Teacher A's instructional activities.

The reporting is however presented with respect to the three main research questions:

1. What characterises exemplary teachers' instructional practices in school physics?
2. How does the exemplary teacher's instructional practice support learners in accessing school physics content?
3. Why does the exemplary teachers' instructional practice in school physics support learners in accessing school physics content?

It consists of descriptions of the instructional activities followed by analyses of the activities. The descriptions are of the researcher's selection of the main instructional activities and strategies used by Teacher A in supporting learner access and understanding thermal physics content.

Throughout the reporting in this chapter, the symbols T, L, Ls for transcript excerpts represent Teacher A, learner, or learners respectively. Where there was a sustained discussion, learners are identified by number like L2 for each lesson. The same label L, L1 or L2 is used generally to apply to learners even though learners in one lesson may not necessarily have been the same learners in another lesson. For instance, L1 in lesson 2 and L1 in lesson 7 is not necessarily the same learner in lesson 2 and lesson 7. It is noteworthy that the introduction is numbered 6.1 to highlight this close link to the rest of the chapter.

6.2 Description of instructional activities

As already mentioned in Section 5.2.4, Teacher A was observed while teaching thermal physics. All lessons were conducted in two physics laboratories except lesson 1 which was conducted in a classroom. The physics laboratories had five fixed benches (see Pic. 3.).

Pic. 3: Physics laboratory in School A

The physics laboratories had no gas and no electricity although facilities for their use were installed and there was shortage of equipment for demonstrations such as bimetallic strips, and ball and ring apparatus. There was a laboratory assistant who helped the teacher in collecting equipment for demonstrations.

This section provides a description of Teacher A's instructional activities on the topic of thermal physics over seven lessons. In the lessons observed the teacher's instructional activities covered content on thermal expansion, and methods of thermal transfer specifically conduction, convection and radiation. The study was conducted on the specific topic because it was being taught by the teacher at the time of data collection. The general syllabus objectives on the topic are provided in section 5.2.4. The descriptions are now presented here according to the lessons observed on the topics.

6.2.1 Lesson 1

School: A **Teacher**: A **Lesson Topic**: Introduction to thermal physics

The objective of the lesson was to provide learners with skills for accessing the topic content from lesson activities, texts and other learning material. The main activity of this lesson included a review of the template by the teacher with the support of the learners and an exercise for guiding learners on how to use the template.

Instructional Activities: The teacher introduced the lesson by drawing a template on the chalkboard. He drew a table on the chalkboard and wrote down the heading for the first column. Then learners called out the subsequent headings for him to write which was an indication that Teacher A had discussed the template with the learners before. It also signalled involvement of learners in teacher's presentations. The structure of the template is shown in Table 11.

Table 11: Reading template

Idea/Concept/ Phenomenon/occurrence	Definition	Explanation	Demonstration/ experiment	Consequences/ Results/precautions	effects	Application/use

The teacher then explained the structure of the template. In his words the teacher said,

> In physics as we teach and when you read your textbooks there is normally an idea, concept or occurrence which you should learn about, the idea is defined or explained, there is normally a kind of demonstration or experiment to confirm the concept which would have results or consequences. There may be some effects and applications of the concepts as well.

The teacher then involved the learners in an activity to show how they could use the template. He distributed a laboratory thermometers and a question paper that had a number of questions on it. He then asked the learners to look in the question paper for a question on laboratory thermometer and name concepts that are applied in the design of laboratory thermometer. The answers given by learners were expansion and conduction as reflected in the excerpt that follows.

The teacher distributes some question papers to learners

T: Read any question on thermometers, I don't mind which question you are reading. Don't draw anything.

The teacher then distributes thermometers to groups of learners and some thermometers were left.

L. May I have a thermometer, Sir.

T. Which thermometer, a short one or a long one?

L. A short one.

T There are two types of short thermometers which one do you want?

L. *Pauses*

T *gives the learner a thermometer*

T What ideas or concepts of heat are used in thermometers?

Ls Conduction, expansion

The teacher then wrote the word conduction in the template under column titled idea/concept/phenomenon. He then told learners that they needed to understand and show their understanding of concepts by defining, explaining, demonstrating. He called one student to write the definition and explanation of conduction. The learner wrote the definition as follows.

> L: Conduction is the flow of heat from one part of the object to another. The heated molecules vibrate faster and transfer the heat by colliding with cold molecules.

Other learners commented on what the learner wrote in hashed voices and in some instances disagreed amongst themselves. The teacher kept out of the learners' discussion until he concluded the lesson as the follows.

> T. The definition given is good enough for now. What you need to concentrate on is the ideas used in thermometers e.g. conduction, expansion. Then you should read around the ideas. For instance, you may have to bear in mind that there is conduction in liquid, solids and gases. And, consider which state we are interested in for thermometers.

Summary of observed practice

This section, has described how Teacher A provided learners with a practical approach for accessing information on concepts in thermal physics. It has shown a review of a template which gave an overview of the topic content and highlighted important aspects of the content to guide learners in reading and accessing content from textbooks and lesson activities. It has also described an approach used by Teacher A to guide learners on how to access topic content. The main point in the approach was that learners did not have to start by reading a textbook, but could start with a question, a diagram or a piece of familiar laboratory equipment to identify concepts and/or applications of concepts and then search for the concept definition, and other information according to the template.

6.2.2 Lesson 2

School: A **Teacher**: A **Lesson Topic**: Thermal expansion

The objective of this lesson was to introduce the learners to consequences of thermal expansion and precautions against unwanted expansion. The main activities included activation of learners' prior knowledge on thermal expansion and teacher's presentation on consequences of thermal expansion. The activation of learners' prior knowledge involved engaging them in typical standard demonstration for thermal expansion of gases, liquids and solids as detailed in the course textbook by Duncan and Kenneth (2001). This was followed by the teacher's presentation on consequences of thermal expansion and ways of preventing unwanted expansion. The lesson was concluded with a reading assignment on application of thermal expansion for learners.

Instructional activities: When I walked into the laboratory, most learners were still coming into the laboratory. Some learners were already in the laboratory heating apparatus in five work stations along the laboratory side-bench. The learners who were coming in put their bags on the middle benches and proceeded to the side benches where others were already carrying out demonstrations. As the groups at work stations became big, other learners sat at the middle benches browsing through their books and hand-outs while waiting for their chance at the work stations.

Initially, the work stations were too crowded to record what learners were doing or saying. I also felt that getting a close view of what was going on at the workstations would hamper their movement and observations. Therefore, the recordings were done when the groups became small enough for audio-video recording. I had met the learners for the first time the day before and I did not make audio-video recordings and I was conscious that they were uncomfortable with my presence and more so of being audio-video recorded. As a consequence of the ethical considerations, the recordings show demonstrations and associated discussions that were already in progress. Therefore, analysis was based on demonstrations on expansion of gas, expansion of solids (bimetallic strip and ball-and-ring). The demonstration on expansion of liquid has not been included in the analysis there was no record of learner discussion on it.

Demonstration on the expansion of gases

The gas expansion demonstration was carried out using an empty conical flask with a capillary tube fitted through a rubber stopper and water plug along the capillary tube. There was also a beaker containing hot water for heating the conical flask and electric kettle containing hot water presumably for refilling the beaker placed near the conical flask. The learners took the conical flask, placed it in the beaker of hot water and observed a bubble coming out of the capillary tube. (See pic. 4)

Pic. 4: learners observing a demonstration on expansion of air

In their discussion, the learners asked their peers what the demonstration showed, whether it showed gas or liquid expansion for which they came to a conclusion that it was gas expansion. The following is excerpt about the learners' demonstration that they apparently found a bit challenging to carry out.

L2: *E dira ka bonako* (The changes are very fast)…(inaudible)…watch…
L1: *Puts the flask in the beaker of hot water. The plug of water in the capillary tube is blown out.*
L3: Haa….
L4: laughs...
L5: (*Standing behind the group)Nna ke batla go bona jaanong* (I want my chance to see the demonstration).
L1: (*Takes the flask out of the hot water and puts it on the bench*).
L5: Expansion in liquid. *Dira gape* (Do it again).
L1: *Puts the flask in the beaker of hot water. There are no observable changes. She then takes the bottle and puts it in the beaker of hot water, again there are no observable changes.*
L3: *Graps the bottle from learner L1 and says* tlaa ke go tsenyetse (let me put the water plug in for you). He disappears from the camera with the bottle.
L5: *Goo mo ke eng* (is this), expansion in… gas?
L6: Gas. (in agreement)
L5: feels the outside of the beaker with her hand as she leaves for another workstation.

In the excerpt immediately above, the learners tried to repeat the demonstration but the water plug had been used up. One of the learners volunteered to refill the water plug but the learner left the demonstration to other stations.

Demonstration on expansion of Liquids

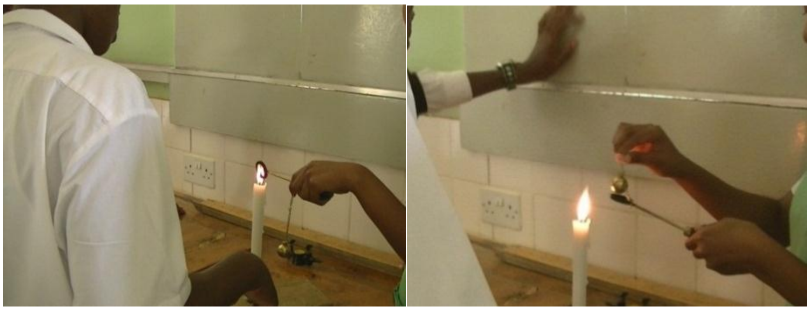
The liquid expansion demonstration was carried out using a round-bottomed flask containing coloured water with a rubber stopper that had a capillary tube fitted (see Pic. 5). The flask was heated using a burning candle stuck at the end of a long plank. The plank made it easy to move the candle away from the flask when necessary by mere sliding or pulling of the plank.

The learners observed the water level moving up the capillary tube as the flask was heated but no record of the learner discussion were recorded. However, the learners removed burning candle stick away from the flask when the liquid level was high and about to flow out.

Pic 5: A learner observing a demonstration on expansion of liquid

The following is an excerpt about the learners' demonstration apparently found a bit challenging to carry out.

Demonstration of solid expansion using ball and ring apparatus



Pic. 6: Learners conducting a ball and ring demonstration

In the ball and ring demonstration, the learners were observed heating the ring (see pic.6). No observations were made before the heating commenced. After some time, the learners tried to pass the ball through the ring but the ball still could not pass through so they continued to heat the ring. The activity showed the learners' knowledge of how to carry out the demonstration which is evident in their discussion. The following excerpt provides part of the discussion that occurred during the demonstration.

L7 heats the ring and other group members are watching.

L8: It has expanded enough.

L9: Try, try and fit it (*fitting the ball into the ring*).

L10 *tries to pass the ball through ring. The ball fits into the ring it doesn't pass through.*

L9: mm; mm just heat it.

L7 *continues to heat the ring*.

L8: So what forces are in this?

L10: Forces?

L8: what is it called…(*Ga tweng*…?) the forms of energy… (inaudible)...*points at the ring that is being heated*.

L7 cautions L8 against pointing his finger too close to the flame.

L7: L8, is your finger not going to fall off? (*monwana wa gago ga o kake wa tswa)*

L8: fall off? (… *wa tswa*?)….Laughing

L8 and L10 continue their discussion in low voices conscious of the camera and perhaps not willing to have their discussion recorded.

L10: *inaudible*…chemical and stuff...

L8: mmm….Just listen to me, listen to me. This thing (*pointing at the ring)*, how does this thing (ring), gain heat? (*e tsaya jang heat?)*

L10: It gains heat by conduction (*E tsaya heat ka* conduction).

L8: By conduction. Then, it expands isn't it?(*a kere*).

L10: … inaudible… I could not understand when you start talking about forces *(ke utlwa o bua ka diforce*).

The discussion shows the learners' knowledge of the procedure and their awareness to conduct the demonstration safely so that they don't get burned.

Demonstration of solid using bimetallic strip

The demonstration on the bimetallic strip involved learners heating the bimetallic strip and discussing the changes which they observed. The following excerpt shows part of the learners' discussion.

The discussion in progress

L11: …. Did you get it?

L12: Say it again. What did you say?

L11: This side (Holding the bimetallic strip in one hand, indicates the inner part of the bend bimetallic strip with the other hand) is a conductor of heat hence…(incomplete). This side (indicates the outer part of the bend bimetallic strip) is a better conductor. The metal on this side (outer part of the bent bimetallic strip) is a better conductor of heat hence it expands first which gets this one to bend.

L12: It makes the other one to bend.

L13: (Takes the bimetallic strip from L1 and holds it in his hand asking the following question) 'How many metals are here?''.

L12: Two.

L11: Two. One is a better conductor and the other one is not.

L12: That’s why it bent.

L11: That’s why it bent.

L13: looks closely at the edge of the bimetallic strip and moves his finger across the edge (*possibly to check if indeed there are two metals*). Which metals are here?

L11: I just know that there are two metals. I don’t know which ones exactly.

In the discussions, learners explained the bending of the bimetallic strip to others and determined the structure of the bimetallic strip. The observation made and the questions posed by the learners indicated their instructional experience with regard to the bimetallic strip.

Exercise on hot air balloon: The demonstrations were followed by a pencil and paper question based on the movement of hot air balloon. The teacher instructed the learners to write their answers individually and to submit them after five minutes which was based on the mark allocation for the questions. He said,

> Write down the answer there as you would in an exam. Let’s see how many marks you get. That would be how many marks? Five marks. Ok. Take five minutes, ee… (yes…) just five minutes then you give me that paper, right.

While the exercise assessed learners’ understanding of the application of thermal expansion of gas in hot air balloon, teacher also used it to prepare learners for answering examination questions such as using the mark allocation for estimating the time they should spend on the question.

Teacher presentation: The teacher then made a presentation on consequences of expansion of overhead electric and telephone cables, railways and bridges in a story-like discussion using diagrams of the structures. During the presentation, the bending of the bimetallic strip was explained as being caused by different expansion rates of the metal strips. In relation to the ball-and-ring demonstration, the teacher said the length of the ring expands more than the ball when they were both heated. He had written the words thermostat, fitting metal tyres and riveting as subtitles, which fall under application of expansion, but did not discuss them in detail. Instead he told the learners to read about them as part of their assignment. At the end of the lesson the teacher handed out a copy of chapter summaries that covered the syllabus topics.

Summary of observed practice

The section has captured the teacher’s strategies to activate learners’ prior knowledge through standard demonstrations preceding his presentation on consequences of thermal expansion. It has described details of learners’ discussions as they conducted the demonstrations which provided evidence of the potential success of the strategy. It has also shown teacher's use of question on hot air balloon to assess learners' individual understanding of thermal expansion of gases and how he made use of the exercise to prepare learners on time management when answering questions. The teacher's presentation on consequences of thermal expansion was concluded with a reading assignment on application thermal expansion which drew from the demonstrations conducted by the learners at the beginning of the lesson.

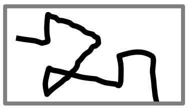
6.2.3 Lesson 3

School: A **Teacher**: A **Lesson Topic**: Thermal expansion in terms of kinetic theory

The objective of this lesson was to help learners understand thermal expansion of gases in terms of molecular motion. The activity involved a question and answer interaction based on Brownian motion experiment and Boyles' law which were covered the previous year. The learners' responses to questions revealed incomplete understanding of Brownian motion experiment which the teacher addressed by simplifying concepts and using learners' knowledge. The question and answer activity was followed by teacher presentation of convectional air currents and cyclones as effects of thermal expansion.

Instructional Activities: Lesson 3 began with two questions from a past examination paper on Brownian motion experiment which was covered the previous year. The first question was "describe the movement of the smoke particles as shown on the diagram". The diagram referred to was similar to the one shown in pic.7.

Pic. 7: Diagram showing movement of the smoke particles



The question was used to remind learners about the movement of smoke particles which was described as random, haphazard and zigzag. Then the teacher asked learners to name the described movement of smoke particles. The answer given by one of the learners was Brownian motion as reflected in excerpt below.

T. By the way there is one name which is used to describe that kind of motion. Have you heard about it?

No response from learners

So these people have not been reading?

L. It is called Brownian motion.

T. It is called Brownian motion. The random movement of particles or molecules in gases or in liquids, this movement is observable in both gases as well as in liquids.

The second question was "what conclusion about the movement of air particles can be drawn from the observation of the smoke particles". The question was used to relate the movement of smoke particles to that of air particles. The teacher simplified and rephrased the question to help learners to answer it as reflected in the next excerpt.

T. Now, what conclusion about air molecules can be drawn from this observation of smoke particles: Why is smoke been used in that experiment or observation or investigation? Why choose smoke?

L. whispers an answer (inaudible).

T. They can't hear you at the back.

L. May be it's because smoke has colour.

T. Because it is visible it can be seen. Right. So (that) it is visible to enable us to make an observation. Air ordinarily as we know air, air is colourless. In that experiment, we have a mixture. So we get a smoke-air mixture, we see smoke but we don't see air but they are interacting.

T. The movement of smoke particles will tell us what about the air particles? That is what the question is saying. Any suggestion? What conclusion about air particles would you get out of this? Two marks are ok. May be you might need to give two conclusions also instead of only one conclusion because the question says conclusions or deductions. What does that show?

L. I think as the particles have energy, they use energy which makes the particles hit each other as they move around.

T. To be very brilliant and direct so that we don't go round and round with our answer. What do we learn from the fact that smoke particles change direction like that? You want to try?

L. I think it's because smoke particles are less dense than air particles.

T. You think we can talk about density? The answer is here. (*Pointing at the notes he wrote on the chalk board: smoke – visible; air-invisible colourless*)

T. This is one thing to be sure of, the particles are in motion, 'kinetic'. Therefore those particles must be moving. …That is number one thing from that experiment, number two?

L. The air particles are invisible.

T. Do you think that is a strong point?

L. We can't see them, *a kere* (isn't it).

T. Therefore you can conclude that they are invisible. May be, may be. The first conclusion, definitely the movement of smoke particles show that also the air particles are in motion. Second question?

However, the learners' responses showed that they were not able to interpret the movement of smoke particles in terms of the movement of air particles despite the teacher's attempts to direct their thinking until at the gave them the answer.

The second part of the lesson was a discussion based on a past examination paper on Boyles' law. The question described a metal container with a tightly closed lid placed in hot sunlight and asked what would happen to air pressure inside the can. The teacher led the discussion as follows.

T. A can containing only air, this time no smoke, has a lid tightly screwed-on and is left in s-t-r-o-n-g sunlight. State what happens to the pressure of the can when it gets hot. Stating simply suggest what? I think you can give us an answer here.

L The pressure Increases.

T. Rises.

Ls. Mm (yes)

T. All you want to do is simply state one word, state. It rises or simply increases.

The teacher then extended the question to elicit learners' understanding as shown in the following excerpt.

T. Is there a question asking why? You might be asked why does the pressure increase? … That means we are talking of gas in confinement or say confined gas. 'Confined' means not free to move, not free to escape. If it is enclosed what explanation would you offer for the increase in pressure?

L1 If we have to explain, the particles will gain more energy and as a result they'll move rapidly randomly and they will hit the container strongly because they have more kinetic energy. So the pressure will have to increase.

T. Why do the particles gain more kinetic energy?

L1. This container is in hot sunlight. May be when the heat is applied to this container the air particles will gain kinetic energy from the heat of the sunlight.

The teacher repeated the question to direct learners' thinking towards thermal expansion. He asked what the effect of the increased kinetic energy on the container was and used the learner's answer to relate the increase in kinetic energy to volume and thermal expansion which created an opportunity for the teacher's presentation on the convection currents in air. The following excerpt shows the discussion.

T. Ok. Directly we are saying the temperature has gone up (*draws a line pointing upwards from the point'(a) temperature' on the board and writes the word 'rises' at the end of line)*. There's been a temperature rise. If the temperature of the gas (*Points at the word GASES written on the chalk board)* rises then there is a gain in kinetic energy (and writes below the word rises 'increase in K.E.').

They move faster and so when these (particles) gain kinetic energy (*pointing at the sentence 'increase in K.E.' written the board*), what happens, then, to the container and why? We say the pressure increases, why does the pressure increase? Kinetic energy – what is the effect of the increased kinetic energy?

L2. I think as the kinetic energy is supplied, the gas …. supposed to move fast.

T. There's only first prize we are getting now (learners laugh softly). *The teacher slightly scratches his head*. Right. What would you say?

L3. I would say the increase in kinetic energy would lead to increase in volume. So if there is no increase in volume inside the container, the pressure will increase.

T. Ok, I like that. She is talking of expansion, there is increase in volume. But, the gas is confined. There is no way out. So the only way is to force pressure against the walls of the container. Right.

Ls Yes

T. What causes the pressure against the wall by gas molecules to increase?

L3. I think rise in temperature causes increase in kinetic energy of the particles. Therefore, it causes collisions between the wall and … (teacher intervene).

T. Right. We are talking about c-o-l-l-i-s-i-o-n-s between the gas particles and the wall of the container. If the gas must exert pressure, you want to imagine gas molecules striking a wall.

The discussion eventually led to a presentation by the teacher on thermal expansion of free mass of air, its decrease in density and the resultant convectional currents. The teacher then introduced the terms low pressure and high pressure regions, depression, isobars and cyclone which were explained more in lesson 4.

Summary of observed practice

This section has shown how the teacher activated and supported learners' prior knowledge of kinetic theory to help learners in understanding thermal expansion of air in terms of the theory. It has shown how the teacher took the learners through a question on Brownian motion which required them to describe the motion of air particles and a question on closed metal can containing air that was kept in intense sunlight which required learners to describe effect of heat on air particles. The strategy provided opportunity for learners to review their knowledge of problematic concepts in Brownian motion and to establish their understanding of thermal expansion which promoted integration and continuity of the concepts across the topics. The strategy showed how Teacher A supported learners in reviewing their prior knowledge.

6.2.4 Lesson 4

School: A **Teacher**: A **Lesson Topic**: Weather

The lesson was to describe formation of cyclones as a consequence of thermal expansion of air. The activities involved a review of definitions of isobars, low and high pressure regions, and cyclones from the lesson 3. It also involved a description of subsequent movement of air between the two pressure regions, and introduction to reading simple weather charts adapted from past examination questions. The lesson was concluded with a summary of a cyclone. The activity revealed the teacher's skill of using high cognitive level questions in developing instructional content where the course texts did not provide adequate content.

Instructional Activities:

The teacher introduced the lesson as follows.

T. We're to carry on with the story of yesterday about the issue of the weather at the highs and lows (pressure regions). We want to think of the issue now where we want to define, say a DEPRESSION (written in capital letters on the board) in terms of weather. You want to be able to tell what an isobar means (writes ISOBAR on the board).

The learners were able to define the terms through question and answer method.

T. We want to define a depression? Depression…. What do we say?

L1. Low pressure region

T. Let's agree it's a 'low pressure region' (writes it on the board). Sometimes it is called what?

L2. Cyclone

T. Depression, you can also refer to it as a cyclone. These are the marking points. And, isobars are what?

L3. lines linking places of equal pressure.

T. A line on a weather chart or map joining or linking places or points of equal pressure (writes on the chalk board).

T. It is important to remember that air moves into a depression but doesn't move in simply in a straight line. What do we say?

Ls. Spiral

T. The motion is spiral…

The teacher introduced the weather chart with emphasis on air movement. He used non-technical words such as spiral, swirling, whirling and cyclic (though without verbal explanation of the meaning of each word) to describe the kind of air movement. He also introduced the direction using specific science words, clockwise and anticlockwise. To illustrate the meaning of the clockwise and anticlockwise the teacher used hand movements. The hand movement showed the kind of air movement and the possible direction it may have. Then he drew curved arrows on the chalk board. The arrows clearly showed the direction that the air movement may take. The teacher also related the directions clockwise and anticlockwise to the way the terms were used under the topic of moments of force which had been covered the previous year in Form 4 (grade 11).

He introduced learners to the interpretation of weather charts by a using a question from a past exam paper through which he developed steps to follow guided by the following questions.

- Are you in southern or northern hemisphere?
- What does the chart show? A cyclone or the opposite of a cyclone?
- Look at numbers, the figures of pressure, on the inside and outside isobars, Are the figures high or low at the inner isobar? Write H where the figures of pressure are high and L where they are low.
- If low (L) at the inner isobar then it's a cyclone, a depression.
- Which arrow shows the direction of the wind? Learners have to interpret the direction of the arrows

The teacher presented a second question on the weather chart. That required learners to work out the direction of air movement at a particular point labelled X. The isobars did not have figures of pressure instead there were labels "H" and "L" representing high and low pressure written at two different locations. The teacher and learners engaged in a discussion in which they worked out the correct option as reflected in the following excerpt.

T. Ok. The answer (multiple options) is saying: to the north, would it be going to the north in that sense? Would you agree with the northern direction?

Ls. No

T. Would you agree with the direction west?

Ls. No

T. Would you agree with the direction south?

Ls. Yes (*They start to discuss amongst themselves)*

L. I am agreeing with the northern direction.

T. You mean it can't go to the east?

L. Yes, Sir.

T. If it goes to the north first it will be in a straight line. If it goes to the west or east it will go in a straight line. If it goes to the north it will also be in a straight line. If it goes to the north it will be like this (*draws a straight arrow from X* *upwards)*. If it goes to the east it will be like that (*draws a straight arrow from X towards eastern direction).* Now which is the most likely (direction)?

Pause.

We would want to think that if we take it like this one here it might have to pass over here, from a region which is generally high to low (*his hand moves from the area labelled high towards the area labelled low indicating an eastern direction)*. Isn't it?

Ls. Yes.

The teacher then drew another weather chart that had areas where the isobars were spaced apart and where they were close to each other. The chart was used to discuss isobar patterns that showed differences in wind speed. The teacher pointed out that in areas where the isobars were close to each other the wind speed was high and low where the isobars were far apart. He also talked about the possible destructions of the high speed wind. Anticyclones were identified from cyclones by the values of pressure on the isobars. The innermost isobar had the highest pressure value and the values decreased on the outer isobars.

The lesson was concluded with a summary of the ideas discussed where the teacher asked learners to state the differences between a cyclone and an anticyclone.

T. State major differences between a cyclone and an anticyclone. Obviously, we can make a summary according to pressure, wind direction, and general weather. Draw a table as follows.

	Cyclone	Anticyclone
Pressure		
Wind direction		
General weather condition		

The learners copied the table into their notebooks and started to complete it. The teacher then talked about the general weather conditions in a cyclone and anticyclone and filled in the row on general weather conditions. The learners copied what the teacher wrote into their notebooks. Later the teacher completed the rows for pressure and wind direction for learners to check against their own summaries.

Summary of observed practice

The description shows how the teacher led a discussion on reading weather charts. It shows how he used questions in developing instructional content. It also depicts his way of not giving the learners detailed notes which for this lesson he instead gave a summary.

6.2.5 Lesson 5

School: A **Teacher**: A

Lesson Topic: Physical properties and Temperature/Vacuum Flask and heat flow

The objective of this lesson was to introduce the electric effect of temperature change and methods of heat flow. The activity involved teacher presentation of a simple structure of the thermocouple thermometer. The focus of the presentation was on the cold and hot junctions of the thermocouple and their electric effect. The activity for the second part of the lesson started with a question and answer session on the purpose of the thermos flask which led to a discussion on ways of reducing heat flow by conduction, convection. The activity on conduction involved a discussion on poor and good conductors of heat and a demonstration.

Instructional activities: The presentation on thermocouple thermometer was based on a written question from past exams that had a diagram showing the structure of the thermocouple. The question was "explain why the cold junction should be kept in ice throughout the investigation". The teacher drew a diagram of the structure of the thermocouple thermometer and described it. He pointed out that the two metal wires were coupled or joined at two points referred to as cold and hot junctions. The cold junction was kept in melting ice and the hot junction was kept in hot water. He asked the learners what the purpose of keeping the cold junction in ice was and learners responded as reflected in the excerpt.

T. Explain why the cold junction should be kept in ice.

L. To keep the temperature constant.

T. To keep which temperature constant?

T. We are looking at a cold junction at **0^oC**. It must therefore be a **fixed point**. It is a fixed point for that thermometer. Let's refer to it as a reference point. It is important to have a reference point on that thermometer.

The teacher said that cold junction was reference point for the thermometer. The teacher explained how the temperature is indicated by the potential difference created between the cold and the hot junctions which causes the current to flow and that the amount of current which is measured by a sensitive ammeter indicates the temperature change from 0^oC. The teacher concluded the presentation by stating that the thermocouple thermometer can measure very high and very low temperatures.

The discussion on thermocouple thermometer was followed by a discussion based on a question on how the thermos flask reduced heat loss or gain. The teacher drew a labelled diagram of the thermos flask on the chalkboard. The discussion began with a question which required learners to state how the thermos flask reduced heat loss by conduction, convection and radiation. The response from one of the learners was that there was a vacuum in the structure of the thermos flask. The teacher elaborated on the learners' response by stating that the major idea about the vacuum space is that there were no particles for conduction to occur as reflected in the following excerpt.

L. There is a vacuum.

T. Ok. Vacuum, the major idea is there are no particles therefore no conduction. No particles means no conduction. Anything else, (pause) is that all you can say about conduction?

If you have observed this one here which is the lid or stopper, you got here a support and another support at the base (labelling the parts on the diagram). Can you qualify those (stopper and support)?

L. I think the stopper is made of plastic so it cannot conduct heat.

T. Stopper cannot conduct heat because it is made of plastic. Plastic generally falls under what group of materials?

L. Insulators

The excerpt also shows how the teacher directed learners' attention to the thermos flask stopper and supports to help them think of other ways by which the thermos flask reduced heat loss by conduction. The learners were then able to state that the materials *could not* conduct heat and identified them as insulators. This led to the discussion on materials that are good and poor conductors of heat. The teacher pointed out that materials which are poor conductors do not stop but reduces heat loss. He said,

T. The idea is to be careful how we use our words. We are talking of reducing heat loss by conduction or reducing heat gain by conduction... Heat loss cannot be prevented. … If you put hot tea here and leave it for several days I am sure after several days it will get cold. If you put cold drink there, ice cold, after several days it will warm up. The idea is we have heat loss or heat gain which is slow.

The discussion on the stopper led to the next question on how the thermos flask reduced heat loss by convection. The learners' response was that the stopper did not allow heat loss by convection because it kept air inside the flask from escaping. As reflected in the following excerpt.

T. what happens there (indicating a space under the subtitle convection)? Any contributions?

L. I think the stopper contains the convectional current inside the flask from escaping. No air escapes.

T. No air escapes through the lid, stopper.

L. yes sir.

T. So you want to say convection is confined inside.

The teacher clarified the learners' response stating that convection currents are confined inside the container.

To conclude the discussion on the thermos flask, the teacher talked about the way the thermos flask lost heat by conduction through the glass wall and how after being conducted to the outer walls of the flask the heat can be lost to the surrounding by conduction, convection and radiation. It is noteworthy that in concluding the lesson, the teacher drew a table having the template headings introduced in lesson 1 and wrote conduction, convection and radiation under the column for concepts and said "I would then want to look and find out what those mean one by one: conduction, convection and radiation." The teacher continued his presentation as follows.

T. ...we said we wanted to consider consequences. We thought we might also want to do application. Was there anything else? (Learners responded, "No') So if you have done that already let's add in case you forgot something. We perhaps want to think of, the need…for particles (written on board), point number one. Did you write that? Heat requires a material to flow by conduction, need for particles, or need for some material. You cannot have conduction without particles. So, that's why we were saying conduction cannot take place (in vacuum)… is for that reason. Then, you want to think of these materials.

Conduction was described in terms of the need for particles without going into the details of how particles conduct heat. He pointed out the need for particles as the reason for saying conduction cannot take place in vacuum. But, in materials, conduction cannot be stopped; it can only be minimised. On materials, he said conduction occurs mainly in solids, very little in liquids with mercury as an exception because it is a metal, and negligible in gas.

T. Remember that conduction will mostly occur in solids. There will be very little conduction in liquids except mercury, which is a metal. This one is an important exception. Mercury is a liquid. It will conduct heat and electricity because it is a metal. Therefore, don't expect much of conduction in liquids generally and very little or none in gases.

He then talked about solids that are good and poor conductors giving metals as good conductors. He also pointed out that there are metals which are better conductors than others as follows.

> Even with metals there are metals which conduct heat better than others... and we might want to perhaps show that we have some transfer of heat.

This led to two typical demonstrations on conduction using candle wax stuck along a metal rod with source of heat at one end of the rod. There was a cardboard shield along the metal rods, between the heat source and candle wax, which the teacher said was meant to reduce the effect of radiation and convection.

> T. The trick is perhaps to put it behind a shield and you heat this end and watch what happens then. Why put this cardboard here? Perhaps some people might say "But sir the heat went from this end to that side by radiation". So, this cover might shield off possibilities of radiation. Some people might say that heat went there by convection well this shield might disturb also convection. So, principally we are investigating conduction.

The demonstration apparatus was set at the side benches and the learners were given opportunity to observe the changes. The results on the two demonstrations showed that candle wax in one set up melted before and faster than in the other set up. The lesson came to an end while learners were standing around the demonstration set ups to observe the changes which involved melting of the candle wax stuck on the metal rods.

Summary of observed practice

This lesson was an introduction to the methods of heat flow with learners' knowledge activated through a question on thermos flask. The learners were given opportunity to answer the question from their knowledge which they probably gained through independent reading. Introducing methods of heat flow through a question on thermos flask was strategic as a common item in homes particularly in towns and therefore familiar for most learners to make sense of the discussions. The demonstration on conduction signalled the teacher's move towards detailed instruction on methods of heat flow. The activities show the teacher's way of sequencing topic content which varies with the syllabus and textbooks where applications of concepts such as the thermos flask would be discussed after activities on the relevant concepts. In the same sense, the discussion on thermocouple which was restricted to the temperatures at the junction might have been to reserve details on the electromotive force created for the electricity topic. The lesson also reflected Teacher A's attention on learners' language needs and possible misconception on heat flow.

6.2.6 Lesson 6

School: A **Teacher**: A **Lesson Topic**: Heat transfer by Convection

The objective of this lesson was to explain heat flow by convection. The activity entailed demonstrations of convection in gases and liquids using convection apparatus which afforded learners opportunity to observe concrete movement of water and air in convection currents an opportunity to repeat some of the demonstrations. The teacher explained the movement in terms of thermal expansion of matter at the molecular level and changes in density.

Instructional Activities:

At the beginning of this lesson, the teacher distributed a hand-out which had diagrams of apparatus commonly used across physics topics including the convection apparatus he was to use in the lesson; he told learners to use the hand out as a study guide. The objective for the lesson according to the teacher was for learners to observe demonstrations on convection. The teacher conducted demonstrations on convection currents as shown in Pic. 8.

Pic. 8: Teacher A demonstrating convection currents in liquid

The learners sat around the demonstration sets which were arranged at one of the fixed benches. This allowed them to all observe the changes as they listened to the teacher which was the purpose of the activity noted in his introduction when he said:

> T. I am not expecting you to do a lot of writing but rather I am looking forward to you doing a lot of observation. The apparatus here is generally called a convection apparatus for demonstration of convection in liquids.

The teacher pointed to specific observations that learners should make. For instance, he told learners to observe the direction in which the coloured water moved and to think of why it moved in the particular direction. He said "Why is it moving this way and not that way (using hand movement to indicate the directions)?"

But, the teacher had to manage the learners when demonstrating the convection in air because the apparatus was too small for all learners to see what was happening. Learners repositioned themselves so that they can see but some learners obstructed others. The teacher then shifted the attention of the learners away from the small double chimney apparatus to convection apparatus for liquid.

T. You see the whole liquid has become coloured.

Then the teacher burnt the piece of paper and put off the flame to produce smoke. He then gave it to one learner to hold it above one chimney. The other chimney had a burning candle below it. At the end of the demonstration the teacher gave learners opportunity to do the demonstrations themselves. This allowed learners who did not see the movement of the smoke to repeat the demonstration. Pic. 9 shows some learners conducting the demonstrations.

Pic. 9: Learners repeating demonstrations on convection.

The teacher elaborated on the changes shown in the demonstrations by pointing out the direction of movement of the liquid and gas as reflected in the following excerpt.

T. So what we are saying is we are looking at cyclic pattern. You can get a diagram like that. Do you have a diagram on that chart which is like this one (convection apparatus for liquids)?

Ls. Yes sir

T. You may want to do the same (demonstrations). I chose that basin so that people can see from a distance. Right. We may want to show the same with …what?

Ls ...with air

T. A smouldering paper. Ok.

The teacher used the same word ‘cyclic’ he used in section 6.2.4 to describe movement of air in a cyclone which links the ideas discussed in the two lessons. He then explained the observed convection currents in terms of kinetic theory as follows.

> T. The air is heated there, it gets warm, it expands, loses density or becomes less dense and the mass tends to go up or rise. The cooler air which is more dense descends and gets warmed then rises. Again we find that there is a cycle that takes place called convection.

The teacher took the opportunity to explain expansion from a point of possible learners’ misunderstanding that particles expand or increase in size instead of moving apart. He said,

> T. Particles do not expand when they are heated. Small as they are individual particles do not expand. Expansion in liquid and gases is explained by kinetic theory: The particles gain kinetic energy, the distance between the particles increases, and the particles get further apart. That means the liquid therefore increase in … (*learners respond ‘volume’*). The particles occupy a bigger volume which means the density therefore decreases.

This had the potential to refine learners understanding that in expansion, the increase in volume is caused by particles moving apart and not increasing in volume.

Summary of observed practice

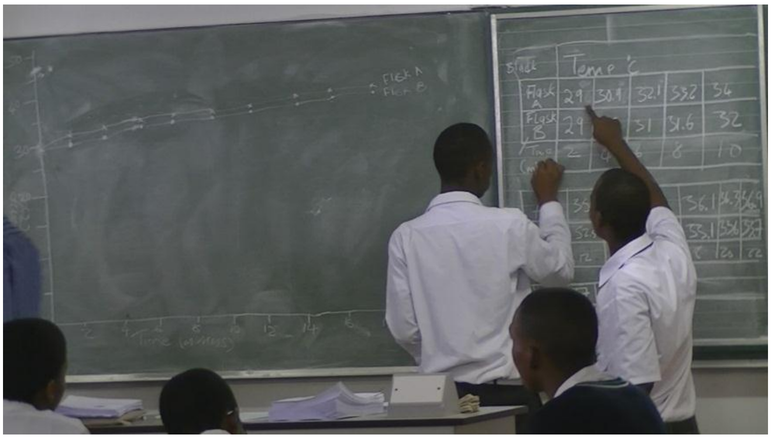
The description has shown how the teacher supported learners in explaining convection currents in terms of kinetic theory. While convection currents are explained in terms particles moving apart and thus occupying more space and becoming less dense, it is not common to specifically relate the movement to kinetic theory which Teacher A did. This further confirms his strategy to integrate and link concepts across topics. It also shows how the teacher addressed learners’ possible misconception to support their understanding of convection currents. He selectively explained the use of smoke in the demonstrations and not the use of potassium permanganate which indicates the teacher’s awareness of learners’ difficulties with and support in viewing air as a substance. The teacher also took the opportunity to explain expansion of particles using possible learner misunderstanding that particles increase in size to support their understanding. The section has also shown how the teacher managed the demonstrations for the large group of learners by having them seated and leaving the apparatus for them to repeat the demonstrations.

6.2.7 Lesson 7

School: A **Teacher**: A **Lesson Topic**: Emission and absorption experiment

The objective of this lesson was to enable learners to develop experimental skills involved in carrying out absorption and emission of heat radiation experiments. The activities involved learners reporting on the absorption of heat experiment carried in out in the previous lesson which was not observed. The then teacher built-on and refined the learners' report according to the scientific method of carrying out the demonstrations.

Instructional Activities: The instructional activities for this lesson began with three learners presenting a report of an experiment on absorption of heat radiation by black and silver coloured surfaces which they carried out in the previous lesson. The learners started their presentation by drawing a graph on the plane board. They drew the **y** and **x** axes free hand, and estimated the scale divisions, plotted the points and joined them. Commenting on the learners' work, the teacher suggested that they should present the table of results on the board and explain how they got the results. The three learners came together at the teacher's bench and had a short discussion and then one learner continued with the plotting of the graph, the other drew a table of results and the third learner explained how they got the results. Pic. 10 shows the learners presenting their work to class.

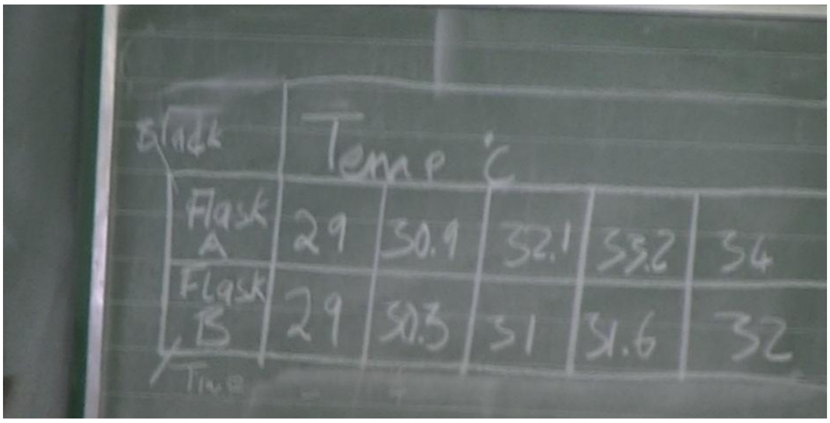


Pic. 10: Learners reporting on the absorption experiment

The learners' presentation of the experimental procedure was based on the teacher's advice that in their report the learners should explain how they got the results they were using to plot the graph.

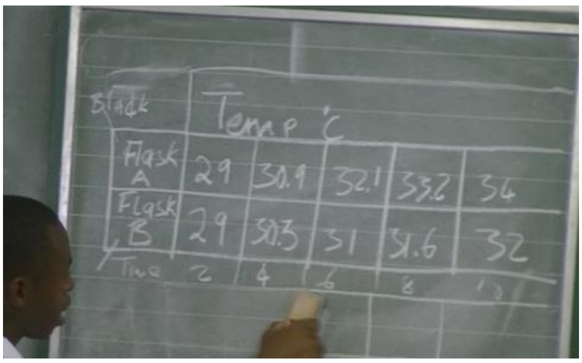
L. We made sure we are starting from the same bridge (temperature). The starting point here was 29°C. By the time we started the experiment both thermometers showed the temperature of 29°C. We recorded the temperature of the two thermometers every 2 minutes so that at the end of the day we can draw up a conclusion, may be, that black flask was on top.

The learner who was presenting the table of results recorded temperature readings in a table with two rows one labelled flask A and the other flask B, and the values of temperature with the heading that indicated the unit of measurement as in the following table.



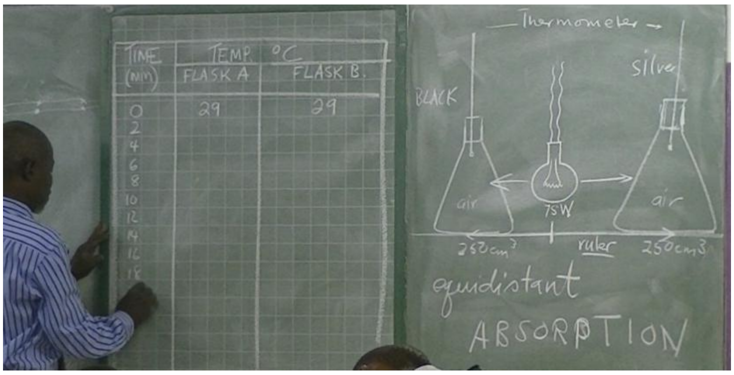
Pic. 11: Learners' record of temperature readings with no time intervals

The learner explained the table of results as follows "This one (flask B) is silver and shiny and this one is black (flask A)". Other learners advised the member who presented the results to add a third row in which to record the time interval for each set of readings (see pic. 11). The member roughly added a third row and labelled it time and asked the other learners whether that was what they meant. When the learners said yes, he then drew a proper column and put in the times in intervals of 2 starting from 2 minutes instead of 0 as shown in pic. 12. However, there was no objection or correction on the starting time.



Pic. 12: Learner adding a row of time interval against temperature

The teacher built on the learners' report. On the experimental procedure, the teacher commented that the learners' presentation was not adequately detailed. He then drew a diagram shown in Pic. 13.



Pic. 13: Teacher presenting on experimental report

He explained what the diagram showed as captured in the following excerpt.

T. We are saying, we had two flasks, where we had a rubber stopper and a thermometer. Each flask had air. Assuming the flasks were of equal volume, 250 ml. We had a lamp, 75 W 12V electric lamp placed in the middle. It was necessary to pay attention to certain issues. The idea of flasks being equidistant from the lamp: It was necessary to use a ruler to measure the distance. We said the reason was to ascertain what?

L1. So that they receive the same amount of heat

T. So that they receive the same amount of heat or say, heat falls on their surfaces at the same rate or you could be saying, to have a fair comparison so that the element of distance was not involved in affecting our results.

The teacher also corrected the table of results. He stated that the table can be horizontal similar to the one drawn by the learners or vertical. He then drew the vertical version of table and included the headings as shown in pic. 13 saying,

T. The temperature column means everything under that heading is temperature. Time: at the start of events time was zero. Remember that.

The teacher then invited a group of five learners from the back bench to carry out the experiment on the emission of heat by black and silver painted flasks. Before the learners started carrying out the experiment the teacher required the rest of the learners to provide some information to be considered in carrying out the experiment. The learners' responses included having the hot water in the two flasks at same temperature at the start of the experiment and have the same volume. They also said the flasks should be closed with rubber stoppers, for which they used the term *air tight*.

L2 We have to make sure these two containers are airtight.

T. Eh?

L2 We have to make sure these two stoppers are airtight.

T. …the stoppers are airtight. In general, yes.

L3 We got to make sure the containers have the same temperature, in warm glass… inaudible

T. You wanted to say…

L3 …stoppers are airtight.

T. You wanted to say… stoppers are airtight (writes)…I don't know why you are saying that, may be you have got reasons. You are saying …To start at

The teacher then told learners to give reasons for the steps they gave. The learners said that the stoppers would reduce heat loss by convection and the same volume and temperature of water would help in making conclusions based on fair comparison.

L2. The flasks or stoppers airtight, I think to, since we are investigating radiation…to avoid heat loss through convection.

T. Oh yes! (Ehe)…you want to minimise convection. That's L4's suggestion. Make sure that there is no air there entering…to minimise heat loss by convection… to minimise convection (*writes*). Any other contribution?

In this activity, the teacher dealt with key steps and the reasons for the steps in setting up the emission experiment. In this way the steps and the reasons were highlighted as equally important in the development of experimental skills. It also showed how they complemented each other in making sense of the process for the learners and the teacher. For instance, when L2 suggested that the flasks should be airtight the teacher said *I don't know why you are saying that, may be you have got reasons* and he wrote the point on the board. When the reason was given the teacher said, *Oh yes! (Ehe)…you want to minimise convection,* a sign that he understood then.

L4 and L5 were engaged in a dialogue but their voices are inaudible. Later L5's voice became audible. The teacher gave learners opportunity to share their discussion about the experiment with the class.

T. L5 has got a question. What about the temperature of the surrounding, that's what she is asking. Can you clarify your question…explain further, temperature of the surrounding?

L4 and L5 continued their dialogue but their voices were inaudible again. Later, L4's voice became audible.

T. L4, so you are helping her?

L4. I was trying to help her, that, we should consider the temperature of the surrounding at the end of the experiment since we are using the apparatus that have temperature higher than that of the surrounding.

L5. What I mean is that the temperature of the surroundings has an effect on the amount of heat lost. Let's say (A kere) for example, may be its too cold in here, and those things (the flask containing hot water), they're hotter than the temperature of the surrounding. It's going to have an effect. As compared to, let's say, when they're of the same temperature.

Instead of insisting that L5 clarifies her question, the teacher gave L4 opportunity to present his case so that L5 could get a chance to talk. Indeed, L5 was able to clarify her point. However, the discussion continued not only among the two but also among other class members. The teacher gave them opportunity again to share their views with the class as follows.

T. …We got to be back on track, we don't know what you are talking about.

L4. Sir, she was talking about the temperature of the surrounding if it has an effect on the experiment. And, what I am saying is that it does not have an effect since we are having the two flasks are under the same atmos..

L6 … surrounding.

L4 … under the same temperature of the surrounding

Ls. Ooh… (*an expression of understanding*)

T. L7

L7. Sir, I think the temperature of the surrounding matters because … if it's cold outside it means the flasks are going to lose heat faster. The temperature of the surrounding matters because it determines the amount of heat which is being lost or emitted to the surrounding.

L5 Looking at the point that Sir said earlier on in the lesson, he said, that (gore), if I have the same temperature and she has the same temperature and we get in contact it means that (gore) there won't be any energy loss, I mean (ke raya) heat loss, heat loss, yah.

L8 There won't be heat transfer.

L5. Yah, transfer, I agree with you (A kere).

This excerpt shows how the learners were able to use their prior knowledge in substantiating their points. For instance, L5 gives an example of how the teacher said in an earlier lesson about heat transfer which was probably under the topic energy according to L5's argument. It also how learners worked as a team by contributing points and helping refine arguments.

Summary of observed practice

The description shows how the teacher activated learners' knowledge and structured instructional activities based on what the learners were able to do. It also shows how he promoted learner-led class discussions which provide learners opportunity to argue in a supervised environment. The learners were able to present their views and to contribute to and refine their peers' arguments. The arguments had potential for creating a positive learning environment where learners were challenged to present and support their arguments to the rest of the class.

6.3 Analysis of Teacher A's instructional practices

This section presents the analyses of Teacher A's instructional activities based on the transcripts of the seven lessons. In some instances video recordings were used to clarify the information on the transcripts. The analysis shows how Teacher A provided opportunities that empower learners to access content on the topic of thermal physics. As Teacher A's instructional practices included activities which activated learners' prior knowledge, built-on learners' knowledge in a meaningful way, developed a sense of confidence among learners and created opportunities for learners to express their knowledge through discussions; these are now discussed in detail.

6.3.1 Teacher A created an environment of reading physics textbooks

Teacher A's instructional practice was organised around learners' independent reading of physics textbooks. Textbooks happened to be main instructional text material for BGCSE physics curriculum, if not the only one. However, the textbooks are based on foreign context which can be a challenge for Batswana learners (Mokibelo, 2010). The teacher promoted learners' reading of textbooks in thermal physics topic by not giving detailed notes, by assigning sections of the topic for learners to read and giving learners tasks on sections of the topic that were not yet covered in instructional activities. The teacher provided learners with a template to guide their reading and note-taking. These strategies created a zone of proximal development for learners in which they grappled with their reading skills and attitudes.

The following sub-sections provide an analysis of the strategies the teacher employed to promote reading of physics textbooks among his learners.

6.3.1.1 Template to guide learners' reading of textbooks

The template presented in lesson 1 (section 6.2.1) was structured around the concepts that constitute the topic such as concept definitions, explanations and concept applications and consequences. Using conduction as an example the teacher showed learners how they could start their reading with a question, a diagram or a piece of familiar laboratory equipment to identify concepts. After identifying a concept, learners could then search for the concept definition, explanations and other information highlighted in the template. Used in that way, the template could focus learners' reading by helping them select information which they require bearing in mind that experiences in the textbooks are set on foreign context (Baiyelo, 2002).

The template could help them by reducing the amount of text they have to interact with and thus creating space for making sense of the text with regard to the selected areas - the concepts, their meanings, and applications. At the same time, the template unified the selected areas into a meaningful whole as expressed in the teacher's comment that when learners read their textbooks there is normally an idea which is defined, and confirmed through a demonstration or an experiment (see section 6.2.1).

The template also provided a basic guide for extended reading. For instance, teacher told the learners that when reading about conduction they would also need to consider the concept as it applies in solids, liquids and gases and note any differences. Thus, the teacher presented the template as a basic guide for learners to expand their reading in accordance with the topic content.

Thus, through the template Teacher A provided guidance for learners' reading of physics text on thermal physics by providing the structure of the topic content and focusing the textbook reading on that structure.

6.3.1.2 No detailed notes for learners to copy

The teacher made textbooks the main text material on thermal physics content for learners by not giving them detailed notes. In all the observed instructional activities, the teacher presentations were detailed with respect to the content and supported learners as reflected in the description of the seven lessons and in other sections of this analysis such as sections 6.3.3 and 6.3.4. But, what the teacher wrote down during instructional activities were point notes (lessons 2.3.6) and summaries (lessons 2, 4, 5). He gave learners reading assignments for reference. For instance, in a post-lesson conversation he said the following.

> T. I have given them these (hand-outs) to go and read. Plus they also have their textbook to read. This one I copied it from one good textbook which is the earlier textbook they were using here. But now they are very few of them left. I don't remember the author. It's bluish/purplish. Then I want them to compliment/supplement with their own textbook which also has something good, a kere? (isn't it?) But if they add this they get a complete picture.

In the interview, when prompted to comment on the kind of notes he wrote on the board for learners the teacher said "Most of them will become good readers." The teacher's encouragement of textbook reading resulted in learners asking questions during instruction (see section 6.2.7) which was confirmed by the teacher's statement during an interview that:

> T. They can do extra reading. *They bring questions which you don't expect*. They even have more knowledge than us, some of them. Some of them they go and search for information.

The frequency of questions posed by learners during instructional activities is high as noted by one learner during interviews in following excerpt.

> L. The learners also are very cooperative. You never find a lesson ending without two or three questions on the topic that we are assigned to read. You'll find that the learners are the ones who are going to answer that same question. Teacher A would then clarify on the answer and gives us all the details about it.

The excerpt also indicates that the learners are the ones who answer the questions and the teacher input is to clarify or provide feedback on the learners' answers. The degree to which learners consider their reading of physics supports the teacher's implication that the learners read their textbooks as reflected in the following excerpt.

> L. Physics is an interesting and challenging subject. *E batla gore o tsoga, o bo o ikanya buka e o e filweng ke tichara. O tshwanetse o itse gore* (learner's words in Setswana) *it's an everyday thing to learn*. It requires one to depend on the book the teacher gave her/him. One should know that it's (reading) a daily exercise.

The excerpt also indicates learners' positive attitude towards the teacher's practice of giving point notes and encouraging them to read their textbooks. In fact, one learner notes the advantage of being given point notes as creating time for activities that would prepare them to perform well for their examinations as shown in the following excerpt.

> L. In physics lessons we don't write notes. So we don't spend a lot of time writing notes. We use the time we would spend writing notes to go over test papers, we carry out experiments, and demonstrations. So that when we get to examination time we would be sharp, sharp.

By not giving detailed notes, Teacher A created a learning environment in which learners took active role in instructional interactions by assuming responsibility for independent reading of physics textbook, and valuing demonstrations and experiments as methods of instruction which can lead to their successful achievement in examinations.

6.3.1.3 Teacher assigned sections of instructional content for learners to read

The teacher intentionally left sections of instructional content out of his presentations for learners to read. For instance, in lesson 2 he presented on consequences of thermal expansion and precautions when building bridges and walls, laying overhead cables and railways. He then assigned learners to read about applications of thermal expansion for which he gave a list including rivets, shrink fitting, unscrewing tight bolts, nuts, or bottle caps, and thermostat. He also guided learners' understanding of the application of thermal expansion by talking about relative expansion rates of different metals as was observed in bimetallic strip demonstration as an example. In the interviews the learners expressed the need for them to participate in their learning by putting more effort than just taking class-work as the only source of information.

L9. *... ga gona sepe se eleng gore se tla motlhofo. Ga o tla mo physics, o bo tsaya se techara a serutang heela, o kwala test kana class exercise, ga go ka ke ga go berekela (learner's words in Setswana). You have to apply yourself a bit.* ...nothing comes easy. If you come to physics lessons to take what the teacher presents as the only information, writing tests and doing class exercises, that won't work for you. You have to put some effort.

L6. *O a bona ga o tla o ntse yalo mo claseng tsa Teacher A, goo o ka jewa (learner's words in Setswana).* You see, if you come for Teacher A's lessons like that, obviously you are bound to fail

The learners comments about putting more effort in their learning and not relying wholly on what the teacher provided during instructional interactions indicated a positive response towards their reading assignments.

6.3.1.4 Teacher gave learners tasks on content which had not been covered

The teacher promoted reading by giving learners opportunities to use the information which had not been discussed in instructional activities. In section 6.2.5, the teacher introduced methods of heat transfer with a question on how a thermos flask reduced heat loss by conduction which learners attempted by stating that the thermos flask had a vacuum space. That kind of answer could come from a learner who clearly had good knowledge about a thermos flask in physics and one way through which such information could have been gained is through reading. In line with the teacher's practice of giving learners opportunities to use their knowledge, the learners' comments suggested the possibility that they did some work individually to prepare for their physics lessons as reflected in the following excerpt

L. Physics, we need to practice it every day, not like preparing for lessons. One should practice it every day like in mathematics.

Teacher A encouraged learners to develop an attitude of reading physics textbooks continually by asking them content on what they have not covered in instructional interactions with the teacher.

6.3.1.5 Learners took responsibility for their learning

By encouraging reading of textbooks, Teacher A's practice influenced learners to search for information (see section 6.3.1). For instance, a learner's comment in the following excerpt, from an interview, reflects his search for information.

> L. I found that *the textbook we are given is lacking some information that I found in another textbook*. Actually, I happened to get hold of the textbook from a friend in another school and I got to understand it much better.

As reflected in the following excerpt, the reading of textbook shifted learners' focus from the teacher as a source of information, to an agent for understanding what has been read.

> L. *Ga gongwe, se ke se bonang ga gongwe ga ke bala ke le nosi, ke kgona go bala mme gone ke sa utlwe gore gona go lo ga go buiwa ka ga eng. Ke itse go na gore go buiwa ka expansion mme gore ga tweng ke sa utlwe. Mme ga ke tsena ko claseng techara ga a tlhalosa expansion, nyaa ke gona jaanong ke simolola go utlwa*. (Learner's words in Setswana)
>
> Sometimes when I read on my own, *I am able to read without understanding* the details about an idea. I would get the general idea like expansion but not able to get the details about it. *When the teacher explains expansion in class, I would then understand what I read*.

Although learners found reading their textbooks necessary, they did not find it easy as indicated in the follows section.

> L. When I think of reading…. It's difficult.
> R. How do you cope?
> L. I depend on group work, experiments, discussion and revising notes and test papers.

6.3.1.6 Teacher A expressed confidence in the learners' reading of textbooks

During instructional activities he referred to information that had not been discussed in lessons as though it had been discussed. For instance, in Section 6.2.5 at the beginning of a discussion about conduction as a method of heat transfer, the teacher said "Remember that conduction will mostly occur in solids. There will be very little conduction in liquids except mercury, which is a metal." In this statement, the teacher's use of the word "Remember" expresses confidence that the learners know or were going to read about the idea that conduction varies in different materials. If learners read in advance of the lesson, then their reading efforts must have been reinforced by the teacher's utterance and if they had not read in advance their role of getting that information on conduction was reaffirmed.

In the interviews the learners generally showed an awareness of their role in learning of physics through reading and other ways of studying. This is explicit in one of the learners' comments that they work as team with their teacher; this was in the words,

> L. Teacher A makes it (physics) easy because his teaching is not too student-centred or teacher-centred. We all do the work as a team.

Teacher A's instructional strategies that promoted an attitude of textbook reading were more likely to increase learners' conceptual understanding than when they copied teachers' notes. In this way, Teacher A's instructional practice created an environment of textbook reading which was found exemplary in supporting learners access thermal physics content.

6.3.2 Open-ended instructional activities to activate learners' prior knowledge

Learners' prior knowledge is an essential aspect of cognitive process which enables them to make sense of new experiences within the zone of proximal development (Vygotsky, 1978). One of exemplary ways in which Teacher A activated learners' prior knowledge was use of open-ended demonstrations.

In lesson 2 (section 6.2.2), learners carried out the demonstrations without teacher's formal introduction, guidance or instruction sheet. The absence of guidelines made the demonstrations open-ended for learners to express what they knew in relation to the demonstrations. The practical nature of the demonstrations provided learners with a range of process skills to express their knowledge. The following sections provide an analysis of the learners' discussions as carried out during the "ball and ring" the "bimetallic strip" and "expansion of gas" demonstrations to show the kind of knowledge activated in the activities.

6.3.2.1 Learners demonstrated their knowledge of the apparatus

In the bimetallic strip demonstration, learners talked about the structure of the bimetallic strip. L13 determined the structure of the bimetallic strip and made observations to confirm their knowledge. He looked and felt the edges of the bimetallic strip and asked how many metals formed it; the conversation is reproduced in following excerpt.

> L13 (Takes the bimetallic strip from L1 and holds it in his hand asking the following question) How many metals are here?
> L12 Two
> L13. (*looks closely at the edge of the bimetallic strip and moves his finger across the edge possibly to check if indeed there are two metals*). Which metals are here?
> L11. I just know that there are two metals. I don't know which ones exactly.

In the excerpt, L13's questions 'How many metals are here?' and 'Which metals are here?' and L11's response to the questions indicated their knowledge of the bimetallic strip as an apparatus consisting of more than one strip of metal. It also indicated the learners' prior instructional experience with regard to the bimetallic strip demonstration.

Based on this observation, it is significant that learners using the ball and ring experiment did not attempt to use the name of the apparatus but referred to the apparatus as *it*. Even though there was an attempt to explain expansion of the ring at the molecular level, it is noteworthy that no attempt was made to explain the expansion of the ring in terms of the observable changes in diameter or volume. Such differences may need further studies to explore the differences and the extent to which they are related to the teachers' instructional practices within BGCSE physics.

6.3.2.2 Learners demonstrated procedural knowledge

The following excerpt shows learners' prior knowledge on the procedure for conducting the ball and ring demonstration (see also section 6.2.2).

L7 heats the ring while other group members are watching.
L8: It has expanded enough.
L9: Try, try and fit it (*into the ring*).
L10 *tries to pass the ball through ring. The ball fits into the ring it doesn't pass through.*
L9: mm; mm just heat it.
L7 *continues to heat the ring.*

When L8 claimed that the ring had expanded enough, a procedural question would be enough for what? But, L9 answered the question by suggesting that the ball and ring be tried, 'try, try and fit it'. The suggestion translated to a test because when the ball fitted in the ring, that is, when it could not pass through, L9 said 'mm, mm, just heat it' and L7 continued to heat the ring. The result of the test according to the group showed that the ring had not expanded enough to allow the ball to pass through. Therefore, according to L9 the process of heating had to be continued. L7 continued to heat the ring without expressed objection from other members. In that way, the activity showed learners' prior knowledge of procedure for the demonstration.

6.3.2.3 Learners explained observed changes in the demonstrations

In addition to demonstrating their knowledge of the procedures, learners' expressed their knowledge of the thermal expansion concept by identifying and explaining changes in terms of expansion as evidenced by the comments they made during the activity. Examples of comments include the following."(See section 6.2.2), "*Goo mo ke eng* (what is this), expansion in… gas?" and "It has expanded enough". They also explained changes in the bimetallic strip in terms of differences in expansion stating "The metal on this side (indicates the outer part of the bent bimetallic strip) is a better conductor of heat hence it expands first which gets this one to bend".

The learners also attempted to *explain expansion in terms of molecular forces* (also in section 6.2.2). In the ball and ring demonstration, one learner, L8, sought for an explanation of thermal expansion of the ring in terms of forces by asking his peer learner, L10, the following question, "So what forces are in this (pointing at the ring)?" However, L10's response through the utterance "chemical and stuff" indicated the type of forces L8 was referring to. In chemistry the type of forces covered at BGCSE level are intermolecular or inter-atomic forces (M. o. Education, 1998d).Although the two learners could not talk about expansion at the molecular level and the issue was abandoned, the question was relevant to the topic content. It created what Saenz-Ludlow (2006) terms effectual interpretations, a suspension of the issue possibly for future refinements. The activity activated the learner's instructional experience of explaining practical observations.

When conducting the demonstration on bimetallic strip, L11 explained the bending of the bimetallic strip to L12 as being caused by different rates of expansion and conduction by the metals that constitute the bimetallic strip. This is shown in the L11's statement in following excerpt.

> L11 ...The metal on this side (indicates the outer part of the bent bimetallic strip) is a better conductor of heat hence it expands first which gets this one to bend.

Although L11's explanation of the bent bimetallic in terms of conduction appeared inconsistent with the basic aim of the demonstration, it may not be taken to be completely inconsistent according to kinetic theory. In terms of motion of particles in kinetic theory, good metal conductors are likely to have higher rates of expansion than poor ones due to high rate of molecular collision (Giancoli, 2005). However, it is not clear from the discussion whether L11 understood the possible relationship between conductivity and rate of expansion in metals. What is important, here, is that the learner gave an explanation and gave it according to his knowledge. The correctness, or not, of the explanation placed him and other group members at a position where they could modify or expand their understanding through the teacher's instruction.

The analysis points to two factors in Teacher A's open-ended instructional activities on activation of their prior knowledge, learners' metacognition and inconsistencies in their knowledge. The learners' metacognition, how learners learned, was indicated by explanations of observed changes which they gave as part of their prior knowledge (Baird, 1990; Gunstone, 1994). The inconsistencies in learners' knowledge indicated by their ability to name and explain observable changes in the bimetallic strip but not in the ball and ring demonstration. Thus, Teacher A's instructional practice was exemplary in activating a wide range of learners' prior knowledge and showing learners' metacognition with respect to thermal expansion.

6.3.2.4 Learners demonstrated social skills

Social skills are essential for social interactions (Wertsch, 1991). At beginning of lesson 2 in section 6.2.2, when the groups at the work stations became big, other learners sat at the middle benches browsing through their books and hand-outs, waiting for their turn at the work stations. The fact that learners waited patiently for their turn to carry out the demonstrations showed their social skill to wait with other learners to finish. In the ball and ring demonstration, one learner who was participating in the ball and ring demonstration advised another learner not to bring his finger too close to the candle flame. Thus, the learners exercised *social responsibility* through the demonstrations.

At the beginning of the demonstration on expansion of gas, L2 alerted other learners in the group to watch the demonstrations so that they would not miss the changes that were expected to occur very fast.

> L2 The changes are very fast…watch...

L5 wanted the demonstration on expansion of gas to be repeated because she was standing behind other learners when the demonstration was conducted and she probably did not have a full view of the changes. L1 tried to repeat the demonstration but the water plug had been used up in the two containers. Then L3 volunteered to put in a plug of water in the capillary tube as shown in the following excerpt (also in section 6.2.2).

> L3: *Graps the bottle from learner L1 and says* tlaa ke go tsenyetse (let me put the water plug in for you).

The sub-section showed how the learners collaborated (Dillenbourg, 1999) in carrying out the demonstrations. Collaboration is a kind of interaction which indicates a process of learning in sociocultural theory (Vygotsky, 1978). Therefore, the activity did just activate learners' prior knowledge but it also involved them in a learning process.

Teacher A's instructional practice was exemplary in the way it used open-ended demonstrations to activate learners' knowledge of the demonstration apparatus, demonstration procedures, related concepts and metacognition, and involved learners in collaborative work. It availed information which the teachers could build-on or adjust new instructional experiences, or use to address possible inconsistencies in learners' prior knowledge on thermal expansion. The exemplariness of the open-ended activity within the BGCSE physics is that it provided opportunity for all learners to activate their prior knowledge on thermal expansion learned from their respective junior secondary schools.

6.3.3 The teacher's instruction built-on learners' knowledge

Activation of learners' prior knowledge enabled Teacher A to introduce new concepts in a way that build-on what learners knew. In lesson 7 section 6.2.7, the teacher gave learners opportunity to use their knowledge to report on the experiment carried out during the previous lesson and used their knowledge to present the standard method of writing an experimental report. The teacher's presentation led to a discussion which was found to make experimental procedure for the next experiment meaningful for the learner as discussed next.

6.3.3.1 Making the experimental procedure meaningful

The learners' responses showed how the steps and the reasons for an experimental set up complement each other in helping them make sense of the process. For instance, in stating the steps for carrying the emission experiment, one learner suggested that the flasks should be airtight or closed. The teacher did not write the point on the board because he did not get the learner's point. But, the learner persisted on stating the point until the teacher responded by saying "I don't know why you are saying that, may be you have got reasons" (see section 6.2.7) and he wrote the point on the board. When the reason for the point was given it made sense to the teacher as evidenced in his response, "Ehe! You want to minimise convection". The teacher understood the point when the reason was given and he was able to rephrase it to make it easier for the learners to understand. The fact that the learner persisted in stating the point even though the teacher appeared to disregard it by not writing it on the board, was most likely because the point made sense to the learner. The fact that the teacher wrote the point on the board even though it did not make sense to him was characteristic of his instructional approach of giving learners a voice in the activities (see section 6.2.7).

6.3.4 The teacher's instruction made concepts accessible for learners

In his instructional practice, Teacher A processed knowledge in a way that directed learners' thinking towards the embedded in physics concepts. The difference between everyday ways of thinking which constitute learners' prior knowledge and ways of thinking in physics (Smith et al., 1993) requires instructional interactions that guide learners' thinking in physics. To this end, Teacher A's instructional practice was found to simplify complex constructs, presented physics concepts to the learners' level of thinking, rephrase questions for learners, use of ideas from other science subjects and refine understanding of expansion based on possible learners' misunderstanding. These are discussed in the following sub-sections.

6.3.4.1 Simplifying complex constructs

The discussion in lesson 3 on Brownian motion based on the question "what conclusion about air molecules can be drawn from this observation of smoke particles" (see excerpt in section 6.2.3) shows how the teacher simplified the question so that learners could make sense of it. The teacher simplified the question by changing it from "what conclusion about air molecules can be drawn from this observation of smoke particles?" to "Why is smoke being used in that experiment or observation or investigation?" In the former question, the term *conclusion* was the subject, and in the latter question the smoke is the subject. The rephrasing of the question changed the focus from a complex construct, *conclusion*, involving analysis and synthesis of information to *smoke* which is something concrete and familiar for learners to understand the question. The change of focus in this instance did not change the question; instead it highlighted its main point which was the use of smoke in the experiment. The teacher further simplified the question to "Why choose smoke?" *Choosing* is more appealing to the learners in that it has personal connotations of an act of picking one thing from a number of things even though it has to be an informed act than *using*. *Using* has an implication for a purpose which the learners may not have acquired yet to talk about.

6.3.4.2 The activity presented science ideas to the learners' level of thinking

The discussion also shows how the teacher presented science ideas to the learner's level of thinking. After simplifying the question "what conclusion about air molecules can be drawn from this observation of smoke particles" the learner's response was "May be it's because smoke has colour". The teacher expanded on the learner's response by stating the importance of the colour, that colour makes smoke visible which enables observations to be made. He then combined the two points to describe air as colourless and invisible. The learners' ideas or level of thinking in a particular conversation is signified by the learners' words. When the teacher used the learner's words, he presented the science idea at the learner's level of thinking. In that way, he made the content more accessible. It also promoted learners' contributions in discussing science ideas during instructional activities. This view also applies in the subsequent question, "The movement of smoke particles will tell us what about the air particles?"

6.3.4.3 Rephrasing questions for learners

In the discussion, the teacher pressed for the relationship between the smoke and air particles to be made explicit in the learners' responses. The learners' first response to the question "The movement of smoke particles will tell us what about the air particles?" was "I think as the particles have energy, they use energy which makes the particles hit each other as they move around." The response did not relate the movement of smoke particles to air particles. Therefore, the teacher rephrased the question once more and said "what do we learn from the fact that smoke particles change direction like that?" The teacher also set some standard for learners' answers during the discussion as reflected in the following excerpt.

> T. Therefore you can conclude that they are invisible. May be, may be. But, I am looking for some idea which can score a mark in an exam: a second idea. The first conclusion, definitely the movement of smoke particles show that also the air particles are in motion. Second?

The learners could not relate the movement of smoke particles to air particles and the teacher had to give them the answer. Regardless, the teacher took the opportunity to highlight the idea when demonstrating convection currents in air and liquid (see section 6.3.4.5). The teacher's comment about the exam in the above excerpt shows he prepared learners for examinations in the instructional activities.

6.3.4.4 Use of ideas from other science subjects

The teacher reminded learners that the smoke is mixed with air. He talked about, smoke-air mixture, which is not commonly used in this experiment. The teacher was possibly drawing from learners' instructional experiences of mixtures in chemistry according to the chemistry syllabus they had covered the previous year. The topic of mixtures also appears in junior certificate level integrated science syllabus (M. o. Education, 2007). The teacher's use of the idea of a mixture had the potential to help learners imagine the presence of the invisible air particles in between the smoke particles and the possible interaction in that state.

6.3.4.5 The teacher highlighted the idea of movement of air particles

In section 6.2.6, the teacher's demonstration of convection currents included the double-chimney apparatus for convection in air where he again used the idea of smoke particles to show movement of air particles. Although learners had difficulties relating movement of smoke particles to that of air particles when discussing Brownian motion, during interviews, they expressed the understanding they had gained as a result of observing the convection demonstration.

> L. When you are told that there are particles around, sometimes you don't believe because you can't see them. But then it occurred to me when we did the demonstration on convection in air when the smoke was introduced into one tube, that air was inside (the box), and it escaped through (the other tube) because it had expanded and was looking for space. You understand what I mean.

The learner's comment that he did not believe there were particles around concurs with the view expressed in section 6.2.6 that learners do not readily conceive air as a substance unless it is brought to their attention (Driver, Leach, Scott, & Wood-Robin, 1994) and therefore have difficulties thinking of it as mixed with smoke. It substantiated the teacher's instructional actions in making learners aware that air is a substance and the possible success of his actions in letting learners make sense of the demonstrations.

6.3.4.6 Refined understanding of expansion from possible learner misunderstanding

The teacher took the opportunity to explain expansion at a molecular level from a point of possible learner misunderstanding that particles expand instead of moving apart. He explained expansion as follows.

> T. Particles do not expand when they are heated. Small as they are, individual particles do not expand. Expansion in liquids and gases is explained by kinetic theory: The particles gain kinetic energy, the distance between the particles increases, and the particles get further apart. That means the liquid therefore increase in … The particles occupy a bigger volume which means the density therefore decreases.

This had the potential to refine learners' understanding that expansion is due to the increase in volume caused by particles moving apart and not the particles increasing in volume as described in one of their textbooks by Duncan and Kenneth (2001)

Teacher A's instructional practice was found exemplary in its complexity in addressing learners' difficulties in understanding English words and physics concepts. The teacher introduced learners to difficult constructs and explained them by using simple words, rephrasing questions, using learners' language and drawing ideas from chemistry subject. The teacher's instructional activities addressed possible learners' difficulties with thermal expansion and Brownian motion experiment which he used as a theoretical basis for thermal physics. The learners' difficulties included understanding air as a substance that can interact with smoke.

6.3.5 Teacher A used questions to structure instructional activities

Teacher A's instructional practice was characterised by use of examination and textbook questions in which learners were engaged in high level cognitive processes such as applying and integrating concepts from different topics. The examination and textbook questions were used in lessons 2, 3, 4, lesson 5 and 7 (See sections 6.2.2; 6.2.3; 6.2.4; 6.2.5; 6.2.7). The analysis of the teacher's practice based on his use of questions follows.

6.3.5.1 The questions enabled the teacher to present content in a holistic way

Lesson 3, in section 6.2.3, was structured around past examination questions on kinetic theory specifically Brownian motion and Boyle's law, which was covered the previous year. The question on Brownian motion had a diagram showing movement of smoke particles which the learners were asked to interpret in terms of the movement of air particles. The activity led to a review of the Brownian motion experiment. In that way the questions enabled a holistic view of prior instruction on Brownian motion.

6.3.5.2 The questions enabled the teacher to present content in an integrated way

The second question was on temperature-pressure relationship in gases which led to a series of questions that brought about a discussion of the changes in pressure. The question was used to link movement of air particles to thermal expansion, convection currents, and air movement under the topic of weather (see Sections 6.2.3; 6.2.4; 6.2.5). In this way, topics under kinetic theory were integrated into thermal physics. The topic of weather which comes after thermal physics in the BGCSE physics syllabus (M. o. Education, 1998c) was also inserted in thermal physics. This shows integration of content from kinetic theory through questions on Brownian motion and Boyles' law and weather changes through questions on cyclones.

6.3.5.3 The questions enabled learners to apply their knowledge

In section 6.2.2, a question on hot air balloon was used as an exercise for learners after demonstrations on thermal expansion. In the interviews, the learners were asked how they felt about the question. The learners said they preferred answering that particular question because they were able to use their understanding of what they had observed in their own words. They reported that in instances where they had only been told about concepts without a demonstration they tended to use the teacher's words. The use of the question therefore enabled the learners to apply their knowledge.

While the teacher's use of examination questions shows the impact of summative assessment on instructional practice which can be negative, the way the questions were used was found exemplary when concepts were made accessible as discussed in section 6.3.4. This applies particularly to the BGCSE physics curriculum in which physics teachers have limited guidance to providing high cognitive level instruction for learners.

6.3.6 Making learners' voice a factor in instructional activities

Teacher A's instructional practice was characterised by learners' contributions which according to sociocultural contribute to meaning making processes (Scott, 1998; Wertsch et al., 1995). In Section 6.2.7, the learners, L4 and L5, were engaged in a dialogue about whether or not the temperature of the surrounding was important as part of the initial data for the experiment on emission of heat. This occurred after a class discussion on how to set up and carry out the experiment. The learners were talking about the steps they thought should have been considered during the discussion. One of the steps was the timing process which the teacher advised the learners who were conducting the experiment to take into account. The discussion took place when the learners were supposed to be plotting graphs using data obtained from the absorption experiment which was reported earlier in the lesson. The following provides an analysis of the teachers' efforts in formalising the learners' dialogue.

The teacher called out and magnified the learner's question. Although the point about temperature of the surrounding was not brought to the teacher's attention, the teacher picked up the point as the learners were discussing. He then brought the point of dialogue to the class by calling out and amplifying the learner's questions to share it publicly with the class as reflected in the following excerpt.

T L5 has got a question. What about the temperature of the surrounding, that's what she is asking? Can you clarify your question…explain further, temperature of the surrounding?

The teacher kept the question under the learner's authority. The excerpt shows that the teacher kept the point within the learner's authority as implied by the statement "that's what she is asking". He invited L5 to present her point to the class for them to understand her question "Can you clarify your question…explain further, temperature of the surrounding?" The teacher acted as a moderator. L5 was engrossed in the dialogue with L4 and did not respond to the teacher's call. So, the teacher called on L4 to present the issue to the class but still kept the point within L5's ownership. He said "L4, so you are helping her?" This protected L5's position to present her point. In response to the teacher's call, L4 presented his point with respect to L5's question as follows.

L4 I was trying to help her, that, we should consider the temperature of the surrounding at the end of the experiment since we are using the apparatus that have temperature higher than that of the surrounding.

L5 then presented her point that the temperature of the surroundings has an effect on the amount of heat lost therefore it was important.

L5 What I mean is that the temperature of the surroundings has an effect on the amount of heat lost. *A kere* (Let's say) for example, may be its too cold in here, and those things (the flasks containing hot water), they're hotter than the temperature of the surrounding. It's going to have an effect. As compared to, let's say, when they're of the same temperature.

The teacher kept the dialogic nature of the discussion. L4 presented the point of their discussion with L5 in a less personal manner by using the word "we". His statement was more appealing to the class because of the word "we" which was inclusive of the members of the class and consistent with the teacher's aim to have the discussion shared with the class. It is noteworthy that L5 presented her point in a personal sense when she responded by using the word "I". This is evident in her first sentence in the excerpt when she said "*What I mean is that* the temperature of the surroundings has an effect on the amount of heat lost". It is also worth pointing out that L5 seemed to be more at ease presenting her view by responding to L4's argument. Perhaps, the teacher's approach which kept L5's ownership of the point of discussion and maintained dialogic level of the discussion by letting L4 present his point is what enabled L5 to articulate her point publicly for the class in accord with what Peräkylä (2005) called "circular questioning" (p.877) where one person is asked to describe the thoughts of another.

The learner articulates her point in a dialogic discussion. The following excerpt (also in section 2.6.7) shows how L5 articulated her point in response to L4.

L4. I was trying to help her, that, we should consider the temperature of the surrounding at the end of the experiment since we are using the apparatus that have temperature higher than that of the surrounding.

L5. What I mean is that the temperature of the surroundings has an effect on the amount of heat lost. Let's say (A kere) for example, may be its too cold in here, and those things (the flask containing hot water), they're hotter than the temperature of the surrounding. It's going to have an effect. As compared to, let's say, when they're of the same temperature.

L5's elaboration is explicit in that her argument was not that the temperature of the surroundings should be considered. Rather, her elaboration portrayed the amount of temperature difference as the basis of her argument. When the experiment was conducted it was a hot summer day and L5 was saying that had it been cold instead, the difference would have been larger. This was expressed in her statement that the flasks would be "hotter than the temperature of the surrounding" if it was cold in laboratory.

Teacher opened the discussion to the class. After L5 presented her point to the class, the teacher opened it to the other members of the class *to* allow other learners to contribute their points to the discussion. L5's point was shared by L6 who was called by the teacher to comment. L6 used L5's example by comparing the temperature difference when it is cold outside with when it is as hot as it was when the experiment was conducted. But he built on L5's point when he stated that the rate of heat loss would be higher if it was cold**.** See excerpt reproduced immediately below (also see section 6.2.7).

L6 Sir, I think the temperature of the surrounding matters because it determines the amount of heat being lost to the surrounding…*inaudible* (other learners were talking)

T. They are complaining (referring to the noise from the learners)…Perhaps, don't talk to them rather talk to me.

L6. Because of the temperature of the surrounding, if it's cold outside it means the flasks are going to lose more heat faster. The temperature of the surrounding matters because it determines the amount of temperature (heat) which is being lost or emitted to the surrounding.

Teacher commented at the end of the discussion. The teacher commented at the end of the discussion when there were no additional points coming from the learners. In his comment, he showed L4 and L5's points as relevant by stating that it was important to start off with an understanding that heat is lost because of the temperature difference between the contents of the flasks and the surrounding air. He also stated there was a temperature difference because the temperature of the surrounding air according to the weather bureau was around 30^oC and that of the flask was around 70^oC. The teacher probably did not want the discussion to continue as the points would better be explained by discussion of the results, but which were not yet available.

The foregoing showed Teacher A's strategy in bringing about dialogue between two learners to a formal class discussion in which other learners were able to contribute to the dialogue. It provided opportunity for learners to refine their understanding and views about the experiment. The teachers' instructional practice in this regard was exemplary in the way the teacher acted as a moderator to allow learners to present their views and to support their arguments on thermal physics concepts.

6.3.7 Why teacher A supported the learners in the way he did?

Teacher A mentioned that the learners generally face difficulties in performing well in physics at the University of Botswana. This is in agreement with the 1993 National Commission on Education report that tertiary institutions expressed dissatisfaction with the mathematics and science at school level (Botswana, 1993). The teacher designed his instruction to provide learners with the opportunity to develop skills that would prepare them for tertiary education. For instance, the instruction encouraged use of textbooks as the main source of information (see section 6.3.1). The teacher also engaged learners in high thinking level questions (see section 6.3.6) and exposed learners to complex constructs (see section 6.3.4.1).

The teacher integrated cyclones from the content on weather topic and Brownian motion and Boyles' law from kinetic theory topic in thermal physics a to make use of elaborations given on a particular concept through syllabus objectives and textbooks as apparent in the following excerpt from a post-lesson 3 interview.

> T. I am trying to take advantage of thermal physics (by) bringing it into the weather stem. That's why we talked about air masses being heated, expanding and losing density and then it creates these tropical winds then it becomes weather."
>
> The concept that I wanted them to get was the concept of rise in temperature, expansion in free space. That expansion leading to decrease in density and then the rising causing air cycle, replacement of … and then the speed of replacement and the direction of movement.

Drawing from his experiences as a learner during his schooling, the teacher used questions to access content knowledge in a topic and ways of thinking that are eminent in learning the topic for learning purposes.

> T I embarked on some distant learning program in my country. I was studying marketing management. You know when you get to those courses on distance learning, the lecturer is far away from you and all you may have is lecture notes, books and sometimes you don't know what the syllabus is about. So I asked myself what best can I do to tackle this… So I said before I even look at the topic or heading, let me go to the questions

Teacher A engaged learners actively in instruction because he considered instruction as a time for learners to learn together when they still have energy as compared to learning after leaving school (also in section 6.3.7). He stated that:

> T One thing I've discovered [it] is better to give them time to do this during lessons when they're together. That's where the excitement is. They've got the energy and the time to do it.

In addition, Teacher A felt that engaging learners was important for addressing some of the challenges they faced when studying on their own such as the large amount of work due to the number of subject they had. He was of the opinion that the challenges were reflected by the quality of their homework.

> T If you tell them go and do this at home, the quality of work that comes is substandard. When they're going to do it at home, they're crowded with work from other subjects. Some of them are doing 10 subjects and eight teachers have given them work to do. They can prefer to do biology and ignore physics.

Teacher A said that the poor quality of learners' homework might also be caused by the fact that learners may have no assistance at home.

> T …the student may have no other assistance except him/herself. But if they do this kind of work, little as it is and they are helping each other, I find it more helpful…

In conclusion, Teacher A's practice gave learners opportunity to acquire learning skills to enable them to access school physics content and at the same time prepared them for tertiary education in physics. His practice took into account the challenges of independent learning by making full use of instruction time.

6.4.0 Chapter Summary

This chapter has reported on and discussed Teacher A's instructional practice on thermal physics content in six lessons. The analysis of the instructional activities in the six lessons has shown the Teacher A’s instructional practice as characterised by: promotion of learners’ independent textbook reading; Open-ended demonstrations to activate learners’ prior knowledge; activities which build-on learners’ knowledge; use of examination and textbook questions to engage learners in high level cognitive processes; making concepts accessible through simplification of language of instruction; integration of concepts from different topics; and strategies for involving learners in class discussions.

CHAPTER 7

Analysis of Teacher B Instructional Practice

7.1 Introduction

The purpose of this chapter is to provide an analysis Teacher B's instructional support for learners by exploring successful and effective instances of support. The profile of Teacher B has been provided in Section 5.1.3. Similar to approach taken with Teacher A in Chapter 6 the analysis was based on the data obtained through observation of the teacher's instruction but in eight lessons as the main method of data collection; in this case also, observation data was augmented with interviews of Teacher B.

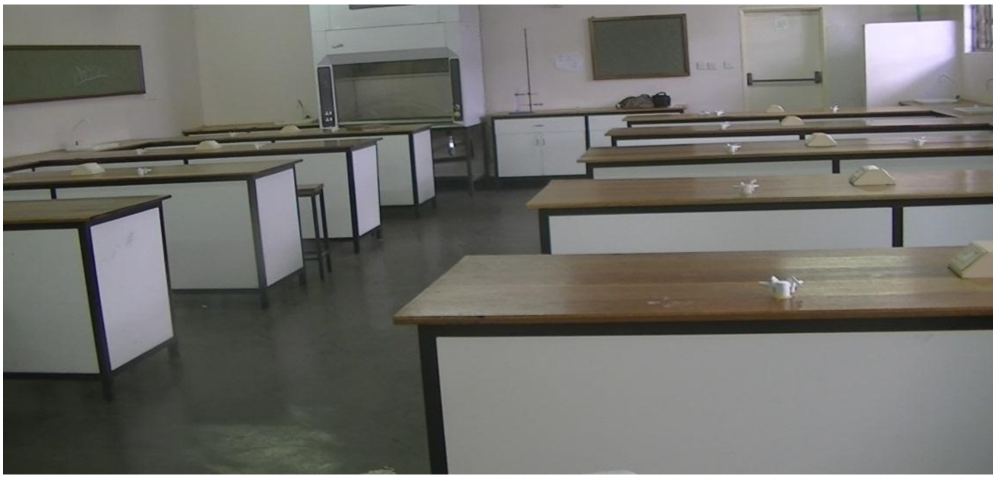
Same as with teacher A in Chapter 6, the focus of the analysis was three fold: (a) to capture instances of support in Teacher B's instruction; (b) identify to the kind of support provided; and (c) to establish learners' responses to the support. The analysis outcome is presented in two sections: the first section is a description of the instructional activities is first presented followed by the review analysis of the activities. The descriptions are the researcher's selections of the main instructional activities and the strategies used by Teacher B based on the aims of analysis; the second section is a review of instances and kinds of support, including learners' responses to the Teacher B's instructional activities. Evidently, therefore, the analyses are to source answers to the three main research questions as reproduced here (see also section 1.3)

1. What characterises exemplary teachers' instructional practices in school physics?
2. How does the exemplary teacher's instructional practice support learners in accessing school physics content?
3. Why does the exemplary teachers' instructional practice in school physics support learners in accessing school physics content?

Throughout the reporting in this chapter, the symbols T, L, Ls for transcript excerpt represent Teacher A, learner, or learners respectively. Where there was a sustained discussion, learners are identified by number like L2 for each lesson. The same label, L, Ls, L1, L2 etc., is used generally to apply to learners even though learners in one lesson may not necessarily have been the same learners in another lesson. For instance, L1 in lesson 2 and L1 in lesson 7 is not necessarily the same learner in lesson 2 and lesson 7. It is noteworthy that the introduction is numbered 7.1 to highlight its close link to the rest of the chapter.

7.2 Descriptions of instructional activities

As already documented in Section 5.2.3, Teacher B was observed while teaching the topic Light and Waves. All lessons were conducted in two physics laboratories. Unlike in School A, there was no laboratory assistant in School B. The laboratories were spacious. They had ten fixed benches which accommodated a maximum of five learners each. The space between the benches was large enough for learners to conduct hands-on activities in small groups. Pic 14 shows a view of one of the physics laboratories used by Teacher B during this study.



Pic. 14: view of a physics laboratory in School B

This section provides a description of Teacher B's instructional activities on the topic of waves and light in eight lessons. In the lessons observed the teacher's instructional activities covered content on 'waves' and 'light' topics. The study was conducted on these topics because they were taught by the teacher at the time of data collection. The general syllabus objectives on the topics are provided in Section 5.2.3. The descriptions are presented according to the lessons observed on the topic.

7.2.1 Lesson 1

School: B **Teacher**: B **Lesson Topic**: Properties of water waves

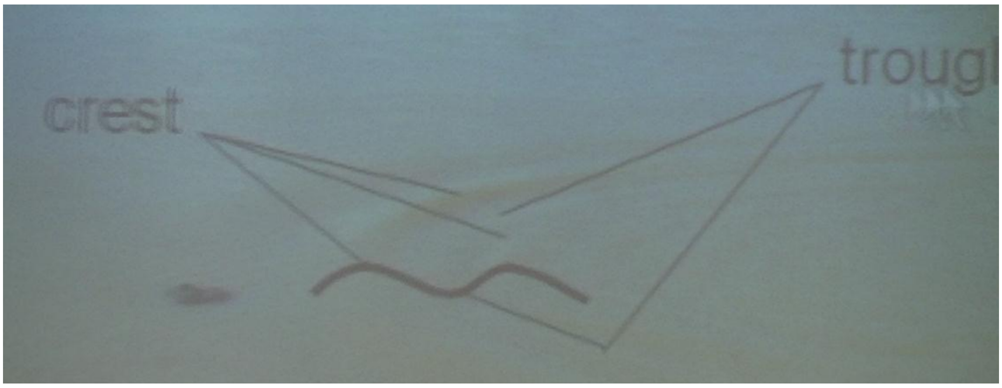
Type of lesson: PowerPoint Presentation and Pen & paper learner activity

The objective of this lesson was to introduce the wave motion and properties of water waves. The activities involved teacher presentation of movement of water waves and terms that are used to define the waves. The wave motion and definition terms were introduced with the aid of a video clip of a pool of water, shown in a PowerPoint presentation, in which water waves were produced by disturbing the water. The presentation included a discussion of the wave speed. The learners worked on teacher developed worksheet which included calculation of wave speed and frequency up to the end of the lesson and were to complete the work as an assignment.

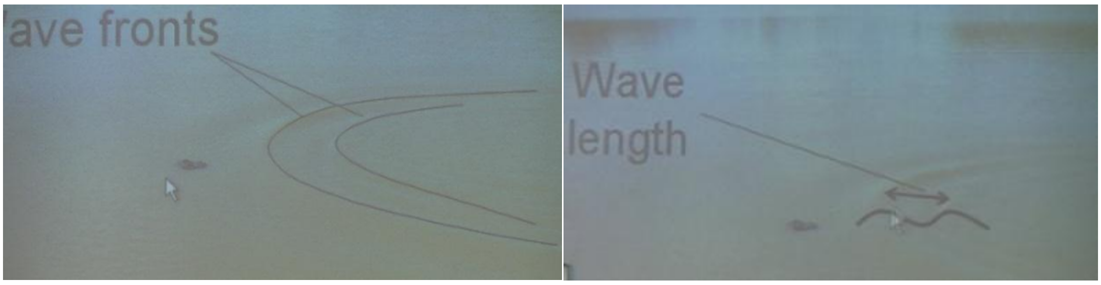
Lesson activities: The teacher introduced the lesson by reminding learners to submit work on the topic of energy which they had just completed and to refer to the hand-out on light and waves which he had distributed.

> T. I gave you a hand-out on waves and light. But I'm still correcting a hand-out on energy because you didn't finish working on it. If you have not submitted the hand-out on energy which I gave you that had things like power stations, solar heaters, biofuels all of that…please bring this to me. Now this hand-out today (on waves and light) has four pages on it. You'll start work on it today and finish it as an assignment.

He then introduced the topic "waves" by stating the following subtopics: what waves are; longitudinal and transverse types of waves; and wave equation. The lesson was started with a question "What is a wave?" The focus was on wave movement which was described as energy spreading out in vibrations. The teacher used two concepts 'vibrations' and 'spreading out' to develop instructional activities for the lesson. The teacher then showed a video clip of water waves in a typical pool where cattle normally drink water. In the clip, stones were being thrown into the pool and the spreading out movement of vibrations could be observed which the teacher said depicted wave movement. He used the term 'ripples' which he said referred to small waves. The wave motion on video clips was then used to introduce the terms crest and trough (see pic 15), wave-front and 'wavelength' (see pic 16), 'speed', 'amplitude'.



Pic. 15: video clip of water waves showing wave trough and crest



Pic. 16: video clips showing wave-fronts and wavelength

The following excerpt shows how the teacher presented the terms using the video clips.

T. The top of that wave is called a crest the bottom of that wave is called a trough. In fact there are two (waves). The waves are highlighted with a line drawn along the crests. The next word is a wave-front. A wave-front is a line joining all the parts of a wave which are at the same stage. For example this line here (indicating the line drawn along the crest). That's where this part of the wave is. That's a wave-front. Here is another wave-front, indicating another line drawn along the crest.

If I show a picture of a wave and I ask you what is the length of the wave what would you do? Look at the picture there, a line from here to there (tracing a single wave-front). That's a very long wave. That's not how we define a wavelength. A wavelength is the distance between one wave and another wave next to it. And we can measure the distance from the crest of one wave to crest of another wave. Or you can measure from the trough to the trough of another wave. You can find the same answer.

The term frequency was discussed later in the lesson based on the frequency of oscillations of a pendulum covered the previous year under measurement of time. The introduction of wave terms was followed by activities on vibrations and spreading of vibrations. The vibrations were illustrated by animation on PowerPoint that showed a ball floating on water surface. The vibrations were transformed into the waveforms by measuring and tabulating values of displacement in relation with time which were used to plot a displacement-time graph. The relative direction of vibrations to direction in which they spread out was described as perpendicular or 90^o. This type of wave was given as an example of transverse wave.

The spreading of vibrations was illustrated in the movement of water waves on the video clip. It was defined in terms of wave speed. The video showed two vertical sticks which the teacher said were one meter apart in the pool of water. The time taken by a single ripple was measured and used for calculating the wave speed. The calculation of speed was also used in the context of sound where an animation of five circular wave-fronts representing sound waves was shown spreading out from a point labelled "P" to point "Q" in a particular time. The relative direction of vibrations to the direction in which they spread out was described as parallel which in turn described a longitudinal wave. In the discussion, the ideas of speed and displacement were used from earlier topics on motion and time measurement using a pendulum. The teacher's presentation was concluded with an activity in which the learners were taken through the formulation of the wave equation.

T. The wavelength is the distance between crests. Remember that? So, first of all look at Q there and P here. I am going to ask you how many waves are between Q and P.

L. 5

T. 5. 1 wave, 2 waves, 3 waves, 4 waves, 5 waves *pointing as he counts*. You are right. How many wavelengths are there between P and Q?

L. 5

T. 1 wavelength, 2 wavelengths, 3 wavelengths, 4 wavelengths, 5 wavelengths *pointing as he counts.* This is a new symbol (referring to the label **λ**). It's not what you learn from English language or Setswana language *learners laugh*. It's from the Greek language. This symbol is called lambda. Say lambda.

Ls. Lambda

T. Concentrate now because there are some difficult questions on the hand-out which I set. We are back to the question. Now we are going to look at the distance moved in 1s. Is the number of wavelengths moved in 1s 1 wavelength, 2 wavelengths, 3 wavelengths, 4 wavelengths, 5 wavelengths multiplied by? You want to know this distance and there are 5 waves. What do we need to know to calculate the distance?

The discussion continued on the calculation of distance and distance moved in one second as number of waves produced in one second multiplied by the wavelength as follows.

T. Distance moved in 1s distance moved a second, what is that?

Ls. Speed

T. Right. Speed. *He erases Distance moved in 1s from the equation and replaces it with speed*. The number if waves in 1s, what is that?

Ls. Frequency

T. Right. Frequency. *He erases number if waves in 1s from the equation and replaces it with Frequency*. The length of each wave, what is that?

Ls. Wavelength

T. Wavelength. (*He erases length of each wave from the equation and replaces it with wavelength)*

The equation became

speed = *frequency* *X* *wavelength*

Then, learners changed position to face the chalkboard at the front of the laboratory and worked on an exercise on wave equation. During the exercise, the teacher moved around helping learners with the work up to the end of the lesson. When the bell indicating the end of the lesson rang, the learners called their teacher for help before they left for another lesson.

The teacher stood at the front of the laboratory checking their work and attending to other matters.

Summary

This lesson has shown how the teacher presented terms used to describe waves such as crest, trough, wave-front and wavelength using a video clip of waves in a pool of water. The presentation showed how the teacher sequenced the terms in ways that related to each other. It also describes how the teacher used the wave phenomenon demonstrated in real wave motion in a pool of water which he described as the spreading out of vibrations to develop an activity through which wave motion was explained. The activity had an exercise in which learners were involved in supervised counting of the number of waves, calculating frequency, measuring wave length and using the wave equation to calculate wave speed. Some learners sought for teachers' help as they left the laboratory at the end of the lesson probably to prepare themselves to work on the assignment at home.

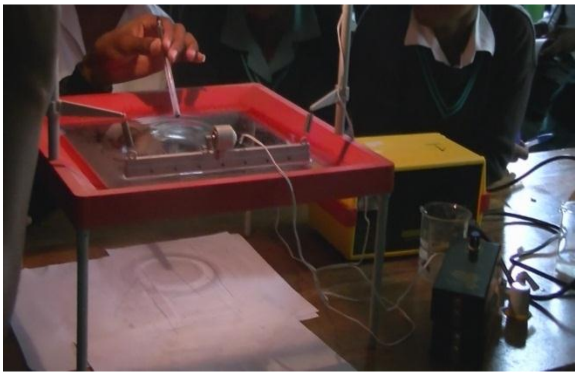
7.2.2 Lesson 2

School: B **Teacher**: B **Lesson Topic:** Properties of water waves - using a ripple tank

Type of lesson: Teacher demonstration

The objective of this lesson was to review wave motion and definitions of wave motion introduced in lesson 1 (section 7.2.1) such as the wave-front, frequency, wavelength and wave speed. The activities involved the demonstration of water waves using a ripple tank. The demonstration was then used to introduce reflection and refraction of water waves. The learners continued working on pencil and paper problems on the worksheet the teacher gave them in lesson 1 up to the end of the lesson.

Instructional activity: The lesson started with the teacher introducing the ripple tank to the learners (see pic. 17). The learners stood around the ripple tank but most of them could not see it. The teacher told them to just listen if they could not see as he was going to repeat the demonstration in small groups.



Pic. 17: Learner demonstrating ripples

He pointed out the key components of the ripple tank and the functions of each by using simple words such as clear water which contrasted with the muddy pool water in the video referred to in lesson 1. He also used the word ‘shadows of waves’ instead of ‘wave-fronts’. The teacher tapped the water surface with the tip of a pen to produce circular waves as a review of the waves observed on the video clip. He then tapped the rectangular wooden frame supporting the electric motor to produce plane waves.

The teacher then reviewed the meaning of ‘frequency’ by varying the frequency of the electric motor. The electric motor caused the rectangular wooden frame to vibrate and produce plane waves continuously. The change in frequency effected a change in the wavelengths which the teacher brought to the learners’ attention. After adjusting the frequency, the teacher defined the speed by estimating the wavelength and the time a wave took to move through the distance marked on the sheet of paper that was placed below the tank.

The ripple tank was also used to demonstrate refraction and reflection of water waves. Regarding refraction, he informed the learners that they learned the meaning of refraction as bending of light in junior secondary science and that the real meaning of refraction was ‘slowing down’. To illustrate refraction of waves as slowing down, the teacher told the learners that water waves move fast in deep water and not very fast in shallow water. He placed a glass sheet flat on the base of the ripple tank so that it covered part of the base. Water waves were observed moving from the wooden frame where they were produced, through tank, and over the glass sheet. The teacher brought the learners’ attention to the change in the shape of the plane wave-fronts as they moved over the edge of the glass sheet which he said showed that the waves were dragged back. As the waves slow down, the wave-fronts moved closer but the frequency did not change.

The next demonstration was on reflection of water waves. The teacher said the words that learners know from the topic of light are used in ripples because ripples and light are waves. The reflection of waves was demonstrated and the teacher pointed out the change in direction to the learners. The reflection of circular waves was also demonstrated in which the teacher pointed out the shape and the direction including the point where the reflected waves seemed to be coming from.

The teacher then sent the learners back to their places in the laboratory to continue work on their worksheets which were handed out in the beginning of lesson 1 (section 7.2.1). He then repeated the demonstration with small groups of learners to ensure that all learners are able to observe and participate in the demonstration. The teachers got learners to participate in the demonstration by tapping the water surface in the ripple tank to produce waves (see pic 7.4). After the end of the demonstration with the last group the teacher allowed learners to use the ripple tank. At the end of the lesson, some learners stood around the frontbench to talk to their teacher about their work on their way out of the laboratory.

Summary

This section has described the activities in Lesson 2. The teacher introduced the parts of the ripple tank which were important in the demonstration to assist the learners in viewing the waves. He also used the ripple tank to show circular and plane water waves and how they were reflected. The ripple tank demonstration involved a review of the terms that are used to describe waves which were introduced in lesson 1 (section 7.2.1). The review helped learners to make sense of the waves as presented in the ripple tank demonstration including the demonstration on refraction and reflection of waves.

The lesson described Teacher B's class management when conducting a ripple tank demonstration. The demonstration was done for the whole class and small groups of learners to ensure that individual learners had a clear view of the ripple tank. The rest of the class worked on the hand-outs when the demonstration was conducted for small groups of learners.

7.2.3 Lesson 3

School: B **Teacher**: B

Lesson Topic: Formation of plane mirror image and Refraction of light

This lesson had two objectives which were to introduce image formation by a plane mirror and refraction of light. The activities included a PowerPoint presentation on image formation by a plane mirror which entailed construction of a ray diagram and a discussion of refraction of light as it travels from one medium to another. The discussion on refraction entailed definition of refraction and introduction of the terms used to define it.

Instructional activities: The teacher used PowerPoint slides to present a diagram that showed how plane mirror images were formed. He introduced learners to diagram symbols for a plane mirror, an object and the observer's eye. In the diagram, light rays radiated from the object in all directions. The teacher explained how the rays that reached the eye directly from the object and those that were reflected by the mirror before reaching the eye enabled the observer to see the image. The teacher took the learners through the basic properties of the image through questions that were projected on the screen. The first question was "where do we see the image?" The learners' response was that it appeared behind the mirror. The teacher said the reason the image was seen behind mirror was a limitation of the brain to follow the reflected rays back to the object. He said,

T …your eye has spent years and years looking at things without the mirror. So you are used to light coming directly from the object. So when these rays come into your eye from this direction *pointing at direction of the reflected rays*, your eye and brain understand that it must be coming from a source which is in straight line with those rays.

All the rays radiating from the object were removed except for two reflected rays that reached the observer's eye. The teacher then refined the location of the image as behind the mirror, directly opposite the object. To illustrate "directly opposite" he moved to the screen and directed the learners where the image of his face would be located if the screen was the mirror. He went back to the projector and drew a straight solid line from the object perpendicular to the mirror and in line with a straight dotted line to the image and said the lines showed that the image is directly opposite the object.

He then drew two solid lines which he said represented distance. The learners' response was that the distances are the same. The next question was "How does the object size compare with image size?" The response projected on the screen was that the sizes are same size. The last question was "Is the image real or virtual?" The response was that it is a virtual image. The teacher said virtual was a textbook word which meant that the light rays were not going to the image. In each case the correct responses were projected on the screen following the question.

The next part of the presentation was on refraction of light. In this section, the teacher introduced learners to the key words that explained the refraction and described the material to be used in demonstrating refraction. For instance, he said the material has to be transparent for the light to go through and asked learners to give an English word that mean the same as transparent as well as examples. The learners gave the word 'clear' which was accepted by the teacher. The examples the learners gave were water and glass. The teacher asked them for another material for which he gave the hint, "what is between me and your eye?" The learners' answer was "air". The teacher then added the material Perspex to the list, which he said was hard plastic. For the word dense, he used heaviness but he also used density which learners knew as mass/volume as reflected in the following excerpt.

T. It didn't go down this way, it bends towards the normal (*using the cursor to indicate the direction)*. So, that's the direction. That's the normal line. When light passes into a denser medium it bends towards the normal. When we say denser we mean how heavy it is. How do you calculate density?

L. mass over volume

T. It's mass over volume. Usually something which is heavy like there are different kinds of glass, if glass is having large amount of glass, it's going to bend light more. So, what do we say, it's optically more dense. But really that's what dense means. (*He shows the speed of light by an arrow moving along a straight line going from air to glass)* Did you notice how the speed of the arrow changes? Let's watch again (*he repeated the demonstration)* that's the arrow in the air, that's the arrow in the glass. You see how it slows down? That's what I'm trying to show you in the animation, the slowing down in the glass.

In the above excerpt, the teacher related the mass over volume to optical density which he illustrated by the relative speed of light when travelling in air and glass. It is also evident that the teacher used the term 'bending of light' instead of refraction but emphasised the change in speed of light as the cause for refraction. He used an arrow that moved along the light ray and changed speed as the light ray entered a material of different optical density to illustrate change in speed. The presentation showed the arrow moving slower in glass than in air which the teacher said is the cause of bending. He then introduced the normal line which he used to describe the direction in which the light would bend for which he introduced and demonstrated the terms "towards the normal line" and "away from the normal line". The learners were given opportunity to state the direction in which the rays bent as they were drawn from air into glass. The words were brought together into the statement, "When light passes into a less dense medium it bends away from the normal. When it goes into a denser medium it bends towards from the normal." This led to identification of the angles of refraction and incidence. The angles of incidence and refraction were identified and the symbols **i** and **r** introduced to the learners. The learners were involved in labelling angles **i** and **r** as reflected in the following excerpt.

> T. Here is another set of rays. (*a diagram showing two light rays from air into glass titled slowing down or bending of light. There were arrows that moved along the rays to show relative speed of light in air and glass*). … It (the diagram) shows that the ray is bending and slowing down (as it moves into glass). There is angle **i**. This here is a bit confusing we are using the same letter for the angle of reflection as for angle of refraction. We're going to use the letter **r** for the angle of refraction. So where should I put it, is it that one? Is it that one? Is it that one?
>
> Ls. Stop.
>
> T. Right. That's the angle of refraction. This time, the arrow moves along the line from air-fast and into glass – slows down. That's **i** and that **r** (*teacher labels them*).

The teacher then showed what happened when the light travelled along the normal line from air into glass. He pointed out that the light does not bend but the speed changes and as a result of the change in speed the light is refracted. The discussion went as follows.

> T. Right. Now supposing the ray is coming straight down the normal, the ray of light is travelling straight down the normal. You see that line, that's the normal, and that's the normal there. You see that ray is travelling along the normal. What is the angle between the ray and the surface of the glass? What is the angle between the ray and the surface?
>
> L. 90^o
>
> T. Right. Notice it does not bend. When it goes into the glass, we know the light bends towards the normal. It's already at the normal, isn't it? If the incident ray is on the normal there no bending but there is refraction. In other words, angle **i** is 0^o and angle **r** is 0^o. If two lines are drawn at the same place there is no angle between them, the angle is 0^o. But, does the light slow down as it enters the glass?
>
> L. No.
>
> T. It does slow down a little bit but it doesn't bend. So in a way, although we said the light does not bend it is refracted. That's because it slows down.

The discussion on definition of refraction was concluded with an activity titled reversibility through which the teacher helped the learners to state whether light is coming from more dense or less medium, to describe the direction of bending that should occur and label the angles **i** and **r**. He used diagrams that showed same paths but different direction of light rays between air and water. The discussion ended with an exercise in which learners were involved in matching values of angles **r** to the given values of angles of **i** in a diagram that had three rays from air into glass. This led to the next activity on refractive index in which refractive index was described as a mathematical relationship between **i** and **r** that showed how bending is going to occur. In the activity the learners participated by entering the matched angles in a table in columns with headings **i** and **r**. The learners also participated in the calculation of values of sine of angles **i** and **r**. The teacher gave them a hint of how to calculate refractive index by telling them how other learners calculate it when answering examination questions as reflected in the following excerpt.

> T. What is sin 40^o? Anybody with a calculator?
>
> What form 5 sometimes do in their examinations is to just divide **i** by **r** don't do that you must divide sin **i** by sin **r.**

A few learners got out their calculators and calculated sine values for the angles **i** and **r** that had been recorded in the table. The teacher entered the values of sin **i** and sin **r** in the table. The learners then calculated sin**i**/sin**r** and the teacher entered the values in the table. The values were correctly calculated.

Summary

This section has shown how the teacher introduced and described the images formed by a plane mirror using PowerPoint presentation which were later followed by a construction of the diagrams by learners using notebooks. It has also shown how the teacher defined refraction of light as a change in speed associated by a change in direction of propagation of light and introduced the terms used in refraction through use of diagrams. The diagrams were used to illustrate bending of light due to refraction.

Use of ray diagrams drawn by the teacher and formulas using PowerPoint and verbal presentation of image formation by a plane mirror and refraction of light concepts had a potential to support learners in making sense of the concepts. The shift from one slide to another provides a flow between from one diagram to another which is not possible to sustain when using a chalkboard or whiteboard. This had a potential to keep learners' focus and direct their thinking.

7.2.4 Lesson 4

School: B **Teacher:** B **Lesson Topic:** Refraction of light through rectangular glass blocks

Type of lesson: Teacher demonstration and learner hands-on activity

The objective of this lesson was to get learners trace a light ray through a rectangular glass block as an illustration of refraction of light which was presented in the lesson 3 (section 7.2.3). The activities involved demonstrations by the teacher to direct learners on how to carry out the activity and provide reasons on why they had to follow the steps demonstrated. The teacher demonstrations were followed by learner activity in which learners worked in groups of three to trace a ray through a rectangular glass block using optical pins. The learners completed the activity and submitted their work to the teacher.

Instructional activities: The teacher began the lesson by developing an understanding of the procedure for tracing the light ray through a rectangular glass block. He used a demonstration to bring about the understanding that light travels in a straight line. The teacher, with the help of a learner positioned his eye in line with four meter rules held vertically one behind the other and asked learners why he could only see one rule and not the other three. The learners' response was that light moves in a straight line. He then moved to the large transparent container filled with water and asked one learner to look at the rods with eye level above the container and asked him what he noticed about the rods. The learner said the rods were in a straight line. He then asked the learner to look at the rods through the large transparent container filled with water and to say whether the rods appear to be in a straight line. The learner said the rods did not appear to be in a straight line. The teacher asked the learners whether the light was no longer travelling in a straight line and a learner said the light bent. The following excerpt shows the discussion between the teacher and the learners.

T. Why can you not see the back ones (rods)? Because light travels in a straight line and the rods are in a straight line. Only one or two people can make the observation. But all of you will do this thing using glass blocks instead. Now looking *at the rods* through the water, do they appear to be in a straight line now?

L. No.

T. No. What has happened? If you look up here the rods are still in a straight line. But looking at the rods through the water they're not in a straight line. So, something has changed. Are the stands still in a straight line?

Ls Yes.

T. Yes. They have not been moved. So, this means that the light is not travelling in a straight line.

L. It is bent.

T. Yes. You are using the right word. What do we call the bending of light?

L. Refraction

T. Right. And really the word refraction means something else. What is it, do you remember?

L. Changing of position.

T. No. Not changing of position, the speed, it changes speed of light. When the light from those rods comes to this water, it slows down a little bit. That's why it bends. So you got to remember that. Refraction means the slowing down of light. But really the way we use the word in lessons is that refraction is the bending of light.

He reviewed the other words used in the bending of light such as refraction and change in speed.

The teacher then took the learners through the next step in the procedure, placing the rods in a straight line while looking through the large transparent container filled with water. He said "Now if I want to put them in a straight line, I have to move them until they appear in a straight line through the container." He told the learners that they were going to do the same thing using a glass block and pins and cautioned the learners not to look above the glass block when they are aligning the pins.

He demonstrated the procedure using chalkboard which entailed the following: positioning the glass block and tracing its position on a plane sheet of paper; drawing the normal line; drawing an incident rays at an angle to the normal (see pic. 18); placing pins along the incident ray and marking the ray as it emerged out of the glass block; drawing and joining the ray to show its path through the glass block.

Pic. 18: Teacher demonstrating measurement of angles of incidence

He repeated the steps using a different angle of incidence to help learners internalise the procedure. He cautioned the learners again not to look at the top of the glass block as they align the pins and instructed the learners to put something on the glass block to help them not to look at the pins above the block as stated in the following excerpt.

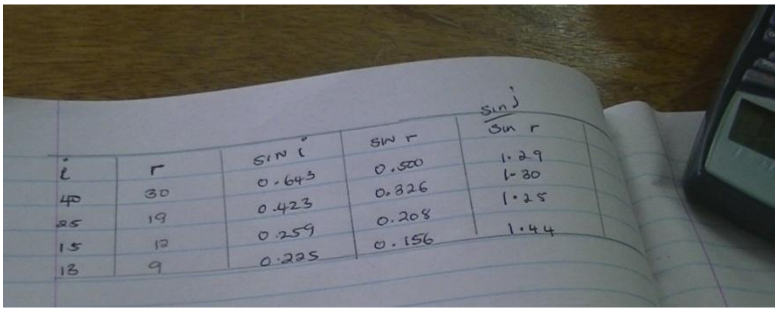
> T. The kind of mistake that students make is they keep looking at the top. You try to make them be in a straight line over the top of the glass block. No. You got to look through the glass block and get them in a straight line.
>
> You're going to be confused because on top of the glass you can see they're really not in a straight line. So, we can help ourselves here. On top of the block put something like an instrument case or a little bag or a book, something that you cannot see anything on top when you look through the glass block.

Pic.19 shows how learners used a notebook to block their view of the pins from above the glass block as instructed by the teacher.

Pic. 19: Learners tracing a light ray through a rectangular a glass block

He gave the learners three values of angles of incidence to work with. The teacher distributed protractors to groups which did not have protractors.

The learners were given 20 minutes to carry out the activity. The teacher announced that the learners should submit their work at the end of the lesson. The teacher went around supervising them. They moved their bags from the benches and worked in groups of three as instructed by their teacher. They worked through the activity without much difficulty. Pic.20 shows some of the learners' results.



Pic. 20: Learner's results on refraction of light through a glass block

At the end of the activity, the learners submitted their work. The teacher collected the protractors while counting them, he then allowed learners to leave.

During the post-lesson interview, the teacher mentioned that he found the learners' work generally good although he felt he did not give them enough time to make conclusions. Looking at some of the collected learners' work, the teacher commented on some of them. The teacher's comments included:

> That's neat.
>
> Good results.
>
> I think that's quite an achievement for a double science class.
>
> This one is way off it only got one pin in. This was the guy who was working by himself. He's got some problems.

Summary

This section has described the instructional activities in lesson 4 which included a demonstration of the ideas applied in using pins to trace a light ray travelling from air into a glass block and out the block. It has shown how the teacher illustrated the idea that light travels in a straight line and how it was refracted when viewed through a water bath. The activity showed how the teacher provided instructions for the practical activity by demonstrating them and how learners followed the instructions successfully as evidenced by the way they carried out the activity and the results they obtained.

7.2.5 Lesson 5

School: B **Teacher**: B **Lesson Topic**: Apparent depth, critical angle and total internal reflection

Type of lesson: Teacher demonstration of and learner experiment

The objective of this lesson was to introduce apparent depth, critical angle and total internal reflection concepts. The activities involved explanations of the concepts with the aid of demonstrations by the teacher and measurement of critical angle using a semi-circular glass block by the learners. The lesson drew from terms and diagrams that were used to define refraction and practical skills for demonstrating refraction in the lessons 3 and 4 (sections 7.2.3 & 7.2.4).

Instructional activities: The teacher introduced the lesson by giving the learners homework which involved drawing a graph using a set of angles they obtained in the last lesson activity. He drew a table with column headings angles **i** and **r**, sin **i** and sin **r** and put in values of angles **i** and **r**. The learners were to calculate sin **i** and sin **r**, draw a graph of sin **i** against sin **r**, and find the gradient. The teacher reminded the learners to consider which variable goes to the x and y axes, to make a proper scale, plot points and draw a line according to examination standards. He told the learners that they can work with each other but should not copy from each other.

The teacher then informed the learners that they were going to learn about the apparent depth and critical angle in the lesson. On apparent depth, the teacher had arranged two sets of apparatus, a container filled with water with a stone labelled fish placed in the water and a measuring cylinder filled with water with a stone inside. He asked the learners to look at the 'fish' in the tank and the stone in the measuring cylinder and note the difference between the depths in relation to where the fish or stone is in real and where they appear to be.

He then drew and explained a ray diagram on the chalkboard showing how apparent depth is formed in terms of refraction. He drew two light rays from the fish to the water surface. The teacher then asked learners which was more dense air or water. The learners' response was air. The following excerpt shows part of the discussion.

T.	Right, why does the fish appear to be higher than it really is? We got to talk about two positions. When you look down at the fish in the water, there is a fish, there, where you think it is - is not where it really is. Really it is below where you see it to be. And, the reason is the light is bent as it comes out from the water. If we want to know where an image is, we draw these rays. We drew them before. You've seen them before. *Hei, monna tsoga*! Young man, wake up! (*The learner was resting his head on the bench and not paying attention to the teacher*) Here is the ray of light coming from the real fish, the object, also from a tin of lucky star. If the ray carries on from the water, going straight out of the water, that won't be true. It doesn't carry on straight because water and air have different densities. Which is more dense, water or air?
Ls.	Air
T.	Air, so air is heavier than the water? Is it difficult to carry a scoop full of air or a scoop full of water?
Ls	…of water
T.	Remember if the scoop is empty is not empty is full of air. So which is heavier air or water?
Ls.	Water
T.	which is more dense?

Ls. Air, water

T. Water is more dense. Density means how heavy one unit body is like one litre of water, one scoop of water. A heavier substance means a unit body has more mass. So, the ray of light moves from more dense to less dense medium. We learned what makes them bent away from the normal *line (showing the direction of bending with his hands)*. But the eye always believes that the rays of light come out without bending.

Commenting during a post-lesson interview on learners' lack of understanding of density, the teacher said the following.

T. I was a bit surprised how they didn't remember or understand that water is denser than air. I am still very perplexed by that. I thought even if the topic of density is not on their syllabus they would still have some ideas left over from junior secondary or primary science. At least density equals heaviness may be.

The teacher drew two straight lines from the image to the eye position through the points where two incident rays from the fish reach the surface of the water. He related the image to the mirror image in that they appear to be where they are seen but they are not really there. He told learners that the eye saw the fish as if light was not bent. This was shown by line from the image of the fish to the water surface being dotted but coming out as a solid line with an arrow. He also mentioned how the refractive index could be calculated using real and apparent depths but did not discuss the calculation.

Critical angle

The teacher presented the concept of critical angle through a class demonstration using semi-circular block and a ray box. Before he introduced the concept, he explained the path of light through the semi-circular block. He put two semi-circular glass blocks together to make a circular block and focused learners' attention to the centre of the blocks and told them it was to be used as the centre for the semi-circular block. Using the notice board for the demonstration, he held the semi-circular block on a plain sheet of paper pinned on the board and drew a line around it, tracing its shape. He informed the learners that he was going to pass a light ray along the radius of the block. To develop the fact that the radius makes 90^o angle to the curved part of the block, he drew a tangent to the curved side and a normal line. After telling learners that a line that enters at 90^o would pass through the centre of the circle, he asked them what name is a line that passes through the centre of a circle. The learners said it is a radius. He then told them that a radius makes 90^o angle to the surface of the circle.

Reminding learners that light bends away or towards the normal when it passes into a medium of different density and does not bend when it passes along the normal line, the teacher drew a light ray entering the block along the normal line to the centre. To explain how the light would emerge from the glass block, he told learners that the light was going to bend because it was moving from one medium to another, that it won't travel straight as it would in the same medium or when it travels along the normal line. He asked learners whether the ray would bend towards or away from the normal. The learners said it would bend towards the normal. In response, the teacher reminded the learners that the bigger angle is always in the less dense medium irrespective of the direction in which the light travels. To stress the point the teacher asked learners questions such as which angle is in less dense medium and which medium is in the smaller angle. The following excerpt shows the interaction between the teacher and the learners on the direction in which light would bend.

T. As it comes out at this point (*the plane surface of the semi-circular block*) it's not normal at this surface so it's going to bend. Is it going to bend away from the normal or towards the normal?

L. towards the normal

T. No. because it is from Perspex (the word perspex was mentioned in lesson 1) into air. The bigger angle is always in the less dense medium. The bigger angle is always in the less dense medium. What angle are we referring to? The angle between the normal and the (light) ray, whether it's the angle of incidence or the angle of refraction, it doesn't matter, the bigger angle is in the less dense medium. What is in the less dense medium?

L. bigger

T. The bigger what?

L. angle

T. You have to remember these things. The bigger angle is in the?

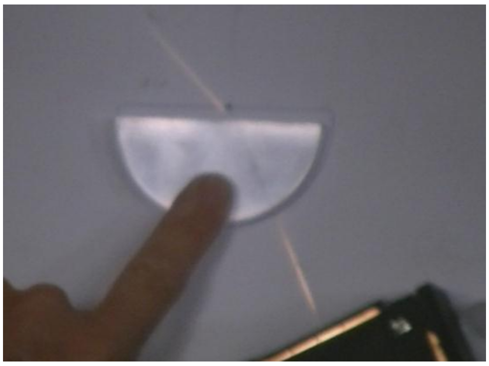
L. less dense medium

T. The lesser angle is in the?

L. more dense medium

To introduce the concept of critical angle, the teacher demonstrated the path of the light ray through the semi-circular block on the notice board, using a ray box as shown in pic.21. He then alerted learners to another ray, the internally reflected ray.

T. So it's going to bend this way like that (*shines the light through the block as in pic. 21).* We're alright. It bends away from the normal. The angle in air is bigger than in the Perspex because the air is less dense than the Perspex. Now some of you might notice another ray. There is a ray going into the block at the bottom, there is a ray coming out at the top. Can you see another ray, it's very dim.



Pic. 21: Demonstration of refraction through a semi-circular block

He increased the angle of incidence to increase the intensity of the internally reflected ray so that learners can see it. He explained the internally reflected ray in terms of images formed by window panes that the images are dim because part of the light passes through the window pane and part of it is reflected.

He continued to increase the angle of incidence inside the glass block. This led to light ray coming out of the glass block bending further away from the normal line until it disappeared which the teacher said was total internal reflection. He told the learners they were going to measure the critical angle and went on to demonstrate how they were to do it.

He positioned the block vertically on a board with the plane side down. He then looked down through the block at the red line marked at the centre of the block, moved his eye down the curved surface tracking his eye position with a pen, and marked the point where the line disappeared with the pen. The position where the line disappeared was to be used to draw a line to the centre of the block that represents the incident ray which marks the critical angle. The following excerpt presents the teacher's instruction on determining the critical angle. In his words he said:

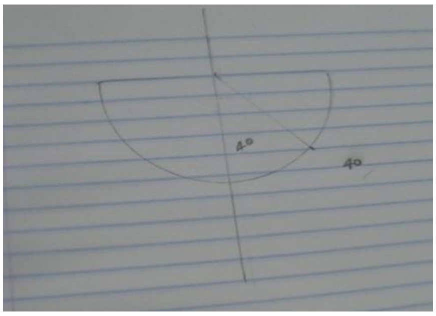
T. Like I said there is a red line at the centre of the block. You put your block down on the bench (*puts the block on the bench with the plane side down)* and look down. I can see the red line. What I'm going to do is put a pencil between my eye and the red line. As I bring my eye down (*demonstrating)* I keep the pencil tip between my eye (*slowly moving the pencil over the semi-circle)* and oh! it's gone. The red line suddenly disappeared. Let me do it again. I can see the red line with my eye on the top. I bring my eye down with a pencil to keep track. Suddenly, the red line goes, there (*at that point*). So I mark the glass (*at the point where the line disappeared)*. Some of the glass has a rough surface which is easier to mark (*using a pencil)*. And then you draw a line. May be that's where you draw a mark and you draw a line to the centre (*through that* *mark)*. What you have found is the critical angle and you need to measure the critical angle.

After the teachers' demonstration, the learners were sent to their work place to carry out the activity in groups of three. The teacher told the learners he was going to stop them five minutes before the end of the lesson to collect the equipment. The learners worked through their activity easily, drew the diagram and measured the angle.

Five minutes before the lesson ended the teacher told the learners to stop working. He informed the learners that they can calculate the refractive index using the critical angle. He gave a range of acceptable angles as reflected in the following excerpt.

T. I showed you this set up. If you can't find the refractive index by dividing sin **i** by sin **r**, if you've got an angle as 42^o that makes the calculation of refractive index as 1.49. The correct angle for refractive index should be about 42^o, 40^o to 44^o will do.

Pic. 22 shows an example of the learners' work and the critical angle of 40^o. The angle of 40^o is very close to the theoretical value of about 42^o.



Pic. 22: Learner's work showing a critical angle

The learners returned the apparatus. The teacher checked the returned apparatus and allowed the learners to leave at the end of the lesson.

Summary

This section has given the description of the activities in lesson 5 (section 7.2.5). It has shown how the teacher demonstrated and explained the concepts of apparent depth using water container and measuring cylinder, as well as critical angle and total internal reflection using ray boxes. In the explanations the teacher used the ideas of refraction introduced in lesson 3 (section 7.2.3) such as the bending of light, and the terms used to describe refraction of light rays such angle of incidence and refraction. It also used the skill used in drawing ray diagrams for images formed by a plane mirror in lesson 4. The section has also shown some of the learners' results in determining the critical angle using a semi-circular block.

Learner activity on determining critical angle involved the semi-circular block only which made the procedure short and less cumbersome and learners were able to carry it out in their individual notebooks although they worked in groups. The demonstration on apparent depth using a stone to represent fish made the concept more accessible as it is common and easier to see stones in pools of water than fish. The use of notice board mounted on the laboratory wall made small ray box used in the demonstration visible to the group of 40 learners which is a valuable skill for teaching large classes.

7.2.6 Lesson 6

School: B **Teacher:** B **Lesson Topic:** Critical angle and total internal reflection

Type of lesson: PowerPoint Presentation

The objective of this lesson was to illustrate the critical angle and total internal reflection. The instructional activities began with the teacher's recap of the ideas covered in the previous lessons which included definition of refraction, refractive index, apparent depth, critical angle and total internal reflection. The main activities included teacher's PowerPoint presentation on critical angle and total internal reflection. The lesson ended with an exercise which involved the learners in the presentation.

Instructional activities: The teacher greeted the class and introduced the lesson by informing learners that they were going to have PowerPoint presentation for 25 minutes and then they would have a learner activity for the next 25 minutes. He told the learners that the presentation was to help them with some of the difficult ideas and that he was going to repeat some things they had done. He said

T. The point of the PowerPoint is to try to understand some of the difficult ideas. When you start to look at the screen is a bit like entertainment because when you start to relax you stop thinking. There is lots of stuff I'm going to show which you did not see before. We need to remind ourselves about some things.

The teacher reviewed learners' knowledge on relative optical density of transparent media, he included in his presentation air, water and glass. The following excerpt reflects how the discussion proceeded.

T. By the way which angle is bigger A or B *using his arms to represent the angles*?

L. B

T. Good. Secondly, which is more dense air or water?

L. Water.

T. It's easier to carry a scoop of air than water because water is heavier than air. Technically we should say it's more dense than air. Which is more dense glass or air?

L. Glass.

T. Which is more dense glass or water?

L. Glass

T. Because glass sinks in water.

The teacher then used the PowerPoint to go over concepts that were presented in lessons 3 and 4 (see sections 7.2.3 & 7.2.4). The concepts included the direction of bending that occurs when light enters or leaves a denser medium. He also used the idea of reversibility where the path of light was kept constant but the direction of travel changed and learners were asked to identify angles of incidence and refraction and to compare the sizes of the angles.

T. We start off showing slides that we used before.

A PowerPoint slide titled 'If incident ray is on the normal' was projected on the screen

T. So here we have a ray of light, an incident ray coming from air entering the surface of the glass. Which way does it bend?

L. Towards the normal.

T. More dense medium, towards the normal, so it passes fast in the air and goes slowly in the glass. If we change the direction of light and follow the same route, (*an arrow moves along the same route in an opposite direction)* which way does the light bend as it comes out into the air?

L. Away from the normal.

T. Now, that's the angle of incidence down there (*labels it **i***), and that's the angle of refraction (*labels it **r**),* which one is bigger.

L. angle **r**

T. In this one (*light going in the opposite direction)* where is angle incidence, *ee, ga gare* (words in Setswana), in the middle (*labels it **i**).* Where should I put **r**? (*moves the cursor to different angles asking for learners' response)*

L. No, no, no, yes.

T. Which one is bigger **i** or **r**?

L. **i**

The teacher also used the PowerPoint to go over apparent depth, internal reflection, critical angle and total internal reflection which were covered in lessons 5 (see section 7.2.5). These concepts were however presented on PowerPoint for the first time. The presentation began with a discussion in which the teacher took learners through a ray diagram showing apparent depth. The following excerpt shows part of the discussion.

T. Remember that I showed you there was a discrepancy between where the fish was and where it appeared to be. The real fish is the object. What do we call where it appeared to be?

L. The image

T. Right. So, what did we notice about the position of the image relative to the object?

L. is nearer

T. What happens to the ray of light as it reaches the surface?

L. It bends

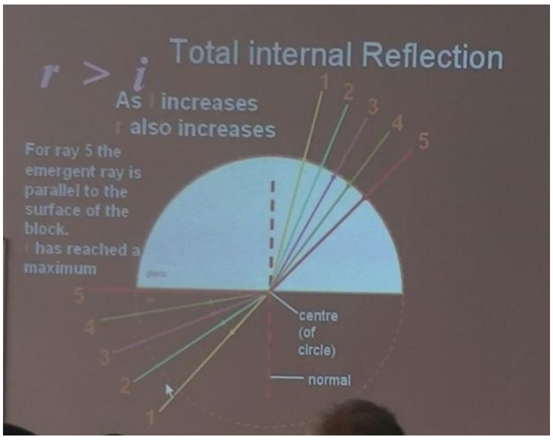
T. *looks at the learners in a questioning sense.*

L. away from the normal

The teacher then mentioned how the refractive index is calculated using the real and apparent depths.

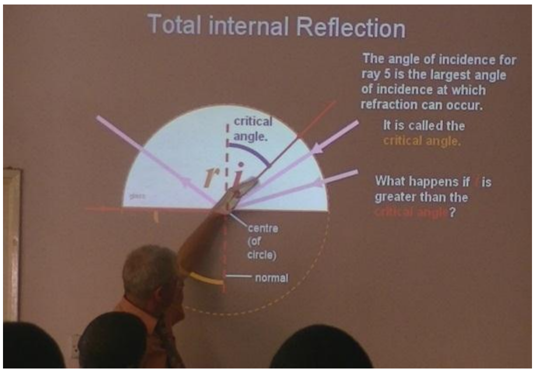
T. The real depth divided by the apparent depth is a way of calculating the refractive index. It is another way of doing it. If you use the ray or pin method, it will still come to the same answer. So if we measure the depth of the stone may be it is 1.2 m, where it appears to be 0.9 m, how do we calculate the refractive index? To 2 significant figures it is 1.3, 3 significant figures is 1.33 Are they more or less than 1?

To introduce the critical angle and the total internal reflection, the teacher projected a diagram of a semi-circular block as part of a circle with the centre of the circle labelled. A light ray was shown entering from the curved section of the block and the fact that it travelled along the normal line was given as a reason for it not bending. The teacher led the learners gradually towards the direction the ray would take when it emerged at the centre, along the plane surface. This he did using questions such as: Which is more dense glass or air? How does light bend as it enters a less dense medium? The teacher added four more rays to show the effect of the increase in the angle of incidence on the angle of the refraction as shown in pic. 23.



Pic. 23: A diagram showing changes leading to a critical angle

He involved learners in the presentation by getting them to match the incident and emerging rays. He pointed out that the angles of refraction are larger in air than the angles of incidence in the glass block. He then asked one learner to indicate to the class the angle of refraction for incident ray 5 on the board and other learners to give the value of the angle; they correctly gave the angle as 90^o. The teacher said any increase in the angle of incidence can't get any bigger angle of refraction than 90^o which makes the angle of incidence for incident ray 5 a critical angle (see the Fig 23). And that increase in the angle of incidence in the denser medium beyond the critical angle would result in total internal reflection. The effect of an increase in the angle of incidence beyond the critical angle was demonstrated through a diagram shown in pic. 24.

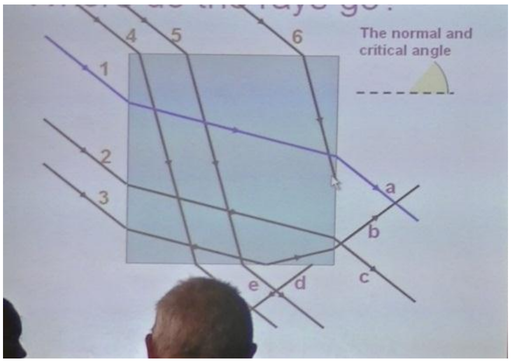


Pic. 24: Teacher explaining changes leading to total internal reflection

The teacher repeated the presentation on the ray diagram with a focus on partial internal reflection for which he made a reference to the demonstration done using a ray box in lesson 5 (see section 7.2.5) on critical angle.

The presentation was concluded with an exercise on refraction titled "where do the rays go" in which learners were involved in matching light rays into and out of a rectangular glass block.

The exercise is shown in pic. 7.25. The learners were given a chance to decide whether the ray would undergo total internal reflection or emerge. The teacher used the critical angle measure next shown in pic.25 to check the learner response. If the angle of incidence made by the ray in the denser medium was larger than the critical angle it would be expected to undergo total internal reflection otherwise it would be expected to bend away from the normal on emerging in air (less dense medium).



Pic. 25: An exercise titled “where do the rays go”

The learners were told to change their sitting and given instruction to work on their activity for the remaining 20 minutes.

Summary

The section has described the instructional activities in lesson 6. It has shown how the teacher reviewed ideas of refraction covered in previous lessons and how he illustrated and explained the concepts of critical angle and total internal reflection for the learners. The PowerPoint in this lesson has allowed the teacher to use different colours for different rays which enabled him to clarify the critical angle and total internal reflection concepts through visual diagrammatic representation.

7.2.7 Lesson 7

School: B **Teacher**: B **Topic**: Introduction to Lenses

Type of lesson: Demonstrations and learner practical activity

The lesson objective was to introduce diverging and converging lenses. The activity involved definition of converging and diverging lenses in terms of their shape, the terms used to describe them and the way they refract light with the aid of diagrams drawn on chalkboard and demonstrations using a ray box. This was followed by learner activity in which learners measured the focal length of a converging lens and object distance of a virtual image formed by the lens.

Instructional activities: To introduce lenses, the teacher held a rectangular glass block and told learners that he could see reflection of his fingers when he looked through block. He told learners that the blocks are placed on their benches and they could play with. He stated differences between the glass block and a lens including the fact that the glass block does not change the shape of objects when light from the objects passes through it, using the window pane as an example. He told learners that lenses do change the shape of objects.

He then led learners through a discussion on how lenses changed the shapes of objects. He illustrated how parallel incident light rays were refracted as they passed through a diverging and converging lens which entailed the bending of light rays as they entered and left the surface of the lens. He used three parallel rays for the illustration. When he drew the last ray which was the middle ray through converging lens, the three did not meet at one point instead they crossed each other at different points. The teacher said the diagram was bad and the learners agreed that it was a bad diagram. The teacher was surprised when the learners also found the diagram bad as reflected in the following excerpt.

T	How about the one in the middle?
Ls.	It goes straight.
T.	It goes straight because, look, at the surface here the normal is here. It's on the normal already. It does not bend. It comes in a straight line. The other side of the glass, the same thing, this is the normal, it (light ray) continues in a straight line.
	I have drawn a really bad diagram!
Ls.	Really bad! It's a bad diagram. The diagram is bad.
T.	You are supposed to say no.
Ls.	It's a bad diagram.

T. What's wrong with the diagram? There is nothing wrong.

L. The line in the middle has to meet…

T. The lines have to meet. They are meeting.

Ls No

T. You mean they all have to meet…

Ls. at the same point

T. At the same point. So may be one is bend too much.

Ls. Yes

T. If parallel rays of light all converge, come together at one point, what do we call that point? Do you remember when you were young in Form 3 you studied this.

Ls. Yes, Yes.

T. That's called the focal point (labels the point on the diagram).

Ls. Yes, yes. Focal point

In the excerpt, the teacher took the opportunity to find out from the learners what they thought made the diagram bad. The learner's response was not explicit, or may be the learner was stuck with words, on what was wrong with the diagram, when he said "the line in the middle has to meet…" The teacher took a defensive stance when he said "They are meeting". The learners said "No" an indication that they wanted to clarify the point.

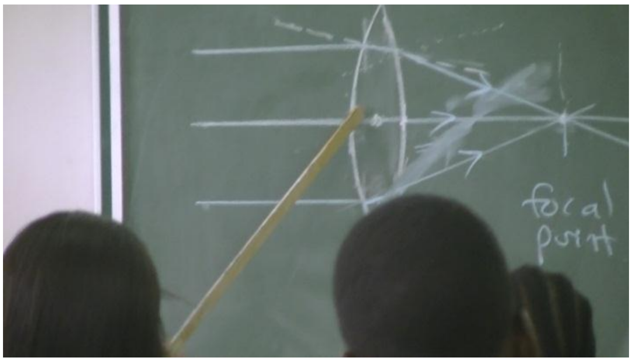
The teacher then structured the sentence for the learners to complete, "you mean they all have to meet…" and learners said "at the same point". The teacher indicated in an interview that the learners do not have the right words to explain science ideas or to ask questions. He highlighted key words in his PowerPoint presentation and he said he highlighted the words to help the learners to use them as reflected in the excerpt that follows.

R what I really found missing in your lessons is learners talking about the ideas you are presenting.

T Ah, that is why those key words are there on the board. Sometimes the kids are trying to explain something and they can't remember the right words. Even to ask the questions they can't remember the right words. If those words are there on the board they can use them.

The teacher wanted the learners to state ideas in a right way. His comment on their lack of the right words implies his perception on the difficulties learners had with the language used in instruction. He also saw it as his responsibility to make the words available for them to use as reflected in section 7.2.8 where the teacher presented words for learners to choose (see pic. 33).

After the learners and the teacher had agreed on what was wrong with the diagram, the teacher erased the initial position of one of the refracted rays and drew a new line so that the rays all met at a point as shown in pic. 26. The position of the erased line can also be seen in pic.26.



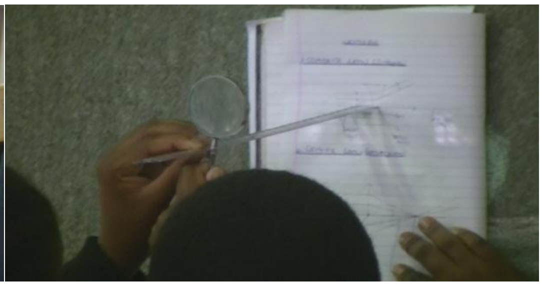
Pic. 26: A corrected ray diagram learners said was really bad

He then used the opportunity to introduce the terms focal point, optical centre and focal length. He used a ray box to demonstrate how light rays pass through a thin and thick convex lens and compared their focal lengths. He also demonstrated how the light rays pass through a concave lens. He then used the terms converging and diverging respectively for convex and concave lenses in reference to the way they bend the light rays.

The teacher drew the diagrams of the lenses for the learners to copy. He explained that the focal point for the diverging lens is where the rays seemed to be coming from and marked it on the diagrams. After drawing the diagrams the teacher used a ray box to demonstrate how the lenses refracted light rays (see pic. 27).

Pic. 27: Demonstration of refraction by a thick convex lens on a laboratory notice board

For the learners' activities, the teacher demonstrated how learners were going to measure the focal length of a thin convex lens and the object distance of a virtual image formed by the lens. Pic.28 and pic.29 show the learners carrying out the activities.



Pic. 28: Learners measuring object distance **Pic. 29:** Learners measuring focal length

The teacher concluded the lesson by posing questions such as why ~~did~~ the pen ~~have~~ had to be at a particular distance for the image to be seen, and why the image of a distant object was at 10 cm. He said that they needed to draw ray diagrams. He reminded the learners to submit the worksheets they had used for the topic of light. The learners were allowed to leave at the end of the lesson.

Summary

The section has described the activities of lesson 7. It has shown how the converging and diverging lenses were introduced through diagrams and demonstrations using a ray box. The discussions engaged upon in the diagrams and demonstrations described refraction of light by the lenses. The section has also shown how the learners were involved through hands-on activities. The highlight of this section was the use of multiple representations in defining diverging and converging lenses in the form of diagrams, demonstrations and hands-on activities. The activities introduced the learners to the next lesson on ray diagrams showing image formation by lenses.

7.2.8 Lesson 8

School: B **Teacher**: B **Lesson topic**: Ray diagrams of formation of images by thin converging lens

Type of lesson: Teacher PowerPoint presentation and learner activity

The objective of the lesson was to introduce learners to the ray diagrams representing formation of images by thin converging lenses. The lesson had two parts. The first part was teacher's presentation which involved construction of ray diagrams showing images formed by a thin converging lens. It entailed terms used to describe the diagrams. The second part involved learners drawing ray diagrams in their notebooks.

Instructional activities: The teacher's presentation entailed key points meant to guide the learners in drawing ray diagrams and description of the images formed. The presentation started with a PowerPoint slide showing a ray diagram with a large number of rays radiating from the tip of the object and the rays that passed through the lens converged at a point. The image of the object was shown after the teacher placed a screen at the point where the rays meet to demonstrate that the image could not be seen unless a screen was placed at the point. He drew the learners' attention to two rays, the ray from the object to the lens parallel to the principal axis and one that passed from the object through the optical centre. The teacher then removed all the other rays expect the two rays which he told the learners were the ones needed to know how and where the image is formed. The following excerpt shows how the ray diagrams were presented.

T. Notice that the rays do not stop at the image they *continue* in their straight lines. An image will not be seen unless you put a screen at the right place. Well let's do that.

A screen is inserted in the diagram where the light rays do not meet. The teacher moves the screen where the lines meet and image appears on the screen.

T. Now you can see the image. Can you see it? Yes. Good. There are too many rays here. If we would like to know how and where to draw the image, which rays do we really need to use?

Ls. Focal point, optical centre

T. The one which passes through the optical centre because that's easy to draw, you can draw a straight line there. We need two. There they are.

The rays are erased except the one passing through the optical centre and the one that approaches the lens parallel to the principal axis.

T. The one (*ray*) that goes through the middle of the lens, the optical centre. What's special about this one?

L. inaudible

T. But how do I describe it? It is parallel to the principal axis. The one which is parallel to the principal axis bends to go through the focal point.

As shown in the excerpt the teacher told learners the reason for using the each of the two rays. He said the parallel ray was used because it crosses the principal axis at the focal point after being bent by the lens and the ray that passed through the optical centre was used because it passed straight through the lens without bending therefore easy to draw. After describing the rays, the image was drawn and described. The following excerpt shows the part of the discussion on how the image was presented in the diagrams.

T. So where is the image?

Ls. Where the lines (*rays*) meet

T. Where the lines (*rays*) meet. There, that's where they meet. The tip of the arrow is there. ... The base of the arrow would still be on the principal axis. Try to use these words. When I ask you a question try to answer. You must use these words and make them your own words.

The teacher reviews the points.

T. Let's try again. (*Projects a diagram showing the lens, the object and the principal axis with focal points marked on both sides of the lens*) So this is the object, how do I find out where the image is? We draw two lines (*rays*).

Which lines do we draw?

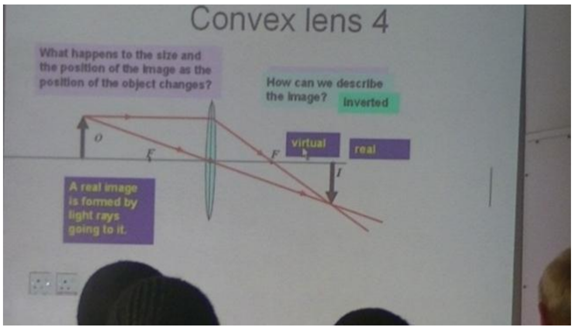
One through the optical centre and the one that's parallel (*to the principal axis*) and of course it will go through the focal point after it goes through the lens. (*The lines are drawn on the diagram*).

Now where do we find the image?

Let's find where the image is.

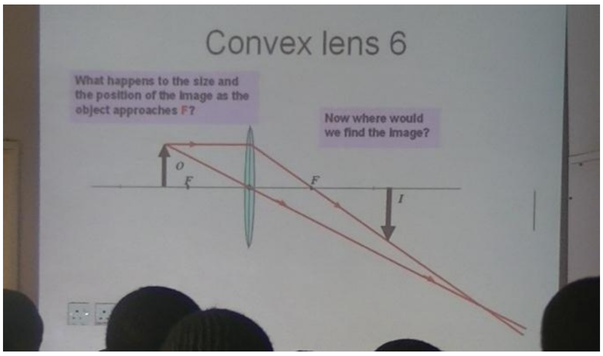
T. & Ls. Where they meet (*An image is drawn where the lines meet*)

Pic. 30 shows the first ray diagram drawn with the object at a distance of 2F which was used to describe the image size, orientation and nature.



Pic. 30: Ray diagram showing formation of a real image

The teacher presented four ray diagrams for different object distances. The distances were changed by moving the object towards the lens on the diagrams from the distance 2F. As the distances were changed, the two rays were adjusted so that they started from the tip of the object in each diagram. This resulted in the rays meeting at different positions after passing through the lens so the image positions and sizes also changed. Pic. 31 shows the diagram before the image was adjusted.



Pic. 31: Ray diagram showing formation of an enlarged real image

The changes were verbalised by the teacher and after two diagrams, learners were able to verbalise the changes as they were made. The teacher involved the learners through questions before stating and making changes for each steps. The teacher also used at least two words with different meanings that could describe the size and nature of the image such as upright/inverted, magnified/diminished and virtual/real for learners to choose the appropriate word.

Teacher moves the image away from the lens to the point where the rays meet and adjusts the image size

T. Yah. But now I've got to stretch the size because it has to touch the principal axis (*Stretches the arrow representing the image to the principal axis*). What happened to the image by the way, since we moved it from there to there (*pointing at previous and present position*)?

L. It increased in size

T. How can we describe the image?

The title, How can we describe the image? *appears on the screen and the following words appear around the diagram:* Upright *and* Inverted (upsidedown)

Ls. It's upsidedown, upright

T. Try to use the word inverted. It's not upright. Upright is the same way as the object (*holds his hand vertically up*). If that's you there wearing a pointed hat (*pointing at the object*) here you are upsidedown *(pointing at the image*), you are inverted, you are not upright.

Teacher moves the word inverted next to the title and the discussion proceeded as follows.

How can we describe the image? Inverted

T. Is the image virtual or real?

The following appear around the diagram.

Virtual Real

A real image is formed by light going to it

Ls. Virtual (*pause*) real

T. Look at what real means (*referring to the point on the screen which read "A real image is formed by light going to it"*). Rays of light are going to meet and form an image. (*moves the word "Real" to the question and erases the word "Virtual"*)

How can we describe the image? Inverted and real

The last diagram involved changing the object distance to less than focal length by positioning the object between F and the optical centre. The teacher presented the formation of the image by taking the learners through similar steps: adjusting the two light rays so that they started from the tip of the object and passed through the lens accordingly. But, the two light rays diverged, instead of converging, after passing through the lens. The discussion was as follows.

T. Now,

What happens to the size and position of the image when the object is between F and the lens?

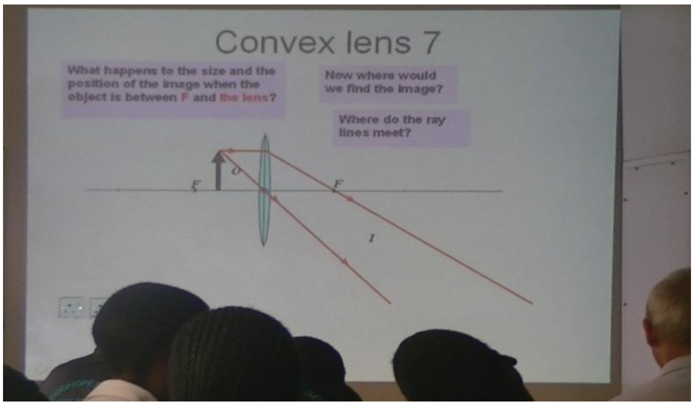
We are going to move it closer again and we are going to put it between F… F stands for?

Ls. Focal point

T. The principal axis is here. So it's going to go somewhere here. Here we are (*moves the object*). Now we've got to change the …

Ls. Lines

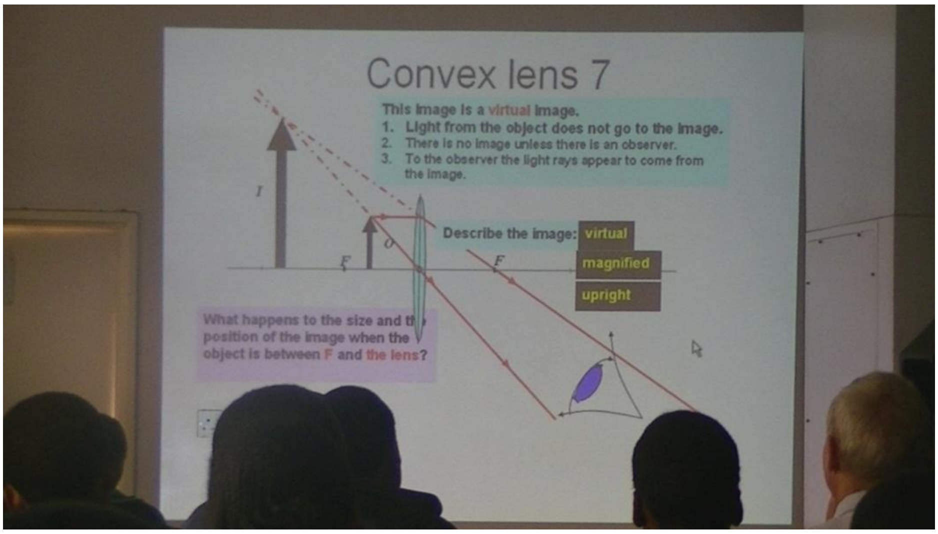
T.	Rays. Change the rays. (*Now that the learners' responses show some understanding of the steps, the teacher guides them to use the science word 'rays' instead of 'lines'*)



Pic. 32: Ray diagram showing formation of a virtual image

Ls	Woo!
T.	Mathata! (It's something else!)
Ls	laugh
T.	The image has nowhere to go. It wants to go there (*pointing behind the lens*) but it can't go there. Why? Because…
Ls.	Lines do not meet.

In order to locate the image, the teacher drew lines that extended the light rays backwards so that they met (see pic. 32). The image was drawn where the extended lines met as shown in Pic. 33, and was described as virtual and magnified.



Pic. 33: Ray diagram showing formation of a virtual image

The following excerpt shows part of the discussion.

T. There is nowhere the lines meet to find the position of the tip of the object. (*Extended the rays backwards.*) Ah! They meet this side, is any light going back here? No.

Ls. No

T But if you put your beautiful eye this side (inserts a diagram of an eye on the other side of the lens) then, it's going to think that the light rays are coming from that point (where the extended lines meet)…your eye is going to think that it comes from there…now it can't believe what it is seeing…It's so happy.

Ls. laugh

T This image is a virtual image. (also see pic. 33)

The discussion proceeded with the description of the image as magnified and upright with alternative words appearing to define the descriptions further as reflected in the following excerpt.

Two words appear near the diagram

Magnified Diminished

Ls Diminished

T. What does diminished mean? Diminished mean made smaller. That's the object there is the image. It looks to me as if the image is smaller than the object.

Ls. Magnified

T. Magnified

L. I really like that word (*sounds like what the teacher normally says*).

Ls. Laugh

Two words appear near the diagram: Upright inverted

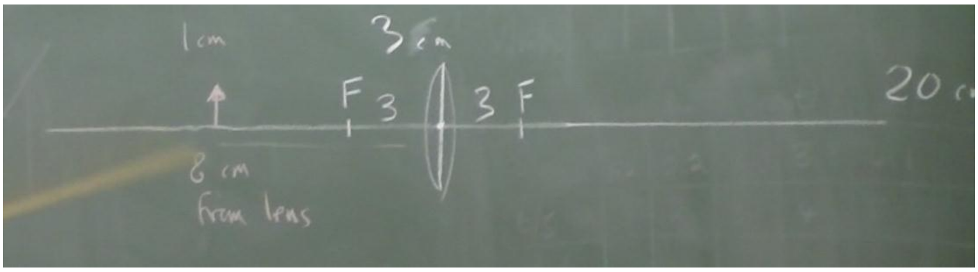
Ls. Upright

After the presentation on PowerPoint, the teacher used the chalkboard to introduce the learners' activity. He used the board to represent the learners' notebook page and to demonstrate how they should draw the principal axis, where and how to position the lens symbol along the principal axis, and where to position the focal points. He also provided the learners with the measurements to use such as the height of the lens and the object. He told the learners that the hand-out for the exercise could not be duplicated so they had to draw the diagrams in their notebooks.

T. There is a hand-out but there is no paper for it to be printed. So, we will get it in due course. So, you are going to draw these diagrams in your notebook. And it's not very easy. I'm going to give you the size and distances to draw your rays, focal points and principal axis. You need to draw everything exactly that way I have drawn.

Sit down and face the board.

Pic. 34 shows how the chalkboard was used to guide learners in their activity.



Pic. 34: Diagram used to guide learners on drawing ray diagrams

During the activity, the teacher used the steps he used during the PowerPoint presentation for guiding the learners' drawings. The following excerpt reflects a conversation between the teacher and the learner during the activity.

T. There is another line (ray) going through the middle of the lens. Why are we drawing that? What do we know about the ray of light going through the middle (optical centre) of the lens?

L. It goes in a straight line.

T. It goes in a straight line. It doesn't bend. Then, where those meet that's where you draw your…

L. No response

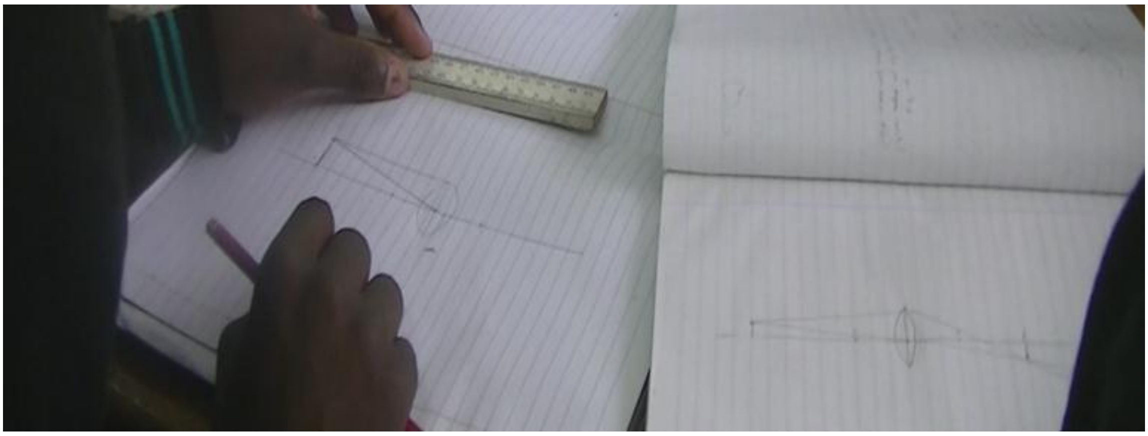
T. Image. That's where you draw the image. That's where the picture of the object is.

The learners worked through the diagrams by collaborating with each other and they consulted their teacher at the initial stages of their diagrams to check if they were drawing the diagrams correctly. Some of learners' work showed some deviation from key points. For instance some learners disregarded the parallel ray and did not have it cross the principal axis at the focal point after passing through the lens. The conversation in the following excerpt reveals how some learners disregarded the parallel ray.

L3. *Goo mona ga se straight line, go tla jaana. E tshwanetse go benda (Setswana).* This is not supposed to be a straight line, it should go this way [*indicating a sloping line for a line that was supposed to be parallel to the principal axis]*. It should bend. (see pic. ~~31~~ 35)

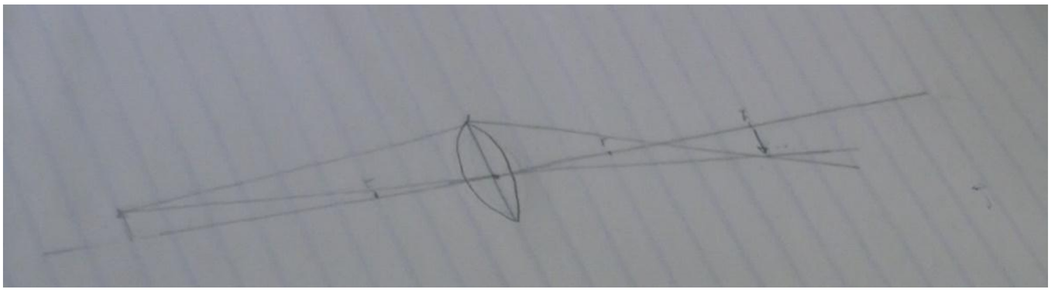
L4. *Ahe! ke a go utlwa*. Ooh! I get your point.

L3. *Raba. Tlaa ke go bontshe. Image ena e tswanetse go lekana le object (Setswana). E tshwanetse go nna 1 cm, 1 cm.* Erase it. Let me show you. This image should be the same size as the object. It should be 1cm, 1cm [*pointing at image height and then the object height*]



Pic. 35: L4 diagram on left and L3 diagram on the right

L3 then showed L4 the size of the image from her book (see pic. 35) and told her to erase what she had drawn. Pic. 36 shows a larger picture of L3's diagram.



Pic. 36: A ray diagram showing some learners mistakes

The discussion between L3 and L4 shows that L3's mind was on the image size which was shown in the first diagram in the teacher's presentation (see pic. 30) and not on how the rays were supposed to be drawn to get the image. L4 had the rays drawn correctly up to the lens (see pic. 35). But, before she could draw the rays through the lens, L3 erased what she had drawn and showed her how to draw them her way.

At the end of the lesson most learners were working on their second diagram so they were instructed to work on the diagram at home. Those who had completed all the four diagrams were given a table on which to record the object distance, image distance, height, orientation and whether images were real or virtual.

Summary

The section has shown how the teacher presented ray diagrams that show image formation by a converging lens and guided learners on how to draw them. It has shown how the teacher argued for the selection of two light rays for determining the position of the image in order to make the drawing simple. The highlights of this lesson are the teacher's selection of critical points which he used to guide learners in constructing the ray diagrams and the repetition of the steps to prepare learners for the opportunity to apply the steps when drawing the diagrams in a class exercise.

7.3 Analysis of teacher B's instructional activities

This section presents the analysis of Teacher B's instructional activities so far described in sections 7.2.1 – 7.2.8 based on the transcripts of the eight lessons that were directly observed. In some instances video recordings and interview transcripts have been used to clarify the information on lesson transcripts.

7.3.1 Creating an environment of competence

Teacher B's instructional practice was organised and managed to provide optimal opportunity for learners to interact with each other, the teacher and the topic content. This was evident in the second half of each lesson which was reserved for learners' activities. The activities included hands-on activities and pencil and paper exercises. In pencil and paper exercises the learners worked in individually or in groups and were free to consult other group members for assistance. In practical work, the learners worked in groups of three but each learner was required to produce his/her own work. The teacher checked and supervised learners' work and monitored their progress. This was in accord with Vygotsky's sociocultural theory that instruction should be organised in a way that enables the learners to interact in order to construct concepts at an intra-personal level (Vygotsky, 1978; Wertsch, 1991).

The learners' hands-on activities had conceptual and procedural components which were clearly illustrated in the teachers' introductory demonstrations for the learners' hands-on activities. For instance, in tracing light through a rectangular glass block, the teacher brought about learners' prior knowledge that light travels in a straight line by placing four meter rules in a straight line and positioning his eyes in front of the first rule so that he could not see the other three. The action demonstrated part of the procedure to be followed by learners. It resembled the way poles were positioned in a straight line when constructing fences which is a common activity in lives of learners outside school and possibly familiar to them. Part of the activity is reflected in following excerpt on the verbal communication between the teacher and learners.

T. The light, I cannot see those rules because I cannot see the light which is coming from those rules. So what does it say about the way light moves?
L. Light moves in a straight line.
T. Light moves in a straight line. Ok.

The introduction of the water bath between the meter rules represented the glass block in learners' activity hence it prepared learners for tracing light rays through a rectangular glass block as reflected in the following excerpt (also in section 7.2.4).

T ... Now looking *at the rods* (*the teacher had replaced the meter rules with the rods*) through the water, do they appear to be in a straight line now?

L No.

T No. What has happened? If you look up here the rods are still in a straight line. But looking at the rods through the water they're not in a straight line. So, something has changed. Are the stands still in a straight line?

Ls Yes.

T Yes. They have not been moved. So, this means that the light is not travelling in a straight line.

L It is bent.

T Yes. You are using the right word. What do we call the bending of light?

L Refraction

The demonstration provided the procedure and underlying concepts in a balanced and integrated manner without emphasising one at the expense of the other which ensured that learners followed the procedure with understanding. This reflected how the teacher prepared and guided learners for practical activities.

In these activities, learners sought to meet the expected standards which they were reminded of in each session such as being able to complete their work in a presentable manner, within particular limits of accuracy, and in the allocated time for the next activity. The teacher was generally satisfied with their practical work. This is based on the teacher's comments on the learners' work that follow (see section 7.2.4).

- That's neat.
- Good results.
- I think that's quite an *achievement* for a double science class.
- This one is way off it only got one pin in. This was the guy who was working by himself. He's got some problems

The teachers' instructional practice organised and managed activities to provide optimal opportunity for learners to interact with the content. The teacher's practice was based on learners' knowledge and it addressed knowledge deficiencies including learners' skills and attitude for learning BGCSE physics concepts on waves and light topic. Therefore, it created an environment of competence.

7.3.2 Use of events from learners' lives to develop instructional content

Teacher B used events in the lives of learners to develop instructional activities on physics concepts on waves. Teacher B's first lesson on waves included a video clip of a pool of water where cattle, sheep and goats normally drink water to demonstrate water wave movement and to introduce basic definition of waves such as wavelength; wave front; crest and trough; and wave speed (see section 7.2.1**)**. The pool of water plays a significant role in the learners' socio-economic life because cattle and small livestock are an essential source of income for every household in the country. When the pools are dry, the cattle drink water from boreholes which have to be paid for, taking away part of the money for school uniforms and fees for some learners. The pool of water is therefore part of the learners' prior knowledge which can assist learners in understanding and constructing concepts on waves in accordance with the zone of proximal development (Vygotsky, 1978).

The pool of water is also part of the young boys' playing site. While caring for goats and sheep after school or during school holidays, young boys often spend their free time throwing stones into the water pool as a part of their play which Burnett (2006) would categorise as games of the environment and context or "a form of interaction with the 'environment" (p.8). As a cultural event in the learners' lives, it is important in the teachers' instructional practice for mediating learners' actions on the wave subtopic (Wertsch, 1991; Wertsch et al., 1995). For instance, as the stones were seen dropping into the pool in the video, the teacher mentioned that "Mr D is throwing some stone into the water (Learners laughed)" (See section 7.2.1) which showed that they were familiar with the event.

The activity was exemplary in mediating knowledge by using familiar events in the learners' lives formed part of their prior knowledge within the BGCSE physics curriculum as it also helped learners developing a positive attitude towards their environment in the subtopic of waves (M. o. Education, 1998a).

7.3.3 Repetition of instructional content

Teacher B instructional practice was characterised by repetition of content. The analysis revealed that Teacher B repeated instructional content for the following reasons: to *clarify concepts; to go over ideas that seemed difficult for learners; to consolidate instructional content; and to reinforce ideas*. The next paragraphs provide elaborations of why the teacher repeated the content and how.

The content was repeated to clarify concepts

Clarity in an important factor in effective instruction (Bransford, Brown, & Cocking, 2000; Seidel et al., 2005). Teacher B's instructional activity in section 7.2.3 was a discussion on how light rays bend when they moved from air into glass using diagrams. The discussion involved introduction of terms used to define refraction such as incident and refracted rays, angles of incidence and refraction. The teacher repeated the same ideas using the same diagrams except that the rays moved in a reversed direction, from glass into air. The discussion on the reversed path of light ray revealed that to some degree, learners associated the incident ray with air and refracted ray with glass in their answers to the teacher's question (see section 7.2.3). This was evident in the teacher's utterance reflected in the excerpt that follows.

T. … that's **i** and that's **r**. Supposing the ray of light is coming the other way and reaches the surface (of the dense medium), where is it going to go? It goes exactly along the same path, so we can use these two lines for either the ray of light coming from air into the glass or from glass into the air. *But in this case, if we have to draw the angle* ***i*** *it'll be there because the ray of light is falling on the surface, the incident ray, is this one travelling* (in the dense medium). So what's this angle here?

L. **r**

T. Here (*reversed the direction shown by arrows on the other diagram)* the angle is…

L. **r**

T. This is coming in, so it is from less dense to more dense. It's angle **i**. And, what's this angle?

L. **r**

T. Angle of refraction. Now, let's say the ray goes the other way, the same thing happens. So, the arrow follows the same path as before along the same line but we have to swap **i** and **r** because the ray is falling on the surface from this side. And is a big thing to remember. The bigger angle is always in the less dense medium. Here, which angle is bigger **i** or **r**?

L. **r**

T. which is less dense, air or glass?

L. air

In the excerpt immediately above, the learners' response to the first question posed by the teacher "So what's this angle here?" was correct. The learners' response to the second question for the reversed direction of light was incorrect. The angle was the same but the name had to change because of the reversed direction in which light travelled. To assist the learners, the teacher had pointed out that the incident ray is the ray approaching or falling on a second medium and it is not used to exclusively refer to a light ray approaching glass from air. By steering the content in this way the teacher clarified the meaning of incident and refracted rays, and angles of incidence and refraction. The activity is viewed as a repetition of content because it was institutionalised by the teacher as a subtopic and not just an exercise for learners.

The content was also repeated to go over ideas that seemed difficult for learners.

Repetition of instructional content to support learners on ideas that seem difficult to them provides opportunity for them to review the concepts (Dempster, 1988). It was considered exemplary in the context of BGCSE physics syllabus which teachers find congested (Koosimile, 2007). This was evident in section 7.2.3 where the teacher explained the bending of light caused by differences in densities of the air and glass. The learners were able to correctly state formula for density as mass/volume as reflected in the following excerpt.

T.	…When light passes into a denser medium it bends towards the normal. When we say denser we mean how heavy it is. How do you calculate density?
L.	mass over volume
T.	It's mass over volume. Usually something which is heavy like there are different kinds of glass, if glass is having large amount of glass, it's going to bend light more. So, what do we say, it's optically more dense. But really that's what dense means.

But, they had difficulties with the concept of density because they were not able to correctly state which of the two media was denser, air or glass as shown in the following excerpt.

T.	…So there is the ray and it travels fast because it's in air. The arrow moves through the line very fast. Which is more dense glass or air?
Ls.	Air
T.	Air is more dense than glass? You are saying it's easy to pick up air or air is easier to pick up than glass. If you use the common word, which is heavier air or glass?
Ls.	Glass

Probably due to learners' difficulties in viewing air as a substance (Driver, Leach, et al., 1994) as the teacher pointed out in the words, "if the scoop is empty is not empty. It is full of air". The learners probably could not interpret the densities of air and glass in terms of sinking and floating as described in junior secondary science. The teacher tried to explain the density in terms of heaviness of equal volumes but learners could not make correct comparisons. Therefore, the teacher repeated the question throughout the topic each time the direction of bending of light rays was to be stated. The following shows the question as was repeated in lesson 5 (see section 7.2.5) on the topic of apparent depth.

T.	Here is the ray of light coming from the real fish, the object, also from a tin of lucky star. If the ray carries on from the water, carries going straight out of the water, that won't be true. It doesn't carry on straight because water and air have different density. Which is more dense, water or air?
Ls.	Air

T.	Air, so air is heavier than the water? Is it difficult to carry a scoop full of air or a scoop full of water?
Ls	…of water
T.	Remember if the scoop is empty is not empty is full of air. So which is heavier air or water?
Ls	...Water
T.	which is more dense?
Ls.	Air, water
T.	Water is more dense. Density means how heavy one unit body is like one litre of water, one scoop of water.

It shows from the above excerpt that content on relative densities of media was repeated because learners had difficulties comparing the densities of air and water and air and glass.

The content was also repeated to consolidate instructional content from separate lessons.

Consolidation of instructional content promotes coherence between separate lessons which is assumed to have a positive effect on learning (Bransford et al., 2000). Consolidation of instructional content was evident in lesson 6 (see section 7.2.6), where the teacher started the lesson with a presentation of sections of instructional content presented in lesson 3 and 4 (see section 7.2.3 & 7.2.4). The content included refraction of light entering glass from air, refraction of light entering air from glass, refractive index from lesson 3 and apparent depth from lesson 4 (see section 7.2.4).

The strategies and the ideas in the content selected from lessons 3, 4 and 5 (see section 7.2.3, 7.2.4 & 7.2.5) were presented together in lesson 6 (see section 7.2.6), the same way they were presented in those lessons. In a way, this repetition promoted continuity of ideas through the lessons (Scott et al., 2011) by reminding learners of the ideas discussed in the previous lessons (Gallimore & Tharp, 1990).

The content was also repeated to reinforce ideas. This was apparent in lesson 1 (see section 7.2.1) when the teacher defined the spreading out of waves in terms of speed. The way the teacher reminded the learners of the formula for speed as distance moved divided by time taken by a wave, and expressed the speed numerically showed that it was a repeat of the way concept ‘speed’ was defined in previous lessons. The concept was repeated in the same manner in lesson 2 (see section 7.2.2) when demonstrating waves using a ripple tank.

It is noteworthy that repetition may result in boredom if it does not lead to processing of content (Dempster, 1988). Teacher B repeated instructional content within and across lessons to process the content in various ways to make it accessible to learners. It was also important for keeping the concepts current in learners' minds within the zone of proximal development (Gallimore & Tharp, 1990).

Repetition is considered important during early stages of development within the zone of proximal development as "the child may have a very limited understanding of the situation, the task, or the goal to be achieved" (Gallimore & Tharp. 1990, p.184). It is an aspect of effective instruction when it is based on processing of the content (Dempster, 1988).

7.3.4 Sequencing of concepts to simplify descriptions

The analysis of Teacher B's instructional practice revealed that he sequenced instructional content in a way that shortened descriptions and made ideas simple for the learners. For instance, he introduced a crest as the top of a wave and highlighted it by drawing a line along it. He then described a wave-front as a line joining parts of a wave at the same stage and used the same line that represented a crest to highlight it. The sequence showed same diagrammatic identity of the two parts which were differentiated by conceptual definition. The use of the same line seemed to make the presentation simple for learners in that the top part of a wave was a line that also showed a wavelength. Instructionally it made the description short. The sequence of the terms is not explicit in the BGCSE syllabus (M. o. Education, 1998c).

The introduction of a wave-front was followed by that of wavelength. The sequence enabled the teacher to refine the definition of a wavelength by contrasting it with that of a wave-front by pointing out that the line representing a wavelength is defined by two successive crests or troughs and can be measured, while a wave-front is a long line that is not defined by measurement. In his own words the teacher said the following.

> T. If I show a picture of a wave and if I ask you what is the length of the wave, what would you do? Would you draw a line from there to there (*tracing a single wave-front).* That's a very long wave. That's not how we define a wavelength. A wavelength is the distance between one wave and another wave next to it. And we can measure the distance from the crest of one wave to another crest of a wave. Or you can measure from the trough to the trough of another wave. You can find the same answer.

The contrast between the wavelength and wave front, reflected in above excerpt, served to reduce possible confusion of the two terms, wavelength and wave-front that could have been caused by the fact that they are both defined by lines.

The analysis showed that sequencing of ideas as a way of mediating concepts by pointing out differences and similarities between ideas can make the content easier to present which can in turn make it easier to learn. Sequencing in this way is part of organising content which can lead to learners' cognitive growth within the zone of proximal development (Hedegaard, 2000). In this regard, Teacher B's instructional practice was found exemplary in sequencing the topic content to make it accessible to learners for reconstruction of the concepts.

7.3.5 Visualisation of concepts

According to sociocultural theory, diagrams are psychological tool that direct and shape understandings of ideas (Daniels, 2000). Teacher B based his instruction on visualisation (Gilbert, 2007) of concepts in waves and light topic diagrammatically through PowerPoint presentations, in six out of eight lessons. The teacher's PowerPoint presentations showed the movement of light by an arrow that moved along a straight line, changed direction at the boundary between air and glass, and continued to move in a straight line in glass which was the second medium. The arrow also showed change in the speed of light by moving faster in air than in glass. On image formation by a thin converging lens, the PowerPoint presentations showed how the image changed position and size when object distance changed as the object distance changed (see section 7.2.8). In that way, the instruction refined and enriched the definition of refraction as would be provided in words or in diagrams on chalkboard or charts to support learners' understanding of the concepts.

The PowerPoint presentation saved time during instruction because it was prepared in advance. Unlike using the chalkboard, the material did not have to be re-written during presentation which made time for supporting learners' understanding. The PowerPoint presentation could be easily shared as opposed to hard (paper) copies which allowed sharing of ideas among teachers as Teacher B mentioned that he shared use of the PowerPoint slides with other physics teachers.

The foregoing has shown Teacher B's use of PowerPoint in his instructional practice on refraction of light to support learners' understanding. The instructional practice was found exemplary in the context of BGCSE physics syllabus bearing in mind that computers were not generally available for instruction at the time of the study.

7.3.6 Using keywords to direct instruction on physics concepts

According to sociocultural theory, words used in verbal interaction contribute to development of meaning and understanding and familiar words constitute part of the learners' prior knowledge considered important for cognitive process which leads to understanding of new concepts within the zone of proximal development (Vygotsky, 1978).

Teacher B used familiar words, referred to as keywords in this study, to introduce the concept of wave motion and develop coherence across activities. The teacher described wave motion as 'vibrations spreading out'. Vibrations were demonstrated by a diagram of a ball moving up and down on the surface of the water as the waves moved through the water. They were elaborated by measuring the displacement of the ball in time intervals of one second and recording the results. The term displacement had been defined in previous instruction using the context of pendulum oscillations. The measurements of displacement against time were used to plot a graph (see section 7.2.1). The term vibrations were represented by an up and down movement of a ball, tabulated values of displacement and time, and a graph.

Similarly, the term "spreading out" was demonstrated by the linear movement of waves across a pool of water. The movement was explained through measurement of distance moved and time taken by a single wave and described by the value of speed obtained from calculations. Thus, the term "spreading out" was represented by circular water waves in a pool of water, and a mathematical formula and numerical value of speed.

The key words introduced learners to the wave concept and its representations. They also linked different modes of representations to establish coherence between representations which is important understanding of concepts (Scott et al., 2011). Teacher B's instructional practice was considered exemplary in the use of familiar words in presenting content on wave motion.

7.3.7 Use of critical ideas to structure instructional activities

The teacher structured instructional activities around ideas that were critical for learners' understanding of critical angle and total internal reflection. In section 7.2.6, for example, the teacher's presentation on critical angle was structured on the idea that light does not bend when it enters the curved side of the semi-circular block. The idea deviated from the emphasis in the sections 7.2.3 that light bends when it crosses the interphase between air and a glass block. Hence, the objective of the presentation was to explain why the light ray did not bend.

Although the idea did not have a direct influence on the meaning of critical angle, it was embedded in its diagrammatic representation therefore it was part of the meaning in the same way that words lead to provide meaning (Scott, 1998; Wertsch & Smolka, 1993).

In his presentation, the teacher institutionalised the semi-circular block as part of a circular frame or circle which had its centre at the centre of the plane side of the semi-circular block and that a line from the curved side of the block to the centre of the plane side was the radius. The teacher used the idea of a tangent line to argue that the radius touches the surfaces of the circle at 90^{o} angle. The learners' response indicated that they knew that the radius passes through the centre of the circle and the confident way the teacher used a tangent line seemed to suggest that he was aware the learners did have an idea about it. This showed how the teacher used concepts from mathematics which learners knew to help them understand why light did not bend on the curved despite changes in the position of the ray.

In terms of sociocultural theory, the teacher's presentation showed how he processed the content by drawing ideas from mathematics concepts which are part of learners' knowledge. In this regard, the activity was found exemplary in helping learners by addressing ideas that were critical for making sense of critical angle.

7.3.8 Defining concepts in operational terms

The analysis showed that teacher B used operational definitions and means to communicate concepts in his instructional practice. Operational definition of physics concepts put emphasis on the actions accompanying the definitions (Bridgman, 1991). Bridgman (1991) viewed the operational definition important for meaningful communication of physics concepts. This was found exemplary with regard to making physics concepts accessible to the wide ability learners. For instance, the teacher's definition of frequency as *how many waves* are produced in 1s appeals to counting the waves when contrasted with defining it as *the number of waves* produced in 1s which would reflect an outcome of counting. He went further to show learners how waves are counted in the context of their motion (see section 7.2.1), how the time it takes for the waves to move is measured, and how frequency of the waves is calculated.

The way the concept of speed was defined in section 7.2.1 also illustrated the operational way in which they were defined. When he defined the concept of speed, the teacher:

- showed the learners the video of moving water waves;
- explained the motion mathematically as *speed = distance moved /time taken;*
- expressed speed verbally as distance moved in one second;

- demonstrated measurement of the distance moved and time taken; and
- calculated speed using the measurements and the formula

The foregoing shows how the teacher defined concepts in operational terms in multiple representations. This combination of operational definitions in multiple representations was found exemplary in preparing learners for their activities and in helping learners' understanding of the concepts in waves and light topic.

7.4 Why Teacher B supported the learners that way?

According to Teacher B, the learners had been performing poorly in school work through most of their school life. Therefore, they had developed some habits of getting along without meeting the expected performance objectives as reflected in the following excerpt from the interviews.

> T This class in particular is the worst of the classes I have. Other people complain about them and the head of house teaches them. I am sure you took a photograph of them sleeping. …But, that's how they are used to, in school, I'm sure. *They just keep quiet. They have all this hard work, if it looks like there's trouble coming they just copy from the next person*.

Teacher B said the learners lacked learning skills such as searching for information and consulting each other when they have a problem. He also said that they were not used to work in a systematic manner.

> T. They are not used to the idea that they can actually work through a hand-out systematically, answer questions and if there's a problem look back at the material they have with them, may be in the hand-out, discuss with other students next to them and come up with an answer.

Teacher B also found the learners impatient when they carry out assigned work.

> T. *They are very impatient. If they're not confident that they got the right answer, immediately they leave it and move to something else.* And, I don't like things which are left unfinished on hand-outs.

The teacher used pencil and paper exercises to help learners understand the concepts and make sense of the topic.

> T. Very often they're (pencil and paper exercises) structured so that they understand this bit and then move to the next bit. They've got some concepts to establish that will enable them to cope with the next topic.

The teacher designed instructional activities to enable learners to cope because he was aware that learners did not find it easy to construct concepts from a combination of ideas.

> T. As soon as you start talking about light rays, the idea of density fades from their minds. When you talk about density, light fades from their minds. They can't think

> about them together very easily. *They're not really so dumb, it's just that they're not accustomed to coping. I am sure they can do a lot more.* I think they can.

Teacher B's instructional practice was therefore to create opportunities for learners to become competent in carrying out assigned work, to develop their confidence and to understand concepts on waves and light topics

7.5 Summary

This chapter has reported on and discussed Teacher B's instructional practice in the way it supported learners in accessing school physics content on waves and light topic. The chapter has provided a description of the salient items of each of the eight lessons. The analysis of the instructional activities in the eight lessons captured the instructional support provided for the learners. The analysis showed that in supporting learners Teacher B's instructional activities created an environment of competence through: repeated instructional content; use of PowerPoint as an instructional resource where instructional activities were structured using keywords and critical ideas; sequencing of ideas to simplify descriptions and to distinguish one concept from another; and concepts were visualised and defined in operational terms which characterised his practice. In the next Chapter, I present a summary of the findings, implications and recommendations.

CHAPTER 8:
Summary of Findings, Implications, Recommendations

8.0 Introduction and Overview

This chapter presents a summary of the findings in this study and how they relate to literature, the implications and recommendations in the context of the Botswana; it also includes discussions of the contributions of the study to knowledge, and issues for further research.

This study was developed to explore exemplary teachers' instructional practice and the way it supports learners in accessing school physics content. It was motivated by the findings of a baseline study by a professional development unit in the Department of Mathematics and Science Education at the University of Botswana (DMSE-INSET) which revealed that physics teachers used mainly lecture approach in their instruction. A few teachers however engaged learners in their lessons (see section 1.1). Two of these teachers have been the participants in this study. The teachers were sampled using purposive intensity sampling approach (see section 5.1.1). The instructional practice of the two teachers is what has been judged as local examples of exemplary instructional practice, hence the focus of the study reported in this thesis.

In the study the instructional practices of the two teachers were observed while teaching each in the topics of 'light and waves' and 'thermal physics' to their learners at two different senior secondary schools. The focus on the two teachers' was for two reasons, to allow for an in-depth exploration and to explore possible variations and commonalities in the teachers' instructional support for learners. The following are three research questions used in the study.

1. What characterises exemplary teachers' instructional practices in school physics?
2. How do the exemplary teachers' instructional practices support learners in accessing school physics content
3. Why do the exemplary teachers' instructional practices in school physics support learners in accessing school physics content?

Vygotsky's sociocultural theory was used to address the complexity of the teachers' instructional practice (Schön, 1987). The methodology was based on social constructivist philosophical viewpoints that individuals develop meaning of new experiences which they encounter as they engage with the world (Crotty, 1998; Schwandt, 2001) on Kuhn's concept of exemplars (see section 4.1.4). A case study approach within qualitative research design was employed for an in-depth understanding of the teachers' practices.

The data collection methods involved observation of instructional activities and interviews of teachers and their respective learners (see sections 4.4.2, 4.4.3 & 5.2.2). Audio-video recorder was used to capture the activities in a total of fifteen lessons [seven for Teacher A and eight for Teacher B] and a voice recorder was used to record interviews per teacher conducted with two the teachers and their learners (see section 5.2.2 & 5.1.1).

Ten learners, five males and five females, were selected for the interviews. However, the males and females were interviewed separately to take into account possible differences in the way they negotiate their ideas and deal with disagreements in small groups (Alexopoulou & Driver, 1997). The selection of learners for the interviews was based on the teachers' knowledge and the researcher's observation of the learners. The recordings were transcribed and the transcripts were used for analysis (see section 5.3).

Inductive analysis approach was employed to identify how the teachers' practices supported learners in learning physics (see section 5.4).

The findings are presented in the sections that follow by questions and main problem but per teacher participant.

8.1 Findings

8.1.1 Teacher A's instructional practice and learner support on accessing content on thermal physics topic

Teacher A's instructional practice was characterised by high involvement of learners in instructional activities. The practice was underlined by instructional strategies which promoted an environment of textbook reading, activation of prior knowledge; simplification of complex constructs; use of high cognitive examination questions to integrate content from other topics which led to sequencing of subtopics in a way that build on each other; and gave learners a voice in the activities.

Activating learners' prior knowledge and linking it to new knowledge

Research indicates that prior knowledge is useful in making instructional content meaningful for learners (Brown, 2004; Clement, 1993; Treagust et al., 1998) and exemplary teachers use it in various forms for different purposes. For instance, exemplary teachers use outstanding events in learners' lives to make school content relevant (Ladson-Billings, 1995) and familiar situations to enable learners to think and reason (Mercer, Dawes, Wegerif and Sams, 2004), understand concepts (McNamara et al., 1996) and improve learners' achievement (Dochy et al., 1999; McNamara et al., 1996; Pressley et al., 1992). This makes activation of prior knowledge an important aspect of instruction. However, activation of prior knowledge in school physics was found in a study by van Zee and Minstrell (1997a) in which the exemplary teacher elicited learners' ideas through a series of questions to help them understand physics concepts during instruction.

The findings on this study showed Teacher A's activation of learners' prior knowledge over a wide range of content knowledge by use of open-ended demonstrations. The knowledge expressed by learners included naming demonstration apparatus, following standard procedures, and explaining changes that occurred in the demonstrations. The findings also showed inconsistencies in learners' prior knowledge with regard to naming apparatus and explaining changes. For instance, learners were able to name the bimetallic strip and explain the changes observed but they could not do the same with the ball and ring demonstration (Baird, 1990; Gunstone, 1994). The activity can be used to make instructional experiences over a wide content knowledge such as a subtopic meaningful as opposed to a specific concept. Thus, the findings in this study contribute to the existing literature with regard to activating learners' prior knowledge over wide content knowledge.

With regard to BGCSE physics, Teacher A's instructional practice was found exemplary on the use of open-ended demonstrations to activate learners' prior knowledge was found exemplary in establishing continuity in thermal expansion between junior secondary science and BGCSE physics. This is in view of the possible gaps that may arise between junior secondary integrated science and BGCSE physics due to differences in the way the syllabuses were developed and the differences in teacher qualifications. Since activation of prior knowledge applies to physics concepts in all topics, the activity can be applied in other topics. Hence, the findings on Teacher A's instructional practice with regard to activation of prior knowledge was found exemplary in the context of BGCSE physics.

The teacher's instruction simplified complex construct

Research has shown that English words and technical words used in science instruction are difficult for learners (Hodson, 2009; Oyoo, 2007; Prophet & Towse, 1999; Wellington &

Osborne, 2001) and that the difficulties are more acute for learners whose first language is not English as were Batswana learners in this study (Prophet & Towse, 1999). Research also showed possible ways of simplifying the language of instruction (Oyoo, 2012; Prophet & Badede, 2009) which included use of learners' everyday words to develop conceptual understanding and to clarify the meanings of technical terms (Brown & Ryoo, 2008). However, the studies were not based on observations of teachers' instructional practice in real classrooms except the study one by Oyoo (2012) which found that experienced teachers used local environment to explain technical science words.

Similar strategies to those found in literature were found in Teacher A's instructional practice. Teacher A explained difficult words by using learners' language, rephrasing questions. The findings are exemplary in the context of BGCSE physics bearing in mind that English language is a second or third language for the learners and had previously been found difficult for Batswana learners in junior secondary science (Prophet & Towse, 1999).

The teacher's instruction sequenced and integrated thermal physics subtopics to make content accessible

Literature reviewed in this study show sequencing and integration of content important for establishing coherence across a series of instructional activities (Bishop & Denley, 2003; Wallace, Hand, & Prain, 2004). The sequence of concepts and subtopics in the syllabus provides a standard for teachers' instructional practice. However, in this study, Teacher A sequenced instructional content on thermal physics differently relative to the syllabus. The sequence was found to establish thematic coherence subtopics of in the teachers' instructional content (Seidel et al., 2005).

Teacher A's instructional content was characterised by use of high cognitive examination questions which facilitated particular sequencing and integration of subtopics that differed from that of the syllabus. For example, the teacher used a question on Brownian motion to define thermal expansion in terms of kinetic theory, and Boyle's law to relate thermal expansion to convection currents and cyclones which resulted in the following sequence: definition of thermal expansion; cyclones; and convection currents. According to the BGCSE physics syllabus, the content on cyclones comes after thermal physics topic. Therefore, its inclusion in thermal physics is evidence of integration of content from different topics. The sequence was found exemplary in establishing coherence in instructional content within the BGCSE physics.

Created an environment of reading physics textbooks independently

Literature indicates that textbooks may be inappropriate in supporting science instruction (AAAS, 2005) with respect to teachers' instructional practice (Ball & Cohen, 1996) and learners' meaningful access to written text (Rollnick, 2004). In addition, research indicates that learners' use of textbooks in science instruction might be limited to answering questions found in the textbook (Lubben et al., 2003). However, development of learners' reading skills are found necessary for acquiring knowledge from textbooks (Rose & Acevedo, 2006) and compensating for deficits in their science knowledge (O'Reilly & McNamara, 2007). Exemplary teachers were found to have high confidence in making learning material accessible for learners (Allington, 2002; Hofstein et al., 1990). But, the studies were not specific to physics textbooks in which study make a contribution.

The findings in this study showed that Teacher A encouraged learners to read their physics textbooks by: providing a template to guide their reading (see section 6.3.1.1); using point notes during instruction (see section 6.3.1.2); omitting sections of the topic content for learners to read on their own (see section 6.3.1.3); and asking learners questions on content that had not been covered (see section 6.3.1.4). The practice encouraged learners to search for information on the topic content, ask questions during instructional activities and see the teacher as an agent for understanding, not a source of information (see section 6.3.1.5). The findings in this study therefore contribute to the existing literature on use of textbooks in exemplary teachers' instructional practice in school physics.

Teacher A's instructional practice was found exemplary in the context of BGCSE physics where textbooks are the main, if not the only, instructional. Although its applicability to topics other than thermal physics may need to be studied because the teacher was using the strategy for the first time which implied that it may not have been appropriate for other topics.

Making Learners' Voice a factor in the Physics Instructional activities

Research in school science encourage active learner participation in class interactions (Duit & Treagust, 1998). While active participation is institutionalised through practical work in school physics, emphasis has been on verbal interactions to engage learners in the concepts and skills being taught (Niedderer et al., 2002). Verbal interactions provide learners opportunity to collaborate and negotiate their meanings in physics (Alexopoulou & Driver, 1997; Dillenbourg, 1999). The opportunity for verbal interactions can be provided through instructional activities organised in discussion and dialogues which employ argumentation skills (Alexander, 2008; Erduran & Dagher, 2007). What is common in these studies is that they are focused on learners and not in teachers' instruction on which this study makes a contribution.

The findings in this study show that Teacher A's instructional practice used class discussions as an instructional strategy. He gave learners opportunity to express their views publicly during instruction by: asking learners to elaborate on their questions; letting learners answer questions posed by their peers; and responding to questions at the end of the discussion (see section 6.2.7). The teacher called out learners engaged in private discussions, magnified their views, and invited them to present their points to the class (see section 6.3.7). He maintained the dialogic nature of learner discussions to enable learners to articulate their points, and gave a neutral comment at the end of the discussion to avoid taking sides instead of giving a correct view according to physics.

The findings contribute to literature by providing insights on how teacher's instructional practice can promote learners' voice in physics instruction. This is particularly relevant in situations where learners may find it unrespectable to talk directly to the teacher in an argumentative way or shy to talk publicly to the whole class in English language as could be the case with the BGCSE physics learners.

Why teacher A supported the learners in the way he did?

Teacher A said his instructional practice was aimed at training learners to own the subject knowledge by taking responsibility in their learning. He did this by creating a supportive learning environment which promoted independent textbook reading, using open-ended demonstrations which activated learners' prior knowledge over a wide content area and making learners' voice a factor which involved in argumentative discussions. His instructional practice was characterised highly integrated content across topics which had potential to help learners to develop deep understanding of concepts by relating them to other topics as noted by (Lemke, 1990) that the usefulness of concepts "comes from their connections to one another" (p. 91). Thus it provided metacognition skills the learners in thermal physics (Baird, 1990, 1998).

8.1.2 Teacher B’s instructional practice and learner support on accessing content on waves and light topics

Teacher B’s instructional practice was characterised by involvement of learners in hands-on activities and pencil and paper worksheets and verbal and diagrammatic representations through PowerPoint presentations (sections 7.2.2; 7.2.8). The hands-on activities which included demonstrations and experiments were used to illustrate concepts and to help learners in developing practical skills (sections 7.2.2; 7.2.5; 7.2.7). The practice made instructional content accessible to learners by operationalising concepts, using keywords and critical ideas, using events in learners’ lives, repeating and integrating instructional content. Teacher B’s instructional practice was found to create a supportive environment of competence with a focus on improving learners’ capabilities for accessing new concepts (Rutherford, 1995).

Creating an environment of competence

Research indicates that learning environments are an important aspect of exemplary teacher’s instruction (Fraser, 1998) in which the teachers support and promote learning in various ways (Fraser & Tobin, 1989b; Van Oord & Den Brok, 2004) including supporting their competence (Seidel et al., 2005). However, research on learning environment has to a large extent relied on learner and teacher perception which are determined through questionnaires. Therefore, this study makes a contribution in that learning environment was found through classroom observation and video recordings. The findings show that Teacher B’s instructional practice created an environment of competence in which learners’ capabilities for accessing new concepts in school physics were catered for. The teacher designed his lessons to provide adequate time for involving learners in the activities. For instance, the second half of each lesson period was reserved for learner activities (see section 7.2.2; and sections 7.2.4 to 7.2.8). The teacher used the time to supervise learners’ work and monitor their progress (see section 7.3.1). The work learners did during instructional activities served to guide their homework. He also rationalised activities on learners’ knowledge.

Teacher B rationalised conceptual and procedural components of the activities on learners’ knowledge. For instance, he conceptualised the procedure for refraction of light through a rectangular glass block on learners’ knowledge that light travels in a straight line even after refraction (see section 7.2.4). He used a demonstration which entailed the following (also described in section 7.2.4).

- Positioning vertical rods in a straight line to demonstrate that light travels in a straight line. The rods represented optical pins in the learners' activity.

- Placing a rectangular water bath between the rods to demonstrate refraction of light. The water bath represented the glass block in the learners' activity.

- Realigning the rods so that they appear in a straight line as a basis for tracing the path of the light ray through the water bath. He cautioned learners to avoid looking at the rods above the water bath. This also presented what the learners would be doing in their activity.

The learners' actions were highly focused and discussions were mainly on task. This made it possible for the teacher to provide feedback and monitor learners' performance.

In addition, Teacher B repeated instructional content through which he clarified concepts, consolidated content, and reinforced ideas (see section 7.3.2). Repetition of ideas was important for keeping ideas current in learners' minds (Gallimore & Tharp, 1990) and supporting their understanding of concepts (Dempster, 1988). Repetition of instructional content was made possible by the use of PowerPoint presentations (section 7.3.4). The findings were consistent with literature on supportive learning environments. The findings however were found exemplary in supporting Double Science learners in BGCSE school physics. They could be applicable to Single Science learners where it is provided as an option, it was not an option in School B.

Operationalizing concepts

Operationalising concepts is a process of defining concepts in terms of actions from which they were formulated. This is in accord with sociocultural theory that knowledge is formulated through action and interactions (Vygotsky, 1978; Wertsch, 1985). Operationalising concepts links concepts to actions to make communication easier which reduces mental effort (Bridgman, 1991). Physics concepts are defined in operational terms which Teacher B exploited in his instructional practice. For instance, he stated the definition of 'frequency' as 'how many waves are produced in 1s' instead of 'the number of waves produced in 1s' which was followed by an activity in which waves counted in a given time and their frequency was calculated. The definition predisposed learners more to a process than to a product implied by the concept (see section 7.3.7).

Teacher B also defined speed as 'distance moved divided by time taken' which was followed by measurement of the distance moved by a ripple and the time it took, and calculation of its speed (section 7.2.1). This also made the instructional activities coherent by directly linking verbal expressions of concepts to their mathematical formulations. Research on multiple representations shows that learners have difficulties linking different modes of concept representations (Duval, 2006; Waldrip & Prain, 2006) and that few teachers expect learners to represent a concept in different modes as part of understanding science (Prain & Waldrip, 2008).

The way Teacher B's instructional practice operationalised concepts agrees with existing literature on effective communication of concepts and was found exemplary in the way he exploited the operational terms in the context of BGCSE Double Science learners in school physics.

Integration

Research shows the integration is important knowledge process. Lemke (2000) stated that "it is only in the integration of these various aspects that the whole concept exists" (p.248). Scott et al. (2011) stated that integration supports deep understanding and formulation of higher order structure (Seidel et al., 2005). The findings in this study were consistent to literature in that Teacher B integrated similar concepts from different topics. For instance in section 7.2.1 the speed of sound was included in the wave topic under the sub-topic of speed of waves. According to the syllabus, the topic of sound comes after that of waves and light. He also used the concept of speed from the topic of motion in mechanics to explain the speed of water waves.

In addition to helping learners develop deep understanding of concepts, the teachers' instructional practice of integrating concepts from different topics was found exemplary in BGCSE physics as it could help condense large volumes of information which in turn could assist in syllabus coverage (Koosimile, 2001).

Use of keywords and critical ideas to structure instruction on physics concepts

Vygotsky (2012) stated that words are tools for direct thoughts and behaviour and that they also represent thoughts. They can be used as analogies to make concepts accessible (Brown, 2004; Clement, 1993; Treagust et al., 1998) and to make thematic connections between activities (Lemke, 1990) in instances where they are familiar to learners (Mercer, Dawes, Wegerif and Sams, 2004). The findings in this study were consistent to literature in this regard. Teacher B's instructional practice supported learners by structuring activities on key words. For instance, when introducing wave motion Teacher B showed a video clip of water waves in a pool of water. He described the water waves as energy spreading out in the form of vibrations which he phrased as "vibrations spreading out" to capture the movement of the circular water ripples (see section 7.2.1) (Hofstein et al., 1990; Oyoo, 2012).

The words "vibrations" and "spreading out" are referred to as keywords in the analysis because Teacher B used them to structure the illustrations on wave motion. From the transcripts, the word vibration was illustrated by (see section 7.3.6):

- Description of up and down movement that was also demonstrated by a piece of dried cow dung floating on water as the waves moved through the pool of water.
- Diagram on PowerPoint showing a ball floating on water as waves passed.
- Measurement and recording of displacement of ball floating on water against time.
- Graph of displacement of ball floating on water against time

The illustration of the keyword "spreading out" entailed:

- Demonstration of circular waves moving outwards from the source.
- Measurement and recording of the distance moved and time taken by a single wave.
- Calculation of speed using the measured values of the distance moved and time taken.
- Description of "spreading out" in terms of the linear speed.

Teacher B's instructional practice was found exemplary in the way it used words that are familiar to learners to establish thematic coherence across activities in the context of BGCSE physics.

Use of critical ideas

Exemplary teachers use various strategies that enable learners to process knowledge including learners' prior knowledge (Taber, 2005), analogies and models (Brown, 2004; Clement, 1993; Treagust et al., 1998) and familiar situations (Mercer, Dawes, Wegerif and Sams, 2004). In this study, ideas from mathematics subject that were familiar to learners to explain why light did not bend when it crossed the curved side of a semi-circular glass block in the representation of critical angle and total internal reflection. Teacher B took into account features of representations that could not be directly explained from the topic content covered on a rectangular glass block. The teacher considered the fact that light enters the curved side of the semi-circular glass block without bending as a critical idea that needed to be differentiated (Scott et al., 2011) from the way light would enter a plane side of a glass block without bending. The teacher differentiated it by using familiar concepts of a circle - the radius and the tangent from mathematics (see section 7.3.6) to help learners develop deep understanding of the concepts. The findings were therefore consistent with literature in this respect.

However, they were found exemplary with regard to helping learners develop deep understanding of critical angle and total internal reflection concepts in the context of BGCSE physics.

Use of learners' lives to develop instructional content

Vygotsky stated that development of a scientific concept derives from the phenomena it represents (Daniel, 2001) and the understanding of the concept lies in its relevance to lives of learners (Seidel et al., 2005). Teacher B used events in the lives of learners which were part of the natural phenomenon to introduce and support understanding of physics concepts (see section 7.3.2). For instance, he used video clip showing a stone dropped in water in a pond that plays a significant role in the learner's socio-economic life to present definitions of water waves (See section 7.2.1). Same wave definitions were reviewed using a ripple tank demonstration (See section 7.2.2). The use of the event in Teacher B's instructional practice was found exemplary in view of the fact that BGCSE physics curriculum, syllabus and textbooks, are based on foreign context.

Use of visuals

Various forms of representations are used in physics content to help visualise concepts. Diagrams help to visualise concepts by relating them to concepts through labelling and process arrows (p.13, Gilbert 2008). Teacher B's instructional practice increased the value of diagrams in this regard on the topic of waves and light by relating them to demonstrations and events in learners' socioeconomic life and by use of PowerPoint presentation. The PowerPoint presentation enhanced the quality of presentations in supporting understanding of concepts (Gilbert, 2007) as evident in sections 7.2.6 and 7.2.8 where for example the teacher used movement of an arrow to help learners visualise changes in the speed of light and actual movement of water waves to visualise wave speed. Hence, Teacher B's instructional practice was found exemplary in this regard because as noted by Gilbert (2008) visuals in this regard has not been adequately explored in practice. In Gilbert's (2008) words "The attainment of metavisual capability must, in today's world, involve students being able to fluently scan the internal structure of a dynamic representation" (p.12) and that "Given the current lack of attention to these issues at a pragmatic level directly accessible to students, the attainment of metavisual capability is perhaps more a matter of luck than instructional judgment" (p.14).

Teacher B's instructional practice was also found exemplary in the specific context of BGCSE physics in that compared to the use of chalkboard, PowerPoint presentation reduces the time for teacher presentations which is important for topic coverage and for creating time for learner activities (McFarlane & Friedler, 1998) (see section 7.3.5).

Why teacher B instructional practice supported the learners in accessing school physics content

According to Teacher B, the learners have been performing poorly through most of their school life (see section 7.4). Consequently they developed some habits of getting along without meeting the expected performance standard. The teacher found that they lacked learning skills and they did not have sufficient confidence to take time to make sense of new experiences (also in section 7.4). Teacher B's instructional practice was therefore to create opportunities for learners to gain some knowledge before they could work on their assignment. For instance, the teacher presentations were structured on the learners' activities (see section 7.3.1) and took into account possible delays that the material that learners were to use for their activity might impose on their progress (see section see section 7.2.8). In addition, he rationalised activities on leaners' knowledge (see section 7.2.4 also in section 7.3.1). However, he avoided engaging learners in discussions because they did not have proficiency in basic vocabulary for communicating their ideas in English (see sections 8.1.1.2). Hence, Teacher B's instructional practice was found to create a supportive environment for competence in this regard.

The findings on Teacher A's and Teacher B's instructional practices are based on diverse situations in terms of the different schools in which the teachers taught, teachers' pedagogical knowledge considering that Teacher A was trained in chemistry education and Teacher B in chemistry, learners' abilities and topic content. However, the characteristics of their individual practices with respect to supporting learners are consistent with literature on effective teachers' practices. While the characteristics generally viewed as exemplary in the context of BGCSE physics curriculum, some characteristics may not be viewed as exemplary in curricula other than BGCSE. Examples include repetition of content and lack of verbal involvement of learners by Teacher B's instruction, promoting textbook reading in Teacher A's instruction and use of examination questions to structure content.

8.2 Profile of local exemplary practice

Although Teacher A's and Teacher B's instructional practices were analysed separately, it is important to consider common elements that are likely to be the foundation of their exemplariness within the shared context of the BGCSE curriculum which can inform practice. This section outlines the commonalities in the teachers' instructional practice on 'thermal physics' and 'waves and light' topics to make the content for their learners accessible (Wersch, 1991; Wertsch, del Rio & Alvarez, 1995).

Teacher A and Teacher B both used learners' prior knowledge in their instructional practice (Clement, 1993; McNamara et al., 1996; Treagust et al., 1998). Teacher A activated, refined and built-on learners' prior knowledge including knowledge gained at junior secondary science (see section 6.2.7 & 8.1.1). Teacher B also used learners' knowledge from prior instruction including knowledge from junior secondary science. Activation of prior knowledge from junior secondary school is important for building on learners' knowledge and establishing continuity in instructional activities between the junior and senior secondary instruction in physics concepts to promotes learning (Koosimile, 2005). Teacher B on one occasion used events in the lives of learners (Treagust et al., 1998) to develop understanding of wave motion (see section 7.2.1). This was significant in that it was part of the introductory activities which was explicitly linked to standard textbook activities on wave the ripple tank and the waveforms. In Botswana school system, the teachers' instructional practices that draw on learners' every day knowledge can be viewed as way of making school physics content relevant (Nganunu, 1988).

The two teachers attended to the learners' needs with respect to language of instruction as a second or third language to learners (Hofstein et al., 1990; Prophet, 1990a; van Zee & Minstrell, 1997a). Teacher A exposed learners to complex constructs but simplified them (Prophet & Badede, 2009). For example, the question that required learners to make a conclusion was simplified by breaking it down into four simple questions (also in section 8.1.1) which involved presenting them to the learners' level of thinking by using learners' words (Brown & Ryoo, 2008; Zinchenko, 2007). Teacher A also explained and highlighted key ideas the question to support learners' understanding (Wood, Bruner & Ross, 1976).

Teacher B on the other hand explained meanings of science words and highlighted them in his presentations (see pic. 33 & section 7.2.3). For instance he explained the word 'ripples' as 'little wave' and as 'rings of disturbance that spread out when 'you throw something in water' (Oyoo, 2012). He used simple sentence structures such as 'Describe the image' and provided two words for the learners to choose from such as 'Virtual' and 'Real' to present content (Prophet & Badede, 2009). He also attended to features of concept representations (see section 8.1) to help learners to develop deep understanding of the representation.

The different ways in which the participant teachers supported their learners on language, due to differences in their teaching styles, have elements of appropriateness to the learners' abilities (Brown & Ryoo, 2008). The differences in the learners' ability, Teacher A's learners followed a pure science option and were one of the top classes in School A while Teacher B's learners followed a Double science option and were one of the lowest performing classes in School B (see section 2.3 & 5.1.1).

Both teachers supported learners in developing experimental skills (Treagust, 1991) by linking process skills to underlying concepts (Waldrip & Prain, 2006). Teacher A: involved learners in a whole class discussion in which they described the set-ups and procedures in the absorption and emission experiments (Niedderer et al., 2002). He also guided them on how to record measurements and write a report (see section 6.2.7). Teacher B used the concept of propagation of light to guide learners on experimental procedure on refraction of light (see section 7.2.4). He also demonstrated measurement of angles (see section 7.2.4) and guided learners on how to calculate refractive index (see section 7.2.3).

What was prominent in these experiments was the teachers' emphasis on learner understanding of the underlying concepts and experimental skills (Abrahams & Millar, 2008). For instance, in the absorption and emission experiments, it was noted that the flasks were placed at equal distances from the source of heat to ensure that they received equal amount of heat (see 7.2.7). While in refraction of light through a glass block learners prevented looking at pins from above the glass to improve the accuracy of their procedure. The teachers' management skills were also outstanding particularly where there were shortages in equipment as in lesson 2 where learners carried out demonstrations in four work stations (see section 6.2.2) and where learners were instructed on how carry out hands-on activities by use of demonstrations and illustrations (see section 7.3.1).

The teachers integrated content from different topics (Scott et al., 2011). Teacher A integrated content on Brownian motion experiment and Boyle's law with content on thermal physics and weather (see section 8.1.1; and sections 6.2.3, 6.2.4. 6.2.6). Teacher B integrated content on speed of waves with speed of sound (see section 7.2.1). Integration of content establishes continuity across topics and has potential to support understanding of concepts (Scott et al., 2011). It can also be applied to save time for content coverage.

Teacher A and Teacher B involved learners actively in their instruction. Teacher A used discussions based on questions to direct learners' thinking (Alexander, 2008; Chin, 2006; Wahyudi & Treagust, 2004) and through learner presentations and in encouraging learner discussions (Aufschnaiter et al., 2007; Barnes & Todd, 1977; Boyd & Markarian, 2011), by describing the procedural steps and stating reasons for each step (Siegel, 2006). Teacher B involved learners in pencil and paper exercises (see sections 7.2.2; 7.2.8) and hands-on activities (see sections 7.2.4; 7.2.5; 7.2.7) to support them in understanding concepts and developing learning skills (Parkinson, 2004). Active involvement of learners in instruction is encouraged by the BGCSE physics syllabuses through its recommendation for learner-centred approaches (see section 2.3).

The teachers also set performance standards for their learners (Boud, 1995). Teacher A used mark allocation for high level questions to guide learners in providing explanation and elaboration during class discussions (See section 6.3.4.3). He also used the mark allocation to guide them on the time they should take working on the questions. This was in the words,

> Write down the answer there as you would in an exam. Let's see how many marks you get. That would be how many marks? Five marks. Ok. Take five minutes. (Also in section 6.2.2.4)

The excerpt immediately above provides evidence of how the teacher infused preparation of learners for examinations in his practice.

Teacher B set a range of acceptable values for experimental results. For instance, he set a range for acceptable results for critical angle of glass based on the known value for the refractive index. He told his learners "The correct angle for refractive index should be about 42^o, 40^o to 44^o will do" (see section 7.2.5).

He also made reference to examinations when setting criteria for learners' performance as follows.

> Remember what I said, please listen to me, every time you draw a graph or draw a diagram or answer a question you do it to exam standards, so, draw lines on this table using a straight line (lesson 5 Transcript).

The setting of performance standards promotes self-assessment which in turn enhances learning (Boud, 1995) . The teachers' intention in setting of performance standards was also to prepare learners for examinations.

The two teachers did not give learners copious notes instead they encouraged learners to read or work on the text material provided (Rose & Acevedo, 2006). Teacher A encouraged learners to read their physics textbooks (Allington, 2002). Even though it was not easy for learners they expressed how the reading of textbook helped them in making sense of content presented by the teacher during instruction (see section 6.3.1.5). Teacher B involved learners in pencil and paper exercises (Parkinson, 2004) even though they had inadequate skills (see section, 8.1.1.2). The learners had to work on the exercises which the teacher checked regularly during lessons. They were observed consulting the teacher after the lessons on their way out of the laboratory on what they did and to seek for assistance. The learners' responses indicated that they benefited from the ways in which their teachers encouraged them to access content.

In summary, the two participant teachers' instructional practice showed the following characteristics in supporting learners, though sourced from observations of teaching of 'thermal physics' and 'waves and light', two different topics in school physics:

(a) Learners' knowledge drawn from prior instruction and events in learners' lives to develop instructional content and to introduce new knowledge (Taber, 2001; Thompson & Zamboanga, 2003). The use of learners' knowledge in the instructional activities had a potential to establish continuity in content across school levels (Botswana, 1993).

(b) Simplification of technical science words and non-technical English words to the learners' ability and proficiency level made them more accessible for learners (Oyoo, 2012; Prophet & Badede, 2009) .

(c) Engagement of learners in experiments to facilitate their development of experimental skills (Givry & Tiberghein, 2011; Niedderer et al., 2002) .

(d) Engagement of learners in science texts to develop their reading skills and concept understanding (Allington, 2002; Mokibelo, 2010; Rollnick, 2004).

(e) Integration of content from different topics to develop concept understanding to establish continuity across topics s (Buty & Mortimer, 2008; Scott et al., 2011) which might also reduce time for covering content in different topics

(f) Setting performance standards which challenged learners to perform up to their potential (Boud, 1995). The performance standards were also used to prepare learners for examinations.

(g) Use of multiple instructional resources such as PowerPoint, demonstrations, and hands-on activities (Gilbert, 2007).

There were differences in the details of the characteristics of the teachers' instructional practice. A large part of the Teacher A's instructional practice was through discussions which involved verbal interactions (Hofstein et al., 1990) between the teacher and learners (van Zee & Minstrell, 1997a) and among learners (Alexander, 2008). It showed how activities can be structured to actively engage able learners in high cognitive level content and thinking skills. Teacher B's instructional design for seven of the eight lessons observed involved learners in the second half of each lesson period on hands-on and/or paper and pencil activities. Teacher B's practice provided insights on how learners with low prior knowledge for participating in standard BGCSE textbook activities can be trained and prepared to actively participate in the topic content.

The findings show the two participant teachers' practices to be consistent with literature on exemplary teachers (see Chapter 3) in engaging learners in instructional activities to support them on accessing topic content and concept understanding. They also reflect the practices that show exceptional characteristics which are suitable for Botswana science education (see Chapter 2).

8.3 Implications

In this study, exemplary teachers used a pool of water which plays an important role in the learners' social and cultural life to produce water waves for instruction (see section 8.1.2). Considering the foreign context of the BGCSE physics curriculum on which the teachers' instruction is based (see section 2.3), the implication is that the particular sociocultural event can be used by physics teachers provide local context for instruction on water waves. However, there is a possibility that learners may confuse ideas that are specific to the sociocultural event with the physics concepts (Matthews, 1994). In this regard, the exemplary teacher's use of the context of a social and cultural game and a discussion exclusively focused on physics concepts of water waves is a possible way of avoiding confusion. The implication is that when sociocultural events are used for physics instruction, the discussion should be focused on the physics concepts to avoid possible confusion of ideas.

The study revealed exemplary physics teachers' instructional strategies for addressing learners' incompetency in participating effectively in instruction. Teacher B used pencil and paper exercises or worksheets to provide opportunity for learners and to guide them on how to work on the content of his lessons. He also made hands-on activities an essential aspect of his instruction and rationalised new concepts on learners' prior knowledge to help learners develop experimental skills and understand new concepts (see sections 7.3.1 & 8.1.2). Teacher A used strategies that encouraged learners to read textbooks which consequently promoted learners' questions and participation in lessons (see sections 6.3.1 & 8.1.1). It is noteworthy that textbooks have been found generally inadequate in supporting learners' participation in science instruction (Baiyelo, 2002; Budiansky, 2002; Emereole & Rammiki, 2004) and that teachers may not be providing adequate support for learners to carry out reading assignments (Koosimile, 2005). The implication is that physics teachers can develop strategies to help learners develop relevant skills and access topic content as an integral part of their instructional practice.

Another major finding in this study is that exemplary teachers used elaborate methods to activate prior knowledge. Examples include Teacher A's use of open-ended demonstrations on thermal expansion and Teacher B's review of prior lessons to prepare learners before introducing new concepts on the topic. Teacher A's use of open-ended demonstrations on thermal expansion in particular indicated a great potential for activating learners' prior knowledge which is important for understanding of new concepts (Brown, 2004; Clement, 1993; Treagust et al., 1998) . The implication is that teachers can use elaborate methods which are effective in activating prior knowledge for instruction on new concepts.

In addition, the findings show how participant teachers supported learners' acquisition of experimental skills by using strategies that took into account shortages in resources, large class sizes, and learners' capabilities, in order to support learners' development of experimental skills (see sections 6.2.7; 7.2.4). Teacher A supported learners on experimental skills by using small group of learners to carry out experiments in turns and to discuss their work with the class (see section 6.2.7). He also used demonstrations stations where learners carried out demonstrations by moving from one station to another or circus-type demonstration (Gott & Mashiter, 1994) (see section 6.2.2). Whenever Teacher A conducted the demonstration to the whole class, he left the apparatus for learners to repeat the demonstrations for themselves (see section 6.2.6). Since gas pipes were leaking in the physics laboratory block, Teacher A was able to involve his learners in demonstrations on thermal physics by using candles and hot water instead (see section 6.2.2 & 6.2.6).

Teacher B mentioned that they had adequate equipment for the topic of light to conduct standard experiments but not in other topics. The ripple tank demonstration showed evidence of limitations relative to the class size (see section 7.2.2) which the teacher addressed by dividing the class into small groups. Teacher B's instructional design, which had the second half of each lesson reserved for learner activities, provided adequate time to involve learners in practical activities and to support them on skills needed by learners to participate in the activities (see section 7.2.8).

The two participant teachers were situated in departments of two senior secondary schools which have more or less similar facilities and equipment to many other senior secondary schools considering the equitable distribution of resources by Government (See section 2.1.1). The implication is that physics teachers might be encountering shortages and limitations in laboratory facilities and equipment when engaging in demonstrations and practical activities. They might also be facing problems with learners who do not have adequate skills to participate in practical activities as intended. This might explain why science teachers have a tendency to use chalkboard even in science topics that have a strong practical basis (Botswana, 1993; Tawana, 2009). The practice of Teacher A and Teacher B however suggest that it can be possible for science teachers to improvise or use appropriate strategies and to design instructional activities such that they prepare learners for participation in the activities as has been possible in this study by the participant teachers.

One of the aims of the BGCSE physics syllabus is to develop learners' knowledge and understanding of scientific vocabulary and terminology (see section 2.3). Since learning in a second language, learners need support on language of instruction in school physics. The learners' difficulty with language of instruction in school science is a general phenomenon (Oyoo, 2010). In Botswana, difficulties with the language of instruction have been found among learners at junior secondary school (Prophet & Towse, 1999). It has also been found that the junior secondary school science teachers' instructional methods were insensitive to learners' difficulties with the language of instruction (Koosimile, 2005). It follows that learners would still have problems with the language of science instruction at senior secondary school as their language problems were not adequately addressed at junior secondary level. The implication from this study is that learners' difficulties with the language of instruction can be addressed by simplifying it and engaging learners in verbal interaction to identify their difficulties and to provide support them (Boyd & Markarian, 2011).

In this study, the participant teachers attended to learners' difficulties with language of instruction (see section 8.2) by using strategies that have been found to benefit learners (see section 3.2). For instance, Teacher A simplified, rephrased and used learners' words to provide support on non-technical constructs from past examination questions (see sections 8.1.1.1) and Teacher B explained technical science words such as 'virtual image' (See section 7.2.8 & Pic. 33).

8.4 Recommendations

This section presents recommendations for physics teachers' instructional practices and for senior secondary school physics education in Botswana in the light of the findings of this study. It begins with the recommendations for physics teachers' instructional practices on the use of events in the social and cultural life of learners, followed by instructional methods for activating prior knowledge and instructional strategies for addressing learners' incompetency in participating and accessing content in instruction.

The use of social and cultural events in instructional practice of physics teachers make school physics relevant to learners (Nganunu, 1988; Ogunniyi, 1996) bearing in mind the foreign context in which the BGCSE physics syllabus (Koosimile, 2001) and physics textbooks are based. Therefore, it is recommended that physics teachers use social and cultural events in their instructional practices. Although the recommendation is based on the findings on instructional practice in the topic of light and waves, it is considered appropriate to other topics on physical phenomena which may form part of learners' everyday experiences (Scott, 1998).

Use of elaborate instructional methods such as open-ended demonstrations (see sections 6.3.2 & 6.3.3) and review of prior lessons (see section 7.3.3) has high potential for activating prior knowledge among learners. These methods are particularly recommended for active participation of learners in the knowledge building process of instruction (Scott et al., 2011; Tiberghein & Buty, 2007) and for learners' understanding of new concepts (Seidel et al., 2005).

The exemplary teachers' strategies for addressing learner incompetency in accessing instructional content are important for wide range of learner abilities. The instructional strategy of *creating an environment of competence* (see section 7.3.1) found in this study is particularly recommended. This recommendation is made in view of the poor performance of learners in the examinations (Council, 2013) and the need to improve their performance through instruction (Wertsch, 1991; Wertsch et al., 1995). Although the strategy was specific to the topic of light and waves, it can be applicable to other topics because it was focused on learners' needs to work independently and systematically on the assigned work (see section 8.1.2).

The following subsections present recommendations for senior secondary school physics education in Botswana specifically the Ministry of Education, Teacher education and Professional Development.

Recommendation for Ministry of Education

The BGCSE curriculum recommends learner-centred instructional approaches (M. o. Education, 1998c). However, the findings in this study suggest that learner characteristics are an essential aspect of learner-centred instructional approaches. The study findings show to engage learners in instructional activities that use standard concept representations, the participant teachers had to support learners on skills that might be taken for granted that learners possess (see section, 6.3.1 & 7.3.1). One example is where the teacher gave learners detailed instructions on how to use their notebooks to draw ray diagrams (see section 7.2.8) to reduce the degrees of freedom that might cause unnecessary delays (Wood et al., 1976).

Although these findings are based on two teachers in two schools teaching different topics, they are worth considering as exemplars (Bird, 2000; Kuhn, 1970). The findings have shown the need for activating learners' knowledge from prior instruction and events in their everyday lives to guide the learner-centred instructional approaches. It is recommended that detailed description of learners' knowledge from junior secondary examinations reports be made available to senior secondary school physics teachers to guide their instructional activities (Thomson & Buckley, 2009).

The findings on the success by the two participant teachers to use of texts to support concept understanding in school physics topics can similarly serve as exemplars. As presented in section 8.2, Teacher A encourage learners to read their textbook and Teacher B encouraged them to use text material in the form of pencil and paper exercises. The findings indicate that although learners had difficulties with reading textbooks and using teacher developed text material (see section 8.1.1 & 8.1.2) they eventually developed a liking for the teacher encouraging them to read. Given the uniformity of learner placement in senior secondary schools in terms of ability and equitable distribution of resources it is possible that learners in other schools encounter similar difficulties in using text material. Provision of texts which take into account learner characteristics such as the language (Koosimile, 2005; Prophet & Towse, 1999) and events in learners' lives (Koosimile, 2004; Nganunu, 1988) would be supportive on learners' understanding of concepts (McNamara et al., 1996) and on learners' independent reading (Allington, 2002). It could also reduce the amount of time used to write copious notes and increase teachers' focus on learner-centred approaches. (see section 6.3.1.2). It is recommended that teachers be alerted of their possible input by encouraging learners to use of text material.

Shortage of equipment and lack of maintenance of laboratories found in this study implies that learners might not be accessing adequate experiences for development of experimental and investigation skills (see section 8.2). While funds for equipment and maintenance of laboratories might be limited (Botswana, 2009), senior teachers responsible for laboratory inventory together with the Head of Department need to prioritise on instructional facilities. If laboratories in an established school such as School A do not have gas supply for heating, particularly during the teaching of topics such as thermal physics and light and waves, it is possible that other schools have similar problems. It is therefore recommended that senior teachers and Heads of departments for Science and Mathematics under the supervision of Heads of Schools ensure that laboratories are maintained for instruction in all topics. It may be a recommendation that more funds be availed for maintenance of laboratories and laboratory equipment. Teacher B involved learners in hands-on activities during the second half of the lessons with no laboratory assistants.

The findings show how the two physics teachers were creative and to improvised to actively engage learners in instruction. It is recommended that physics teachers be encouraged to be creative and improvise where need be.

Professional Development

The study shows that active involvement of learners in instructional activities required the participant teachers to develop learning materials in advance, guide learners on how to use it, and design their practice to encourage their continual use. For instance, Teacher A developed an environment for textbook reading which enabled learners to participate in discussions (see section 6.3.1; section 8.1.1). Teacher B rationalised hands-on activities (see section 7.3.1; section 8.1.2) and pencil and paper exercises (see section 7.2.8) on learners' capabilities to enable them to participate. This agrees with Secker and Lissitz (1999) assertion that learners need to be prepared to participate in inquiry instruction which is learner-centred.

While these skills may be part of the pre-service education, the way the participant teachers appropriated them is probably what made the two teachers to stand out in actively engaging their learners compared to other physics teachers (D. o. M. a. S. Education, 2008). The assumption is that it might not be easy for most teachers to appropriate basic instructional skills in the context of increased enrolment which means more work for teachers. It is therefore, recommended that the professional development programs consider appropriation of basic instructional skills in the context of increased enrolment as an effort towards improving engagement of learners in physics instruction.

On the same argument for increased engagement of learners in physics instruction, the role of language in instruction needs attention (Oyoo, 2012; Parkinson, 2004). The findings as discussed in previous sections (see sections 8.1.1.1 & 8.1.1.2) indicates learners' need for support on language. This is especially argued based on the teachers' tendency to lecture and provide copious notes for learners (Tawana, 2009). It is recommended that professional development programs consider assisting teachers on ways of simplifying the language of instruction to the learners' abilities and involving learners in verbal interactions. This is in line with an earlier suggestion that teachers need to be sensitive to the learners' language needs (Koosimile, 2004) in order to improve their proficiency in the language of instruction and for better understanding of concepts (Oyoo, 2012).

The findings show instructional skills which could enhance continuity in school physics content across school levels (Prophet & Vlaadingerbroek, 2003) and between school science content and learners' lives (Koosimile, 2005; Nganunu, 1988). For instance, activation of prior knowledge over a wide content area through demonstrations to cognitively prepare learners on topic content (see section 8.1.1) and use of events in the learners' lives to develop physics concepts (see section 8.1.2). The use of events in the learners' lives has potential to take into account possible inconsistencies between learners' knowledge and school physics that may hinder learning of new knowledge (Smith et al., 1993; Taber, 2001). In this study, visuals were used to capture events in the learners' lives and to link them to physics content. These can serve as examples of ways of enhancing continuity in instruction across school levels. It is recommended that professional development use such strategies as examples for teachers to strengthen the quality of instruction in supporting learners.

Recommendations for teacher education

The teachers' instructional practices that are characterised by generally low engagement of learners in physics instruction (Botswana, 1993; Tawana, 2009) require a concerted effort towards encouraging practices that support learner participation in instruction at pre-service education and professional development of teachers. The findings point towards the need for learner support on prior knowledge, experimental and investigative skills, text material and language of instruction (see section 8.2). While the findings are based on two teachers, they showed exceptional skills in engaging learners. Therefore, as described in the previous sub-sections they are considered as exemplars (Kuhn, 1970). The term 'exemplar' is highlighted by Bird (2000) as the essence of the particular within the overarching influence of a paradigm (Kuhn, 1970). They can be used as possible solution to instructional practices that are generally insensitive to the development needs of learners in school physics (Koosimile, 2005).

While pre-service education provides basic skills for instruction (Loughran et al., 2008), perhaps it is necessary to orient the skills towards engagement of learners in Botswana classrooms as a basis for directing their development during professional teaching practice (Henze et al., 2009; Vermunt & Endedijk, 2010). In this sense, the profile of exemplary practice as so far listed in section 8.2 has potential to actively involve learners thus strengthening the quality of physics instruction (Neumann et al., 2012) at senior secondary schools. Teachers' adoption of practices that involves all on the list is recommended for pre-service teacher education (also in section 8.2).

8.5 Conclusion, Reflections and Way forward

In sum, the study has revealed that the two participant teachers' instructional practices have characteristics which are consistent with literature on exemplary teachers even though the focus was on local context. The contribution made by this study is on practical instances of teachers' instructional support for learners which can be adapted by physics teachers. On the main, it showed how prior knowledge from instruction can be effectively activated through hands-on activities (section 6.3.2); how learners can be encouraged to use their textbooks (section 6.3.1); how social and cultural events from learners' lives can be explicitly linked to physics knowledge on waves (section 7.3.2); and how physics teachers can support learners on the language of instruction and accessing topic content. While research indicates that these instructional practices are beneficial for learning, future research should determine how they can be applied in other topics within the BGCSE physics curriculum.

The study involved two teachers selected from a small group of teachers who participated in the DMSE-INSET study (see section 5.1.2). The findings, therefore, cannot be expected to be generalised to all physics teachers who may show the full story about exemplary instructional practices in Botswana. Similar studies involving a larger group of exemplary teachers in school physics are necessary to provide more information on teachers' instructional practices for supporting learners. The information can hopefully benefit practicing teachers, teacher education and professional development programs, as well as the Ministry of Education on policy decisions concerning instructional practices at school level.

My experience with this study involved an interview method which happened to be inappropriate for Teacher B, what would be referred to as methodological reflexivity (Anderson, 2008). Anderson (2008) stated that reflexivity entails "the researcher being aware of his effect on the process and outcome of research based on the premise that knowledge cannot be separated from the knower" (p.184). My research design for data collection involved video stimulated unstructured interviews with the teachers (section 5.2.2.3). The interview was successfully conducted with Teacher A. I thought that the interview would proceed equally well with Teacher B which was not the case. Teacher B was ready to answer specific questions and I was taken off-guard as I had not prepared for a semi-structured interview. I failed to create conducive situation for an unstructured interview. This is in accord with Maxwell (2013) that "what the informant says is always influenced by the interviewer and the interview situation" (p.125).

I made an arrangement with Teacher B to conduct the semi-structured interview during the last week of the term. The interview could not be conducted due to technical problems. I had limited funds for making more visits to the school to arrange for the interview. The school was a distance of 135 km away from where I resided, I depended on the phone calls but I gave up after a few weeks. When I reflect on this experience, I realise the importance of reflexivity in data collection. Anderson (2008) stated that in methodological reflexivity co-constructing meaning is "technically-oriented reflexivity" while the design of the research remains paramount. I could have asked Teacher B some specific questions and eventually lead the interview to an open-ended conversation (Fontana & Frey, 2000; Peräkylä, 2005). In other words, I lacked adequate skill to be reflexive. I also learned that individual cases have unique characteristics which may require particular skills in conducting unstructured interviews (King & Horrocks, 2010).

Appendix A: Ethics Clearance - WITS

Wits School of Education

27 St Andrews Road, Parktown, Johannesburg, 2193 • Private Bag 3, Wits 2050, South Africa
Tel: +27 11 717-3064 • Fax: +27 11 717-3100 • E-mail: enquiries@educ.wits.ac.za • Website: www.wits.ac.za

Student number: 576390
2011ECE151**C**

4 November 2011

Ms. Rorisang Rammiki
13 Mazoe Road
EMMARENTIA
2195

Dear Ms. Rammiki

Re: Application for Ethics: Doctor of Philosophy

Thank you very much for your ethics application. The Ethics Committee in Education of the Faculty of Humanities, acting on behalf of the Senate has considered your application for ethics clearance for your proposal entitled:

Exploring exemplary physics teacher's instructional practices in supporting learner access to school physics content

The committee recently met and I am pleased to inform you that clearance was granted. The committee was delighted about the ways in which you have taken care of and given consideration to the ethical dimensions of your research project. Congratulations to you and your supervisor!

Please use the above protocol number in all correspondence to the relevant research parties (schools, parents, learners etc.) and include it in your research report or project on the title page.

The Protocol Number above should be submitted to the Graduate Studies in Education Committee upon submission of your final research report.

All the best with your research project.

Yours sincerely

MMabeta

Matsie Mabeta
Wits School of Education

(011) 717 3416

Cc Supervisor: Dr. S Oyoo (via email

Appendix B: Local Research Permit

TELEPHONE: 3655469
TELEX: 2944 THUTO BD
FAX: 3185167

REPUBLIC OF BOTSWANA

MINISTRY OF EDUCATION
AND SKILLS DEVELOPMENT
PRIVATE BAG 005
GABORONE
BOTSWANA

REFERENCE: E 1/20/ 2 XIV (5)

7th February 2012

Rorisang Agnes Rammiki
P Bag 164 # 533
Gaborone
Botswana

Dear Sir/ Madam

RE: REQUEST FOR A PERMIT TO CONDUCT A RESEARCH STUDY

We would like to acknowledge receipt of your application for research permit to conduct a study. This serves to grant you permission to conduct your study in the sampled areas in Botswana to address the following research objectives/question/topic:

Exploring Exemplary Physics Teachers' Instructional Practices In Supporting Learner Access To School Physics Content

It is of paramount importance to seek **Assent** and **Consent** from the Department of Secondary Education, School Heads, Teachers, Parents and Students of the schools that you are going to collect data from. We hope that you will conduct your study as stated in your proposal and that you will adhere to research ethics. Failure to comply with the above stated, will result in immediate termination of the research permit. The validity of the permit is from **7th February 2012** to **6th February 2013**.

You are requested to submit a copy of your final report of the study to the Department of Educational Planning and Research Services, Ministry of Education and Skills Development, Botswana.

Thank you.

F T Siamisang
For / Permanent Secretary

Appendix C: Informed Consent Form (Class Teacher)

Exploring Exemplary Teachers' Instructional Support for Learners' Access to School Physics Content

I ……………………………….............. ………….. (Participant's full name) agree/decline to participate in the research project.

I am aware that my lesson will be video-recorded, I will be interviewed and audio-recorded during interviews, and copies of my written work and my students' work will be used for the research.

I understand that my privacy will be respected at all times and I will not be identified in any research publications. I participate voluntarily, knowing that I may withdraw from the study at any time with no negative consequences.

Signature: …………………………….................................. Date: …………………

Appendix D: Informed Consent Form (Class Teacher) - Video-recording

Exploring Exemplary Teachers' Instructional Support for Learners' Access to School Physics Content

I ……………………………….............. ………….. (Participant's full name) agree/decline to participate in the research project.

I agree/not agree to be **video recorded** together with my class during normal lessons.

I understand that my privacy will be maintained at all times and I will not be identified in any research publications. I participate voluntarily, knowing that I may withdraw from the study at any time with no negative consequences.

Signature: ……………………………................................. Date: …………………

Appendix E: Informed Consent Form for audio recording (Class Teacher) - Audio recording

Exploring Exemplary Teachers' Instructional Support for Learners' Access to School Physics Content

I ………………………………............ ………….. (Participant's full name) agree/decline to participate in the research project.

I agree/not agree to be **audio recorded** during interviews.

I understand that my privacy will be maintained at all times and I will not be identified in any research publications. I participate voluntarily, knowing that I may withdraw from the study at any time with no negative consequences.

Signature: …………………………................................ Date: …………………

Appendix F: Informed Consent Form (Learners) - Video-recording

Exploring Exemplary Teachers' Instructional Support for Learners' Access to School Physics Content

Please indicate your decision regarding your participation in the research.

I …………………………….. (full name on behalf of the class) give permission / do not give permission for participation in this research project.

I also agree (write '**yes**' in the space provided)/do not agree (write '**no**' in spaces provided) that

- we can be **Video recorded during lessons** ……………

I understand that our privacy will be maintained at all times and we will not be identified in any research publications.

I give permission for our participation voluntarily, knowing that any of us may withdraw him/her participation from the study at any time with no negative consequences.

Signature: …………………………….......................... Date: ……………

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